SIGNAL PROCESSING CONSIDERATIONS FOR THE DETECTION AND CHARACTERISATION OF OBJECTS ON THE SEA BED

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1. INTRODUCTION

One of the most challenging research topics in sea-bed imaging is the detection and characterisation of objects that are either partially or completely buried. Objects of interest include pipelines, mines, lost cargo and historical artifacts. The research described here was a contribution to the European Commission's MAST-III *DEO* (Detection of Embedded Objects) project. The approach adopted during this project was to use two complementary parametric sonar systems, one operated by Loughborough University (LU) and the other by the SACLANT NATO Research Centre, La Spezia, Italy. These non-linear acoustic (NLA) systems were chosen because of their capabilities of penetrating sediments to a depth of several metres. LU developed a system that was calibrated and used on sea trials during the MAST-II *REBECCA* project [1-3], while SACLANTCEN used a TOPAS system. The main characteristics of both systems are summarised in Table 1, although only the LU system is described further here.

The LU group carried out two sea trials on Loch Duich, Scotland, during May 1997 and June 1998 using a moored raft operated by the Scottish Office, Fisheries Research Services (FRS). This was done in close collaboration with TNO-FEL, The Hague, whose hydrophone array was deployed as the principal detector of scattered signals from a target. An auxiliary hydrophone was deployed to obtain 'snapshots' of signals and it is these that are described in this paper. The SACLANTCEN group carried out two complementary trials, one in an Italian Navy dry dock at La Spezia, Italy and the other off the Mediterranean island of Elba.

The first trial in Scotland involved the detection, in the free field, of scattered signals from a thin-walled steel cylinder with flat end-caps, both when air-filled and water-filled. The second trial involved the detection of scattered signals from the same cylinder, when water-filled only and lying on the sea bed.

The main objectives were: (i) to achieve real time control of the transmission direction of a parametric sonar array, allowing preferential sea-bed incident angles, optimised signal returns from objects and correction of any instability of the transmission platform; and (ii) to identify spectral components of the back-scattered signals so that randomly-oriented objects that are partially or completely buried may be characterised in the frequency domain. Incident and back-scattered signals from the target at various orientations were recorded for the frequency range 2-12 kHz. An analysis of the results has not yet been completed so this paper is mostly concerned with the experimental aspects of the project and the generation and detection of acoustic signals.

	Loughborough University	SACLANTCEN
Primary frequency (kHz)	75	40
Secondary frequency (kHz)	1-13	1-10
Source Level (dB re 1μPa at 1m)	245	240
Primary beamwidth(°)	3.0	2.5
Secondary Source Level (dB re 1μPa at 1m)	>196 at 8-13 kHz	>200 at 6 kHz
Secondary beamwidth (°)	3 – 6	≥ 2.5
Angular coverage (°)	36	80

Table 1. Comparison of Loughborough University and SACLANTCEN systems

2. SIGNAL SYNTHESIS AND DATA CAPTURE

Transmission signals are generated using a 16-bit digital-to-analogue interface. This allows the generation of 16 parallel channels of data. The waveforms are generated by a 486 DX266 MHz computer programmed in Borland Pascal version 7.0, then written to memory external to the computer. The memory is arranged into 16 blocks of 32k (16-bit) words that are re-addressable on the three most significant bits, effectively sub-dividing the memory per channel into eight sections of 4k words. This provides very fast access under software control to eight pre-programmed signals, each with a maximum duration of 4 ms. Acoustic signals reflected and scattered from the target are detected by hydrophones linked to an integrated PC-based data capture system. Data capture on up to 16 parallel channels is possible over a maximum time window of 16 ms. A 250 kHz (16-bit) sample rate is used to capture signals with frequencies up to 100 kHz, thus suitable for both primary (70-80 kHz) and NLA secondary (1-13 kHz) frequency signals. In addition, 'real time' displays of time and frequency domain signals were provided on the PC monitor. The data capture system was fully integrated with the transmitter signal synthesis system, providing a high degree of signal monitoring during transmission. Other signal processing electronic systems include pre-amplification, filtering and envelope detection. All data can also be archived directly to hard disk for later analysis. Memory relocation under software control also allows an increased capture time window for fewer channels, the limit being 256 ms of data for a single channel.

