The impact of improved transducer matching and equalisation techniques on the accuracy and validity of underwater acoustic measurements

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Abstract

The results of work carried out on improved equalisation techniques for underwater transducers has resulted in a sonar performance where typical transducer phase and amplitude nonlinearities have been virtually eliminated within the operational constraints of the system. Consequently it was thought that such an improvement in transmit and receive fidelity could have a considerable impact on the accuracy and subsequent interpretation of the results from a sonar system when used as an acoustic research tool.

1. Introduction

When making acoustic measurements an accurate transducer response, in terms of faithfully generating investigative pressure fluctuations in the water and their subsequent detection, becomes an essential requirement.

The great majority of transducers are, by their very nature, narrow band devices, and for efficient operation they are often operated near to resonance. If increased information of the underwater medium becomes necessary, then the only way to achieve this is to operate with increased bandwidth. The need for increased bandwidth can be readily appreciated when considering the insonification of a target under investigation, where the use of a shorter transmitted pulse length affords increased range resolution and more echo detail. Such pulses, whilst requiring increased overall bandwidth, also need improved transducer equalisation techniques to maintain a waveform fidelity that enables the full potential of the bandwidth / range resolution to be realised. Also wide band operation, where the available power transmitted is spread over a relatively much wider bandwidth, means that the efficiency becomes increasingly important.

The requirements of wide band waveform fidelity and increased efficiency are both met by the improved equalisation techniques. This paper is not intended to be an in depth description of equalisation and matching techniques. Rather, it demonstrates how the use of these techniques could improve the accuracy and understanding of measurements in underwater acoustic research. It its hoped that the current scientific workers in the field will be able to identify areas of acoustic measurement where these benefits could be fruitfully exploited. One example of a hydrophone distorting an acoustic pulse is shown Section 6, in which dolphin transmissions were observed using an appropriately corrected hydrophone to reveal some interesting possibilities.

2. Conventional distorted transmit response with output equalisation

The electro-acoustic transducer, when used as a transmitter, is inherently a narrowband device, that is, it is only efficient over a very narrowband of frequencies either side of its own resonance. When it is required to transmit over a much wider band of frequencies there are two main considerations:

a) The electro–acoustic efficiency between the amplifier and the transducer.

b) The fidelity of the transmitted waveform.

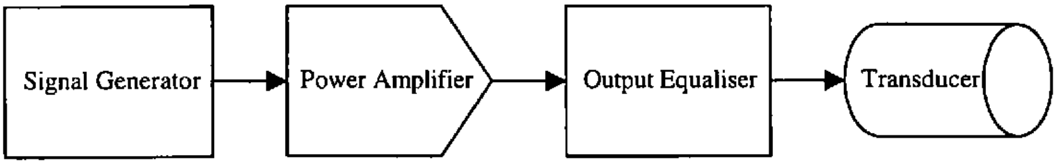

Figure 1. Basic system layout for transducer system using output equalisation only

The first problem to be solved, (a), necessitates the introduction of an output equaliser as shown in Figure 1. This consists of a number of passive electrical components such as inductors, transformers and capacitors, that together with the transducer form a bandpass filter [1-3]. The output equaliser has the effect of significantly improving the efficiency of power transfer between the transducer and amplifier over a much broader band of frequencies, but without significantly improving the fidelity of the acoustic waveform in the water. As a result of the signal generator output shown by (trace 1) in Figure 2, a typical acoustic waveform using output equalisation only is shown as (trace 2).

