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ACOUSTIC SIGNALS IN MARINE SEDIMENTS DUE TO WATER-BORNE PARAMETRIC ARRAYS.

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INTRODUCTION

The "self-demodulation" in water of a sound waveform in the form of a pulsed carrier, was first predicted by Berktay (1) and investigated experimentally by Moffett, Westervelt and Beyer (2). For a Gaussian modulated carrier the process produces (1) (see Figure 1) an acoustic pulse of similar time duration to that of the carrier pulse. This leads to the possibility of producing a pulse with a band width as large as that of the carrier pulse but of a centre frequency dependant upon pulse length. Use is being made at Bath of these low Q pulses for the investigation of water/sediment interface roughness and the detection of shallowly occurring layering in sedimentary bottoms. To complement the work a study of the parametric array in the time domain was undertaken: some of the initial results in this on-going programme are presented here.

A simple time domain model of the parametric array is first introduced. This is followed by a brief description of the electronics and experimental arrangement. Observations on the water-borne parametric array using a water-borne hydrophone are then presented. Lastly signals parametrically generated in the water and received on a hydrophone buried in water-saturated, air-free sand are presented and discussed in relation to the time domain model.

TIME DOMAIN MODEL

A simple time domain model of the parametric array operating in the "self-demodulation" mode has proved to be a useful aid in the interpretation of the experimental results presented below.

With the geometry as in Figure 1, the time domain pressure waveform at the point C is produced by a superposition of the arrivals from the line of virtual point sources located on the acoustic axis, due regard being given to their arrival time and amplitude. The arrival time at C for the waveform from point source B is the travel time along path ABC. The time domain waveform (see Figure 1) which is deemed to radiate from each virtual point source is the same as that which would be received by a hydrophone located on the acoustic axis, say at D (1). When points A and C are both in the same medium, the amplitude of the individual arrivals at C is determined by the intensity at the carrier frequency at the relevant point source, together with spherical spreading losses from the point source to C.

When the observation point C is located in sand whilst leaving the source A in water, additional factors affect the amplitudes of the individual arrivals from the point sources located in the water. These are the pressure transmission factor at the water/sand interface, calculated for the relevant Snells Law angle of incidence, the attenuation along the Snells Law path in the sand and the modified spherical spreading losses. (The attenuation is simply chosen to be constant over the bandwidth of the signal and equal to that at its centre frequency.) The amplitude of individual arrivals at C from point

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sources located in the sand depends on the interface transmission and refraction for the carrier wave, the attenuation with distance in the sand at both the carrier frequency and at the centre frequency of the difference frequency band, spherical spreading losses between the point source and observation point and the non-linearity parameter of the water-saturated sand (3).

A computer programme was written to calculate the signal amplitude and shape at the observation point C when C is either in water or buried at some depth below a water/sand interface.

If the water-borne array of Figure 1 is somehow terminated at point B, the received signal at C (also in water) can be considered to be due to two un-terminated arrays, one originating at A (array (a)) and one originating at B (array (b)). The amplitude of the point sources of both array (a) and array (b) are the same as they would have been had the original array not been terminated. The resultant signal received at C is the difference between that signal produced by array (b) at an angle β and range R_2.

Thus a terminated array may be thought of as two, directional sources, one located at the transmitter A and the other at the point of termination B. If the termination is not discontinuous as would be the case at a water/sand inter-face, then a third, sharply tapered array, array (c), originating at the inter-face may also be considered to contribute to the signal received at C, its contributions adding to the difference between the contributions from array (a) and array (b).

Results obtained using the simple computer model and its interpretation in terms of several unterminated arrays will be presented and discussed with the experimental results.