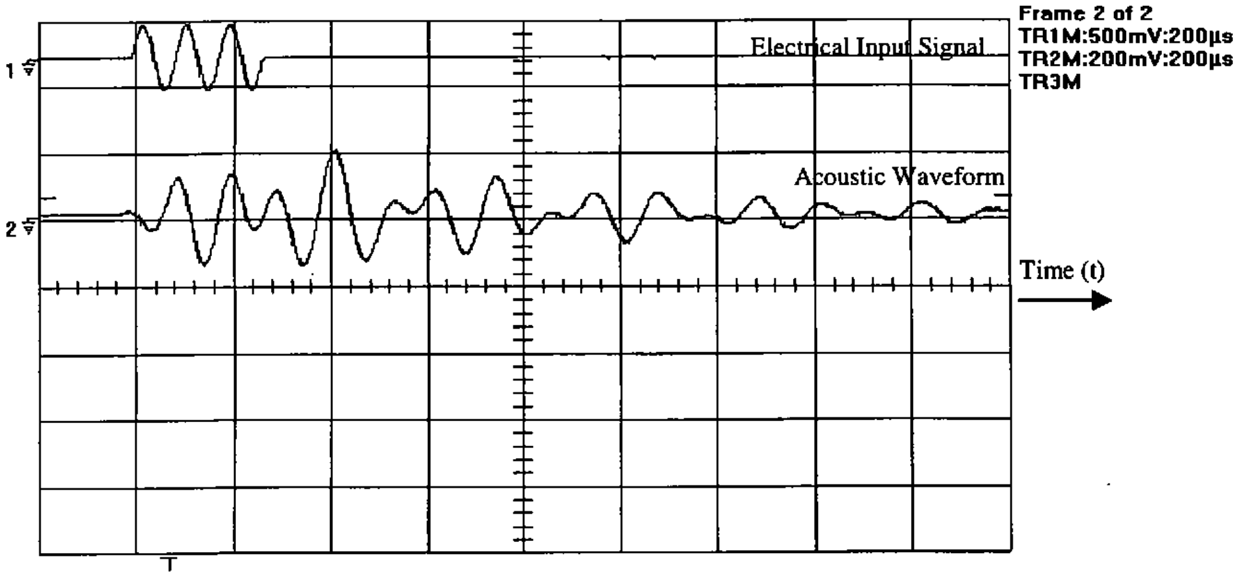

Figure 2. A typical acoustic waveform using output equalisation only

The main cause of the distortion can be attributed to the poor nonlinear phase response of the transducer and its associated output equaliser. To correct for this, a phase and amplitude equaliser is inserted on the input (low power side) of the amplifier to pre-distort the input signal before it progresses through to the output equaliser and transducer. This is shown in Section 3.

3. Improved fidelity of the transmit response with additional input equalisation

The input equaliser can be low power analogue or software/digital, whereas the analogue output equaliser is manufactured using high power electrical components. The block diagram for this system is shown in Figure 3.

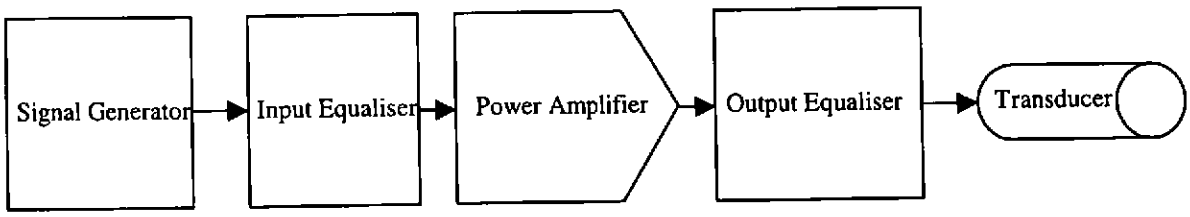

Figure 3. The basic system layout for transducer system using input and output equalisation

Referring to Figure 4, when the waveform is now applied to the system fitted with an input equaliser as well, it can clearly be seen that the equalised acoustic waveform (trace 3), as received on the monitor hydrophone, is a much more accurate reproduction of the electrical input signal (trace 1). It should also be noted that the receiving monitor hydrophone has a resonant frequency of at least ten times that of the resonant frequency of the transmitter. This is to ensure that the phase and amplitude response of the monitoring device is both constant and linear respectively over the known frequency spectrum of the waveform in the water.

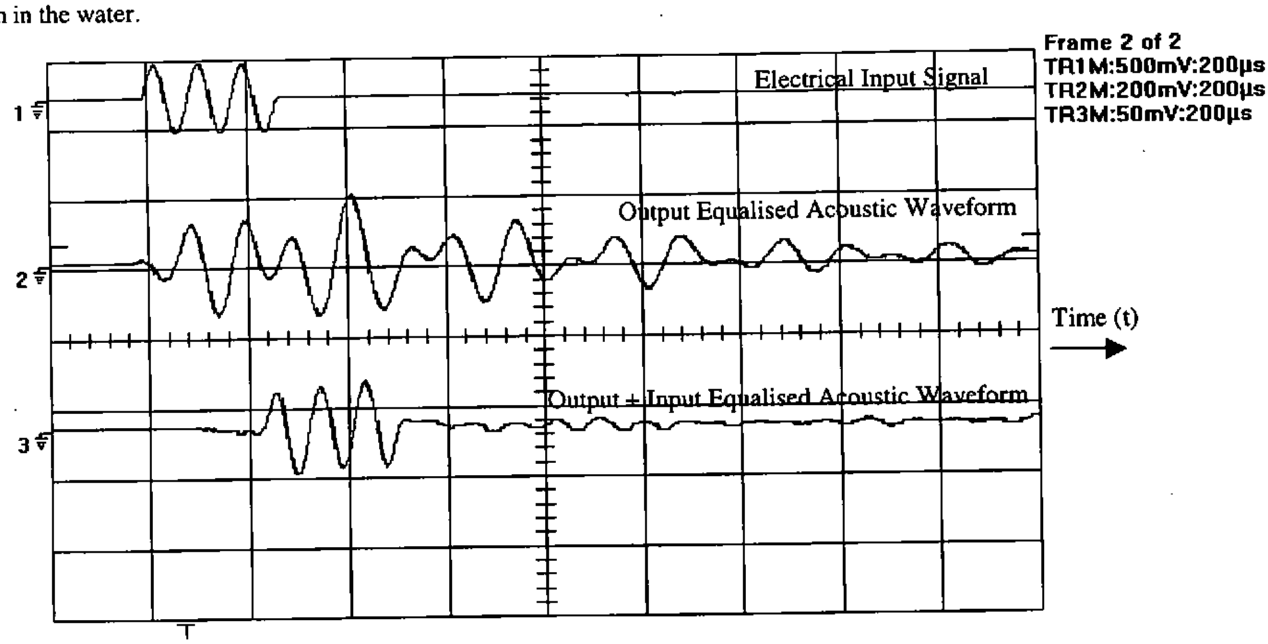

Figure 4. A typical acoustic waveform using input and output equalisation

At this point it is worthwhile to note that no electrically dissipative components are used in the output equaliser. Their presence would cause a reduction in the electro-acoustic efficiency between the amplifier and the transducer.

4. Receive response without equalisation

A standard hydrophone receiver system is shown in Figure 5. Some filtering may be added, but to demonstrate the efficacy of receive equalisation this basic system will be sufficient.

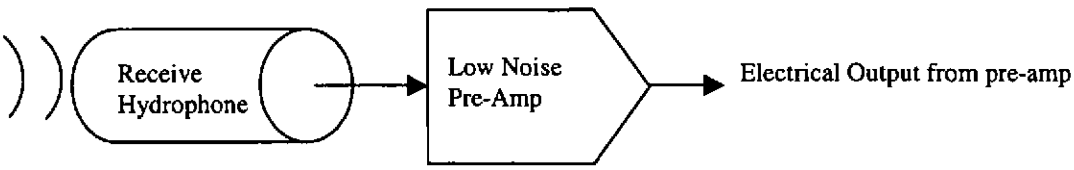

Figure 5. The basic system layout for a receive hydrophone system without equalisation.

Again a high frequency monitor hydrophone is used as a reference. The output from this hydrophone is shown as (trace 2) in Figure 6. If the receive hydrophone that to be used has a resonant frequency near to that of the transmitting transducer, or the transmitting transducer itself is to be used to receive its own transmissions (delayed in time), then the unequalised receive hydrophone output causes distortion of the acoustic waveform. This can be seen as (trace 3) in Figure 6.

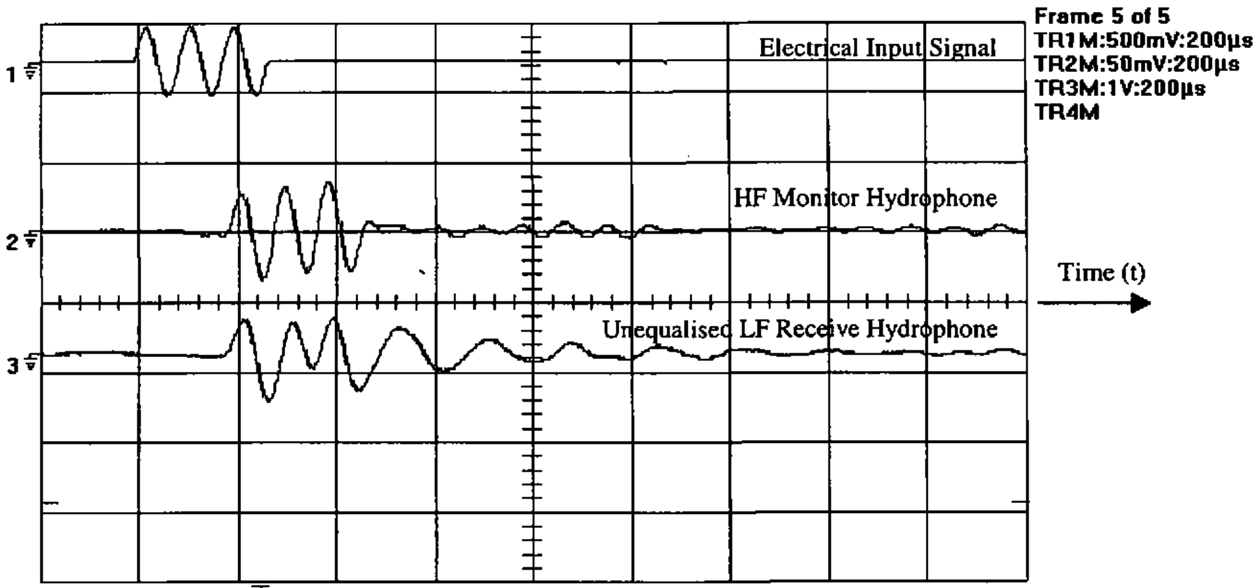

Figure 6. A typical distorted acoustic waveform from an unequalised receiver.

It can be seen that, if the frequency content of the acoustic signal falls within the nonlinear phase response of the receiver hydrophone, then the output electrical waveform will be distorted. In order to achieve accurate observations of the underwater environment, including our own transmitted signals, it is necessary to consider not only the amplitude response of the hydrophone but also, more critically, its phase response. To ensure minimum distortion of the received acoustic signal, a receiver equaliser is added. This is shown in Section 5.

5. Transmit/receive response with equalisation

The block diagram of a fully equalised transmit receive system is shown in Figure 7. The receiver now has its own equaliser added which clearly preserves the fidelity of the acoustic waveform as shown in Figure 8 (trace 4).