EXPERIMENTAL ARRANGEMENT

All the experiments to be described here were performed in a laboratory water tank, 1.5 metres wide, 1.8 metres deep and 5.1 metres long. At one end of the tank, air-free sand, prepared by a vacuum technique, is retained behind a wall. (The sand has a mean particle size of 240 microns, a sound velocity of 1684 ± 6 metres per second at 12^{0}C and a sound attenuation of 0.4 db per wave-length measured between 40 kHz and 200 kHz.) A stepper motor controlled gantry/mast system allows accurate positioning of the transducers with five degrees of freedom. The transmitting transducer consists of four, closely spaced co-planar 2 cm square, air-backed, piezo-electric ceramic plates, working through two quarter wavelength plates (soda glass and araldite) into water at a centre frequency of 1.4 MHz. This design (4) provides an efficient transducer with a short impulse response. The hydrophone used both in the water and in the sand was the B & K Type 8103. Some limitations in this time domain study were imposed by hydrophone effects. The transmitting and receiving electronics are summarised in Figure 2. The pulse envelope generator allows the production and adjustment of the Gaussian modulation. A system option (not shown) allows the more usual single difference frequency mode of operation.

RESULTS FOR THE HYDROPHONE IN WATER

The time domain pressure signal received on axis when the source and receiver are both in water and the transmitted waveform is a Gaussian modulated carrier, is expected (1) to have two, equal amplitude, positive excursions and one, somewhat larger negative excursion, as indicated in Figure 1. For pulse durations* around 15 μ secs this was indeed observed (see Figure 4a). However, following the second positive excursion further, low amplitude arrivals are evident as can be seen in Figure 4a. These are attributable to the impulse response of the hydrophone in water. (When the hydrophone is used as a receiver in sand, the effect of the hydrophone impulse response on the pulse shape is relatively greater.) As the pulse duration is increased towards 30 μ secs, the second positive excursion and the impulse response tail begin to interfere, with the result that the on-axis received signal, at 30 μ secs pulse duration, is not symmetrical: the second positive excursion has a lower amplitude than the first.

Figure 4 shows the angular dependence of the received pulse shape at a range of 75 cm for a 15 μ sec pulse duration. The main feature is the gradual disappearance of the second positive excursion with increasing angle. This is accompanied by an increase in the duration of the remaining positive and negative excursions. These effects are exhibited by the model (Figure 4b) and result simply from the change in time delay between arrivals from successive point sources at C (see Figure 1) as the angle α is changed. The corresponding changes in the power spectrum of the received signal (Figure 4a) with angle are shown in Figure 4c. On-axis the maximum in the power spectrum for this 15 μ sec duration pulse occurs at 100 kHz whilst 15^{o} off-axis this has changed to 50 kHz.

The experimentally determined 3 db energy beam width was ± 1.9 degrees in reasonable agreement with the theoretical value (1).

RESULTS FOR THE HYDROPHONE IN SAND

The geometry of the experiment is shown in Figure 3. The transmitting transducer is oriented so that the on-axis direction is normal to the water/sand interface. The hydrophone is buried approximately 25 cm or 5 pulse lengths beneath the interface, the pulse duration being chosen at 30 μ secs.

Signals received on the hydrophone were recorded as a function of X, the translation of the transmitter in a plane parallel to the interface: these are shown in a mormalised form in Figure 5a. The departure from symmetry of the signal waveform received for X = O, is evident. The waveforms predicted by the model are shown in Figure 5b. The model may be thought of in terms of the three, unterminated arrays introduced in a previous section. Array (a) originates at the transducer and array (b) originates at the water/sand interface as does array (c). Arrays (a) and (b) are tapered due to carrier attenuation in water whilst array (c) is tapered by the carrier attenuation in the sand. The total signal received at the hydrophone thus consists of three arrivals, that due to array (b) being subtracted from the addition of those due to array (a) and array (c). For small X, the arrivals due to arrays (b) and (c) simply act to broaden the time duration of the first arrival (see Figure 5b). At larger X, the arrivals due to arrays (b) and (c) are well separated in time from the first one, that due to array (c) tend to slightly decrease the amplitude and extend the time duration of that due to array (b). In Figure 5b, the dotted curve shows the slight difference which occurs if carrier penetration of the water/sand interface is ignored in the model. The experimental results shown in Figure 5a exhibit to a less marked extent the features predicted by the

* Pulse duration is here defined as the time interval between the points on the carrier envelope which have an amplitude 5% of the maximum envelope amplitude.

simplified model. At present a full explanation of this discrepancy is not available. However, it is felt that the assumption of frequency independant attenuation in the sand may not be appropriate in the case of the low Q pulses being employed. In addition it is thought that the finite apperture of the transducer together with the effect of the impulse response tail of the hydrophone are factors, the latter being evidenced by the lack of symmetry of the two positive excursions of the received signal for the $X = 0$ case.