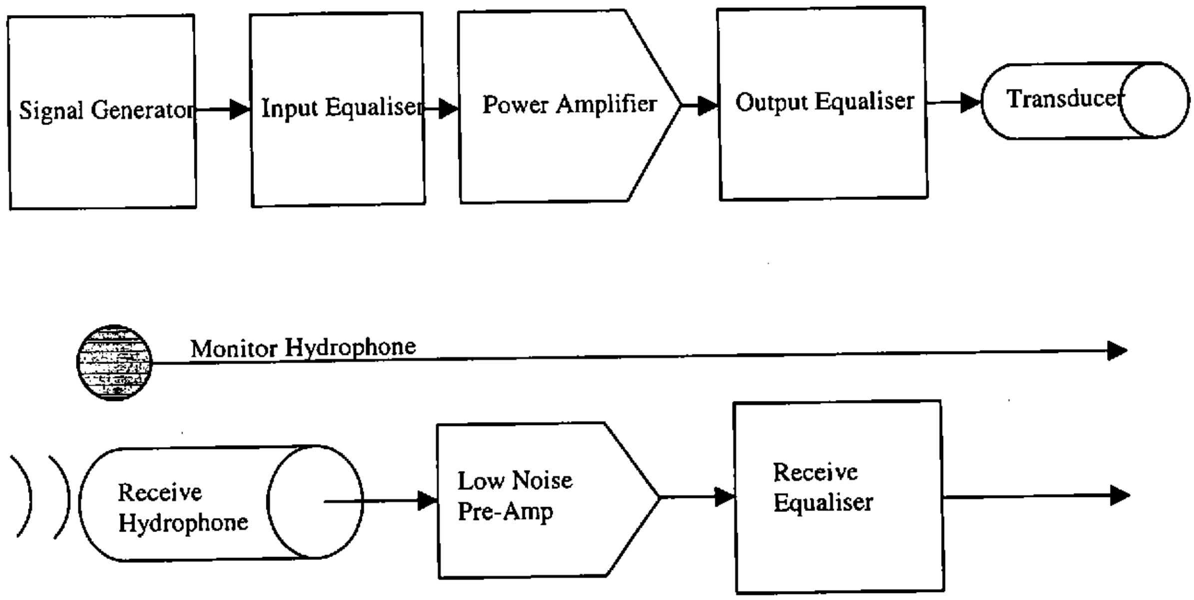

Figure 7. The basic system layout for a fully equalised transmit receive system.

The full system operation shown in Figure 7 produces the waveforms shown in Figure 8. The signal generator produces an electrical signal (trace 1) which is applied to the input equaliser. The input equaliser pre-distorts the signal applied to the Power Amplifier. The signal then passes through the non dissipative output equaliser which is connected to the transducer and is then transmitted in the water as an acoustic waveform shown in (trace 2). The acoustic waveform shown on the monitor hydrophone in (trace 2) is now a very close replica of the electrical input signal.

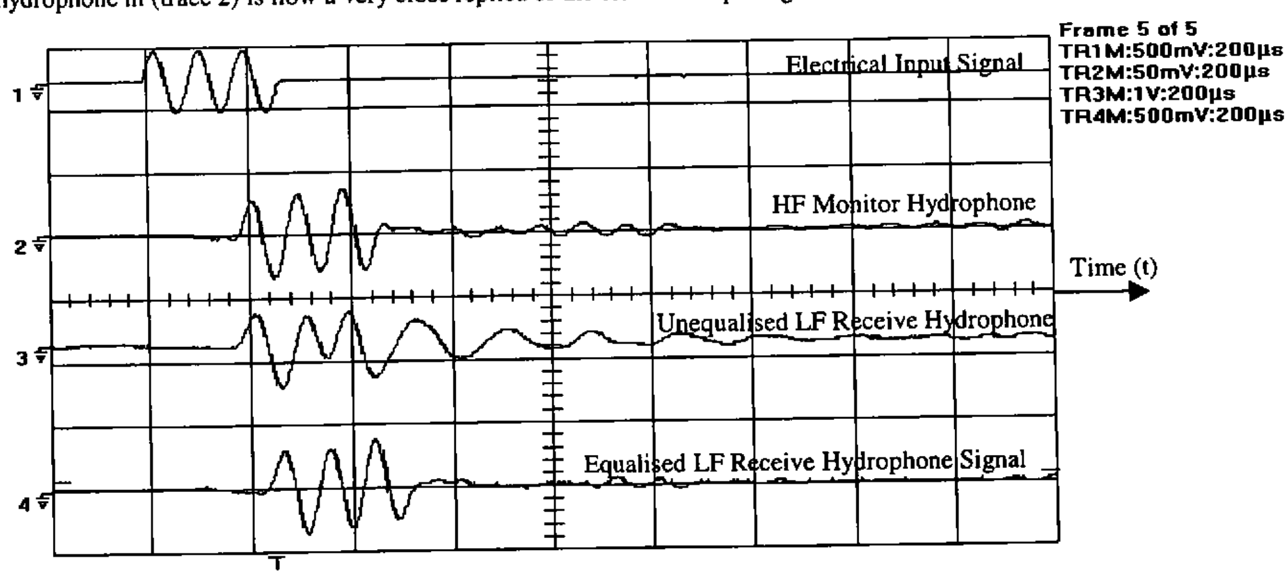

Figure 8. Typical acoustic waveforms using equalisation on transmit and receive.

The waveform shown in Figure 8 (trace 3) shows receiver distortion as described in Section 4. This waveform is now passed through the receiver equaliser where it now emerges as (trace 4). The overall aim of the equaliser technique is to eliminate or minimise where possible any distortion introduced by the transmitting and receiving transducers and their associated circuitry. This enables a true picture of the underwater environment itself to be observed. Important characteristics provided by the new equalisation techniques are improved waveform fidelity and range resolution. A demonstration of dramatically improved waveform fidelity and range resolution is shown in Figure 9.

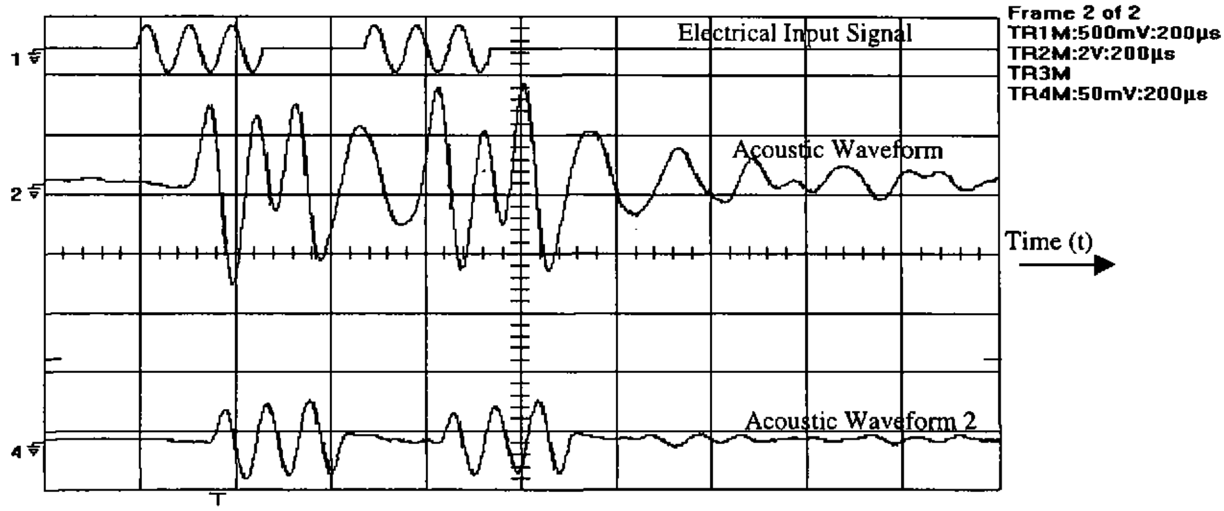

Figure 9. Typical acoustic waveforms to demonstrate waveform fidelity and range resolution.

It can be seen that acoustic waveforms 2 and 4 of Figure 9, because of their fidelity, enable the full potential of the bandwidth/range resolution to be realised. With such high resolution in time it becomes possible to consider the generation of an acoustic impulse in order to measure the impulse response of the acoustic environment. An example of the generation of an approximation to an impulse is shown in Figure 10 where, in practice, the shape is consistent with the bandwidth under consideration.

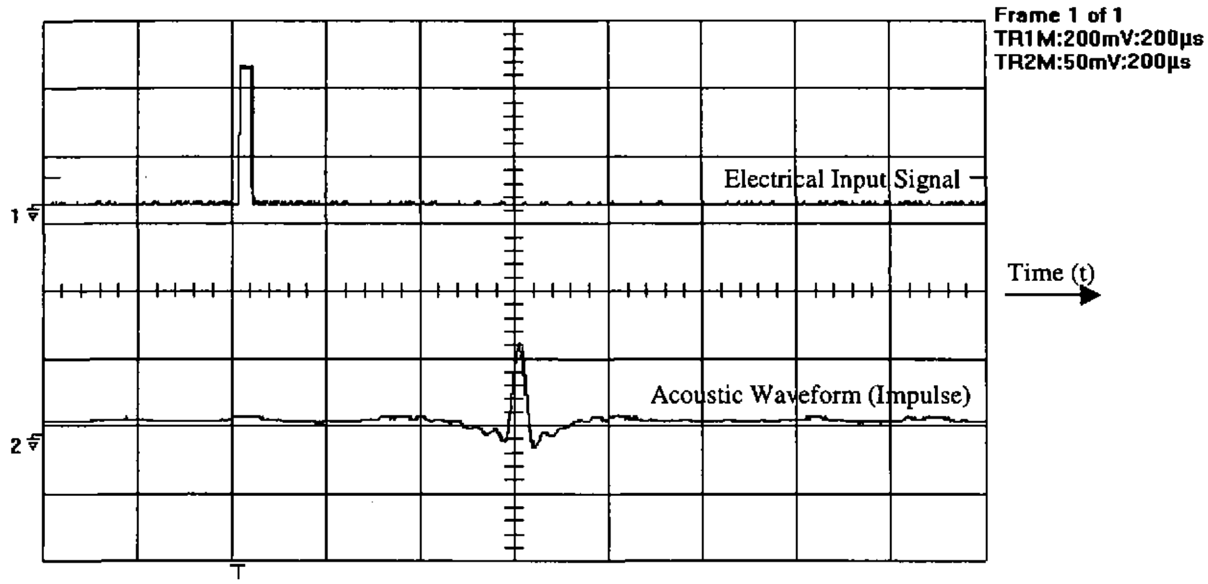

Figure 10. Approximate acoustic impulse response.

A further very interesting consequence of the improved waveform fidelity provided by the new equalisation techniques is outlined in the next section (Section 6) using, as an example, some dolphin waveforms.