If the signal received on the buried hydrophone can indeed be considered to originate from directive sources located respectively at the transmitting transducer and at the interface, then interference effects should be demonstrable. To this end, the signal amplitude received on the hydrophone, was obtained as a function of X (see Figure 3) for the single difference frequency (61.3 kHz) mode of operation. Figure 6a shows the results obtained using the hydrophone buried in the sand (see Figure 3) whilst for comparison Figure 6b shows the results obtained using a water-borne hydrophone at the same effective range. The two "beam patterns" are plotted for ease of comparison on an angular scale: for the water/sand case this angle θ (Figure 3) is both the off-axis angle and the angle of incidence on the water/sand interface for the Snells Law path between transducer and hydrophone, whilst for the water only case it is the off-axis angle. The positions where interference minima are expected are marked: these are those angles for which the time delay between the arrivals from the directive sources which are considered to exist, is an integral number of periods.

Although the general trend of the skirts for the two cases are comparable, the shape of the beam patterns in the region of $\theta = 0^{\circ}$ is quite different. At $\theta = 0^{\circ}$, although the signals considered to come from array (a) and array (b) arrive simultaneously, they are in antiphase. Minima at other angles are expected but at $\theta = 0^{\circ}$ the two interfering signals are more similar in amplitude than at other angles.

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Figure 1 Geometry used in the computer model.

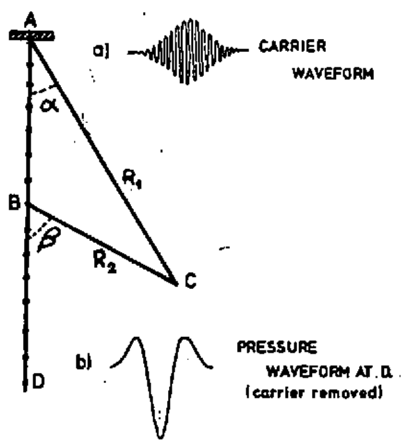


Figure 3 Geometry used in the experiments involving a buried hydrophone.

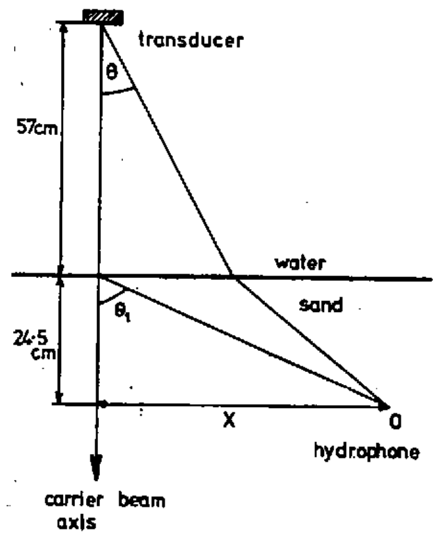
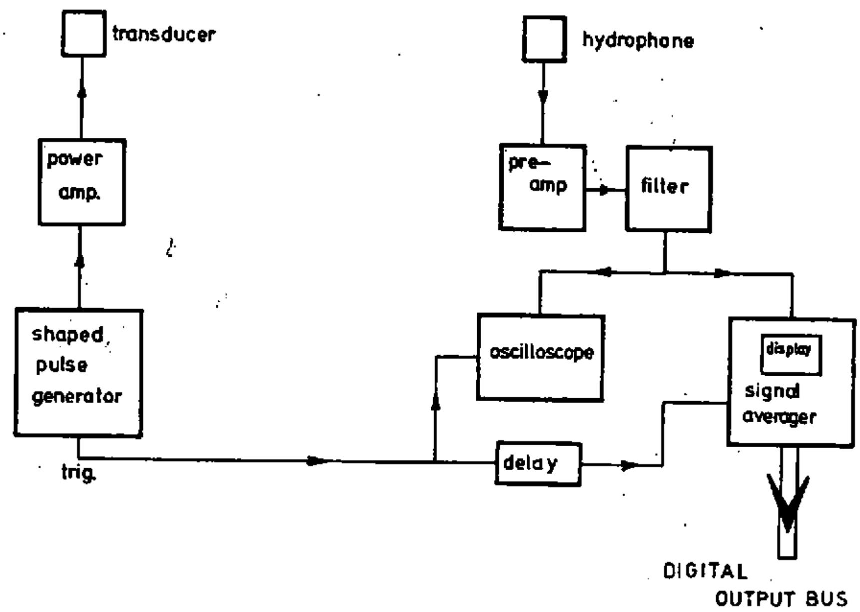