6. Dolphin waveforms with receive equalisation

During the course of work on the development of short pulse equalisation techniques, it was noticed that some of the waveforms produced in the water were very similar to those transmitted by a dolphin [4]. This prompted the authors to take a close look at some dolphin waveforms, very kindly donated by Dr Nick Tregenza, who had taken measurements of a bottlenose dolphin apparently echolocating on his hydrophone in an enclosed tank in Hong Kong. The dolphin was under visual observation whilst it was transmitting at the hydrophone. The hydrophone had a resonant frequency of 134 kHz and was connected directly into a storage oscilloscope so that no extra distortion was added. It was found that the spectral content of most of the waveforms detected by the hydrophone lay between 100 and 150 kHz. It was therefore felt that the nonlinear hydrophone phase response was at its worst within this band, and so would in this case present a distorted view of the pulse in the water. To remove this distortion, a receiver equaliser based around the amplitude and phase characteristics of the hydrophone was constructed. The results, together with the receiving hydrophone, were then subject to evaluation. The system layout for extracting the corrected information from that supplied is shown in Figure 11.

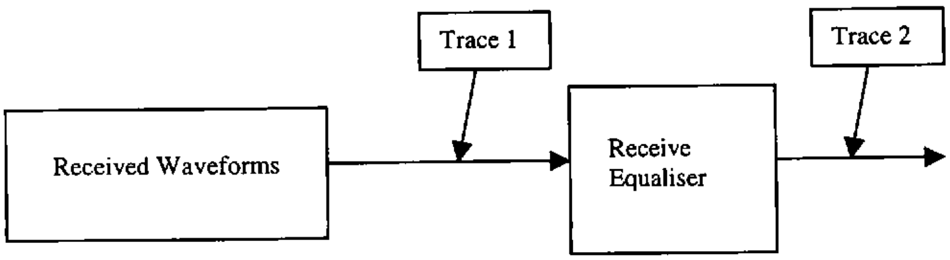

Figure 11. The basic system layout for a receive hydrophone with equaliser for evaluating dolphin waveforms.

To obtain a true picture of the dolphin transmissions, the recorded waveforms from the hydrophone were passed through the receiver equaliser to reveal the waveforms shown in Figures 12 and 13.