Figure 2 Schematic of the electronic arrangement.



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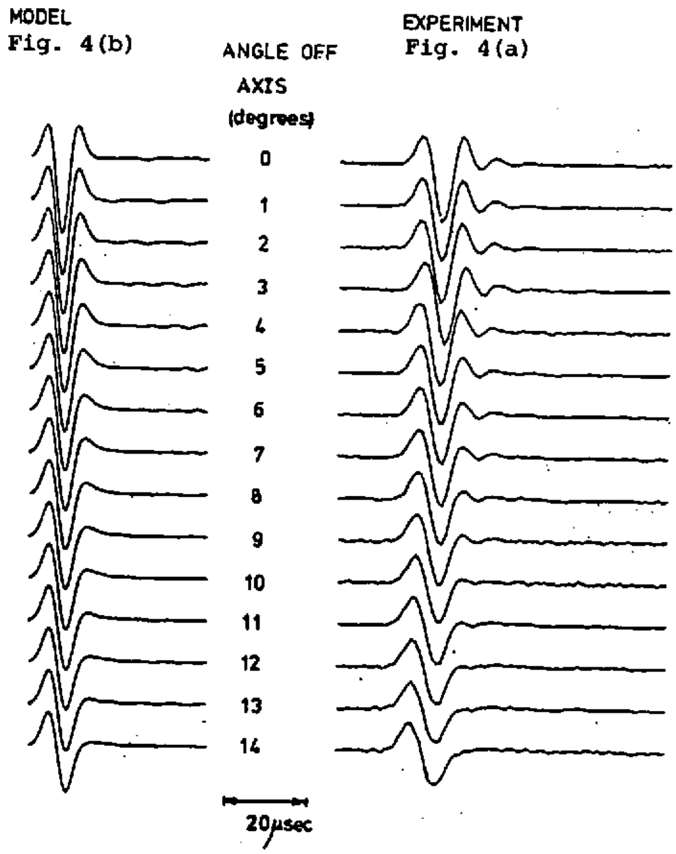
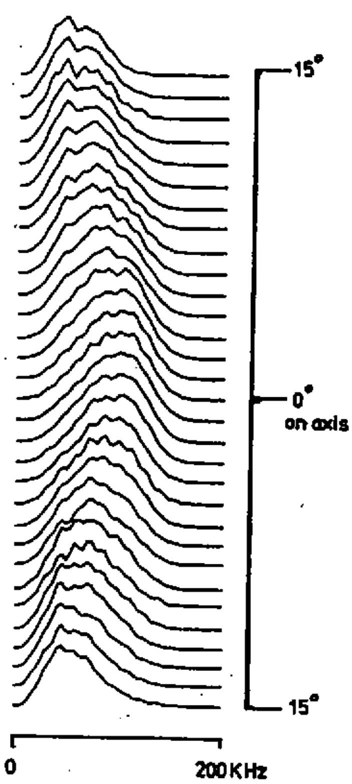


Waveforms for a 15μsec pulse at angles off axis. (75cms range)

Figure 4(a) and (b). The waveforms resulting from the self-demodulation of a Gaussian modulated carrier are shown as a function of angle. In (a) are shown the experimental results whilst (b) shows the predictions of the simple model described in the text. (Each wave form is normalised by its maximum value.)

Figure 4(c) The power spectra of the experimentally obtained waveforms of (a). (The amplitude scale is linear.)



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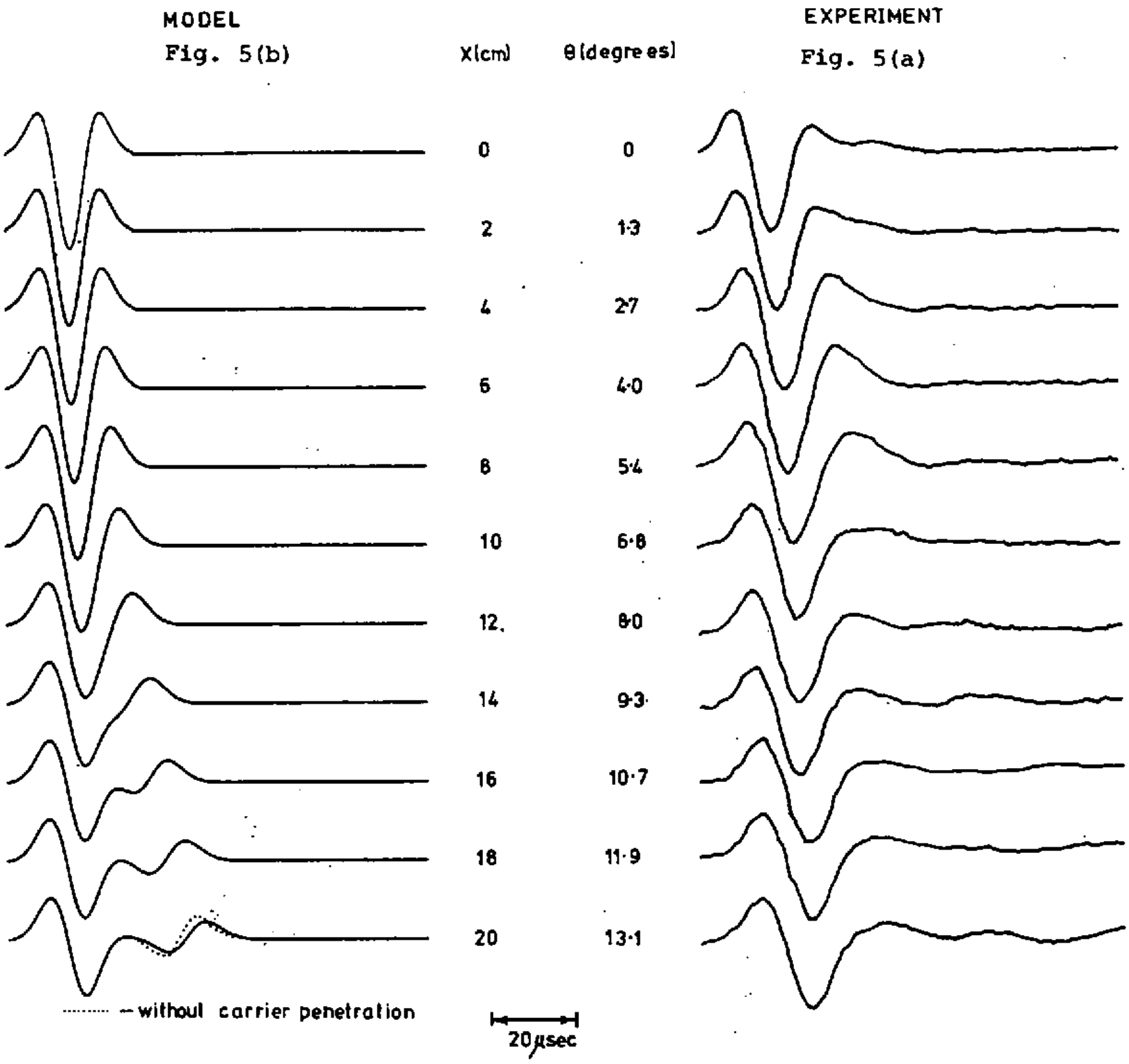

Figure 5(a) and (b) The waveforms resulting from the self-demodulation of a Gaussian modulated carrier are shown as a function of X/θ (see Figure 3). In (a) are shown the experimental results whilst (b) shows the predictions of the simple model. (Each waveform is normalised by its maximum value.)