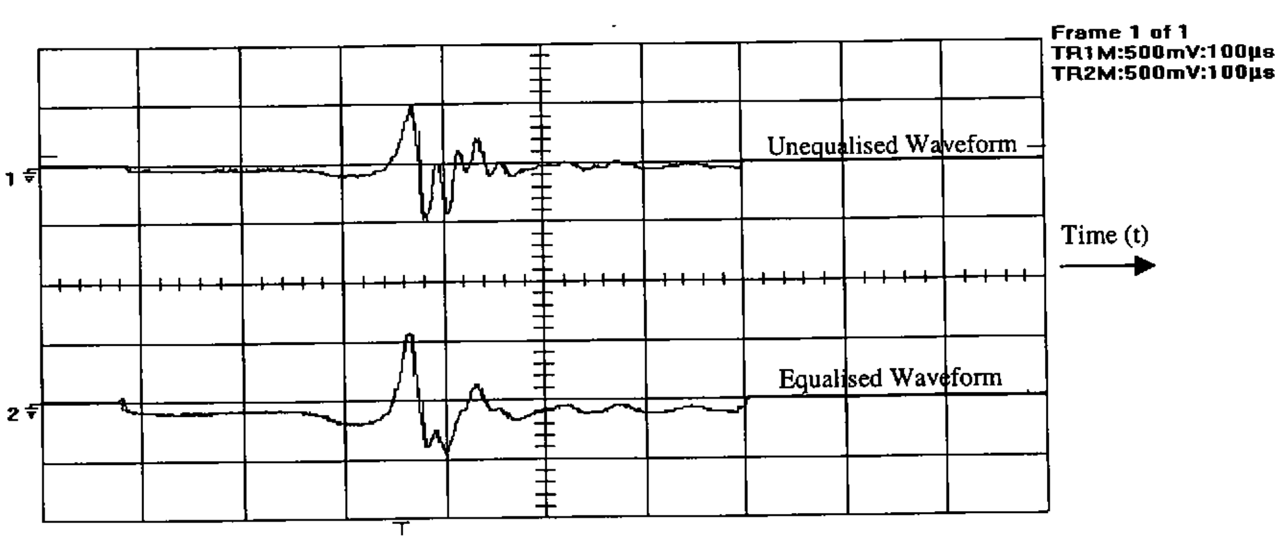

Figure 12. Dolphin transmissions before and after equalization

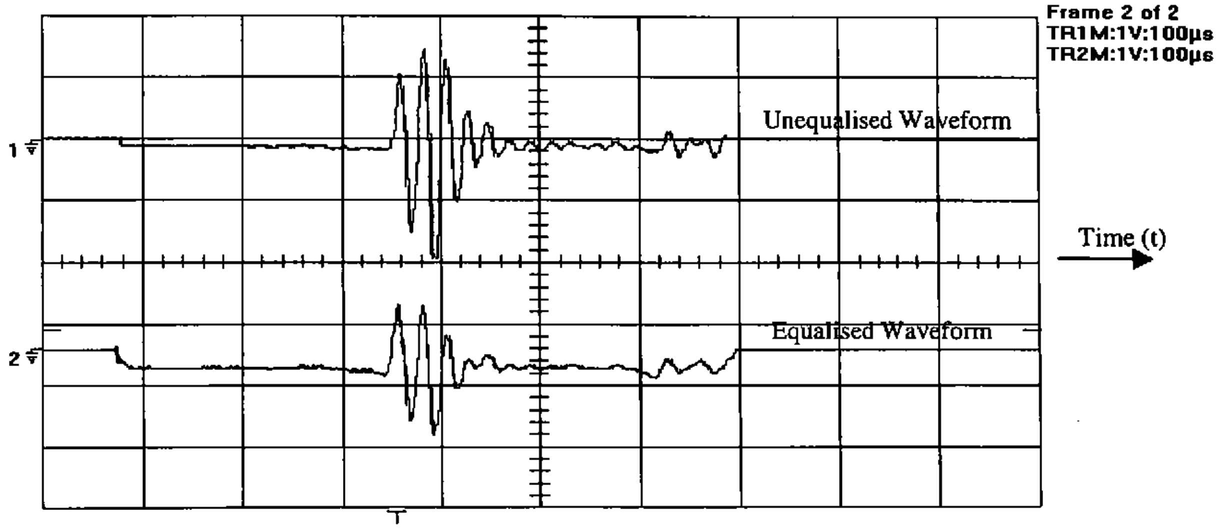

Figure 13. Dolphin transmissions before and after equalisation.

The difference between the equalised and unequalised waveforms can clearly be seen. The validity of the technique, as applied to this hydrophone, was successfully verified by transmitting a single cycle at 120 kHz in the water and monitoring the output of the equaliser. This clearly revealed the single cycle input. Having removed the hydrophone distortion from the dolphin waveforms, it was then possible to recreate the equalised waveforms by means of the following method.

6. Dolphin waveforms with possible perceived transmission method

If we assume that for echolocation the dolphin's sound production technique uses two muscled nasal plugs with connective tissue flaps (lip like structures) [4], then the sound transmission path can be represented as shown in Figure 14.

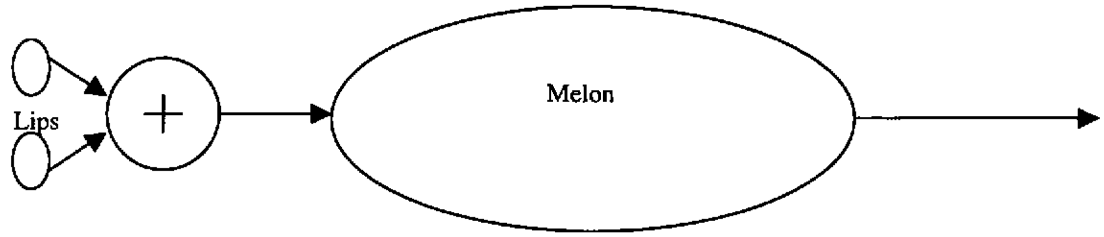

Figure 14. Dolphin transmission mechanism

From experience gained producing a wideband response similar to the dolphin's, the authors propose that the electrical equivalent to the dolphin's sonar transmission path can be represented by the alternative blocks as shown in Figure 15.

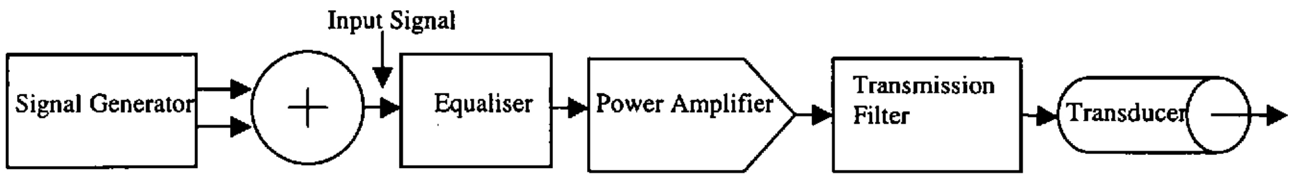

Figure 15. Electrical equivalent block diagram of dolphin transmission mechanism.

It is thought that the 'lips' can be opened and closed to control the passage of air in a pulse-like fashion. This excites the bandpass characteristics (or low Q properties) of the melon, a fatty tissue structure in the forepart of the head. Such a mechanism when applied to an equalised filter system produces the results represented in Figures 16 and 17.

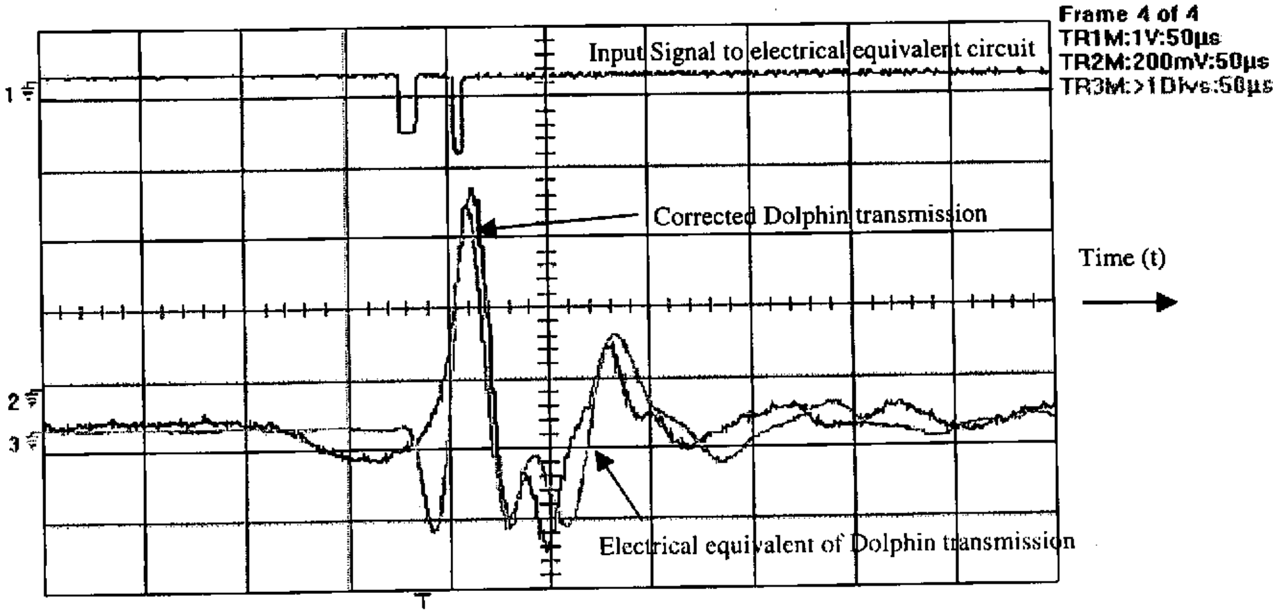

Figure 16. Comparison of Dolphin sonar transmission system 1.

The input signal to the electrical equivalent circuit, shown in Figure 15, is represented as (trace 1) of Figures 16 and 17. This is the summation of two separate pulses of the same polarity with different widths but separated in time. The black waveform represents the real corrected dolphin transmission as shown previously in Figures 12 and 13 (trace 2). The red waveform superimposed upon it for comparison is the simulated output response of the electrical equivalent circuit shown in Figure 15. It can be seen that the traces are remarkably similar. A further example is shown in Figure 17 where the excitation waveform is different resulting in a different output waveform.

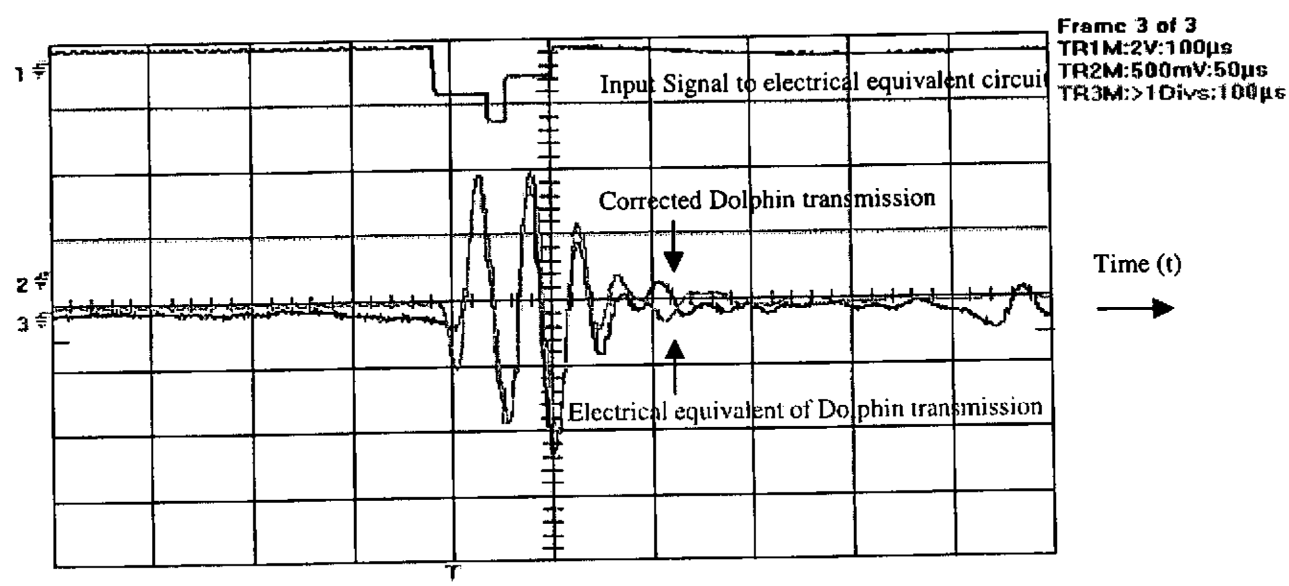

Figure 17. Comparison of Dolphin sonar transmission system 2.

Again the traces are similar, and it is felt that what differences remain possibly arise from a difference between the bandwidth of the melon and the equalised filter circuit used in the model. What the waveforms do demonstrate is the dolphin's ability to change the characteristics of the waveform to control the bandwidth. This could enable them to adopt a coding to allow several dolphins to operate in constrained waters and distinguish each others waveforms or transmissions. The above results represent only an initial, tentative investigation into a dolphin's waveform generation, but provide an interesting outcome. It is hoped that it represents a suitable foundation for further work.

7. Conclusion

New equalisation techniques, applied to both transmit and receive transducers, have resulted in waveform fidelity that offers the benefit of much improved timing accuracy and range resolution for wide band sonar operation. The range resolution of a short pulse is only properly realised when two identical pulses, with a separation of just over the length of a single pulse, can be readily resolved. Such an improvement could well reveal new detail in acoustic measurements. This could provide a much better understanding of the mechanisms involved in a range of underwater phenomena, from complex target highlight structure to sea bed scattering characteristics. Finally it has been shown that, with the improved resolution, it is feasible to think in terms of measuring the impulse response of an underwater acoustic environment, thus accessing a further exciting mode of investigation.

Acknowledgement

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