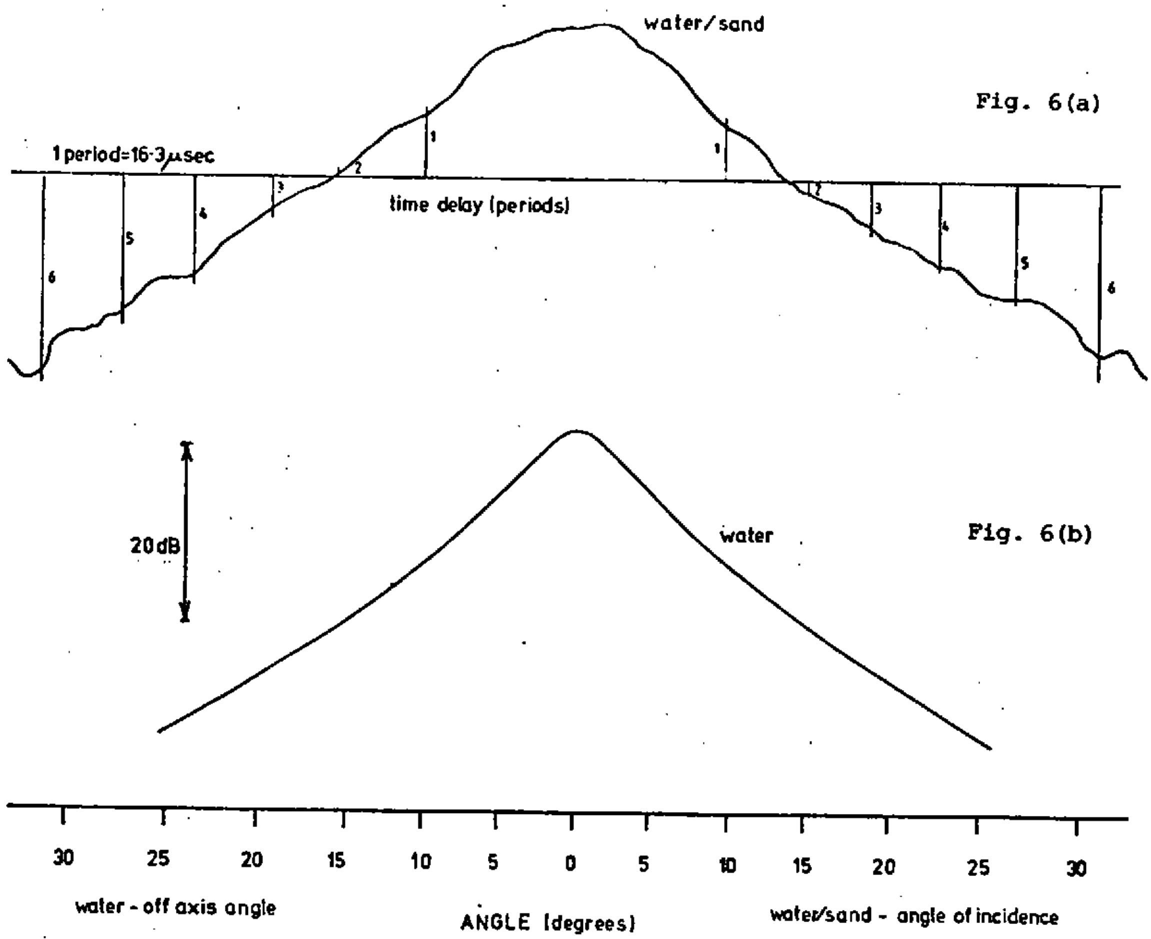

Figure 6(a) and (b) The signal amplitude received at a single difference frequency (61.3 kHz) is shown as a function of off-axis angle (see Figure 3) in (a) when the hydrophone is buried in sand and in (b) when the hydrophone is in water at an equivalent distance. The positions at which minima are expected in (a) are indicated.