3. EQUIPMENT DEPLOYMENT

For the first trial, an air-filled, galvanised steel cylinder, 1m long and 0.25m diameter, with a 6mm wall thickness, was placed 76m downrange of the parametric array. This target was suspended close to mid-water (16m depth) from a separate target raft and the target aspect angle was controlled in the horizontal plane by a stepper motor. The TNO 20-element hydrophone array (with a 5.5-metre aperture) was placed between the source and target, either horizontally or vertically deployed, allowing measurement of both direct and back-scattered parametric signals. The centre of the hydrophone array, when deployed horizontally, was 56m from the parametric source. The source was deployed at a depth of 16m below the FRS raft, allowing transmission horizontally. Fine adjustment of the acoustic beam could then be made by using a pan-and-tilt facility in the vertical plane or by electronic beam steering in the horizontal plane. The target raft was held in place between two horizontally tensioned wires attached firmly to the FRS raft.

Transmitter and target control electronics were operated from the FRS raft, which was moored approximately 300m from the shore. Recordings of secondary frequency NLA signals of both direct and scattered signals were made with the 20-element hydrophone array. Signals were transmitted ashore for processing via a sea-bed cable to the TNO base. Three single-element, 25mm-diameter ball hydrophones were used, each having a sensitivity of -202 dB re 1 V/μPa at 75kHz. These allowed the monitoring of direct and target-scattered signals at both primary and secondary frequencies. An additional low frequency hydrophone, with a flat response in the range 1-13 kHz, was also used. Initial deployment was approximately 4-8m from the target along the transmission axis of the parametric source, allowing the measurement of both direct and scattered signals, i.e. to and from the target. An additional hydrophone placed close to the target itself was used to aid transmitter-target alignment. Transmitter and receiver logging systems were synchronised using a GPS receiver for post-correlation of transmission and received data. Additional transmit signal data and target angle information were transmitted ashore via a fibre optic link for display at the TNO base. Fibre-optic and cable links also allowed transmitter–receiver communications and synchronisation. The system is shown in Fig. 1.

For the second trial the same cylinder was used, but water-filled only, for a bottom-scattering experiment. Three receiver arrangements were used: (i) direct and back-scattered signals were detected by a low frequency (LF) hydrophone; (ii) back-scattered signals were detected by the TNO array; and (iii) high and low frequency direct signals were detected by a hydrophone inside the target to align the parametric array with it. With reference to Fig. 2, the geometry of the experiment was as follows: horizontal range of parametric array to target, 38.5m; water depth 40 – 45.6m according to the tide; TNO hydrophone array to target, 38m; LF hydrophone from target, 13.5m. The target was placed on the sea bed at azimuth angles of –45°, +10°, -42°, +33°, +43°, +51°, +77°, +96°, +114° (0° being broadside and 90° being end-on). The sea-bed incidence angle was 41.9° to 37° depending on the water depth.

4. MEASUREMENTS AND PRELIMINARY DATA

In the first trial, the cylindrical target was rotated continuously with its axis horizontal and recordings of both primary and secondary frequency signals for both incident and scattered data were made. Various secondary frequency signal types were used including: (i) sine wave non-linear acoustic (NLA) signals in the range 2-12 kHz; (ii) linear frequency modulated (LFM) 'chirp' NLA signals of 2-12 kHz; (iii) NLA Ricker pulses centred on frequencies in the range 4 - 10 kHz; and (iv) NLA sector scanning signals at 5 kHz.

Fig. 3 shows a typical transmitted CW pulse formed by the generation of two sine waves with similar frequencies, i.e. an example of (i) above. The advantage of transmitting this type of pulse is that the difference (or secondary) signal generated is a single frequency, as shown in Fig. 4. Thus, it should be easy to identify any spectral "colouring" of the signal scattered from the target as a result of exciting resonances in it. Many thousands of such transmitted signals and their scattered equivalents, along with their spectra, have been archived but have not yet been analysed. Fig. 5 shows the secondary frequency components of both the direct and scattered signals received at a single hydrophone for a 7 kHz Ricker pulse incident at an end cap, after processing with a band pass filter, i.e. an example of (iii) above. Again, many thousands of such signals and their spectra have been archived also.

5. CONCLUSIONS

Two sea trials of the MAST-III *DEO* project were carried out on Loch Duich, Scotland. During the first trial a cylindrical target, first air-filled then water-filled, was insonified in the free field. During the second trial the same water-filled target was insonified on the sea bed. The capture of back-scattered signals for various transmitted signals generated by a parametric array was successful and a large numbers of signals have been archived for analysis. Any spectral "colouring" of the scattered signals by the resonances of the target should lead eventually to the identification and characterisation of objects embedded in and under the sea bed.

6. REFERENCES

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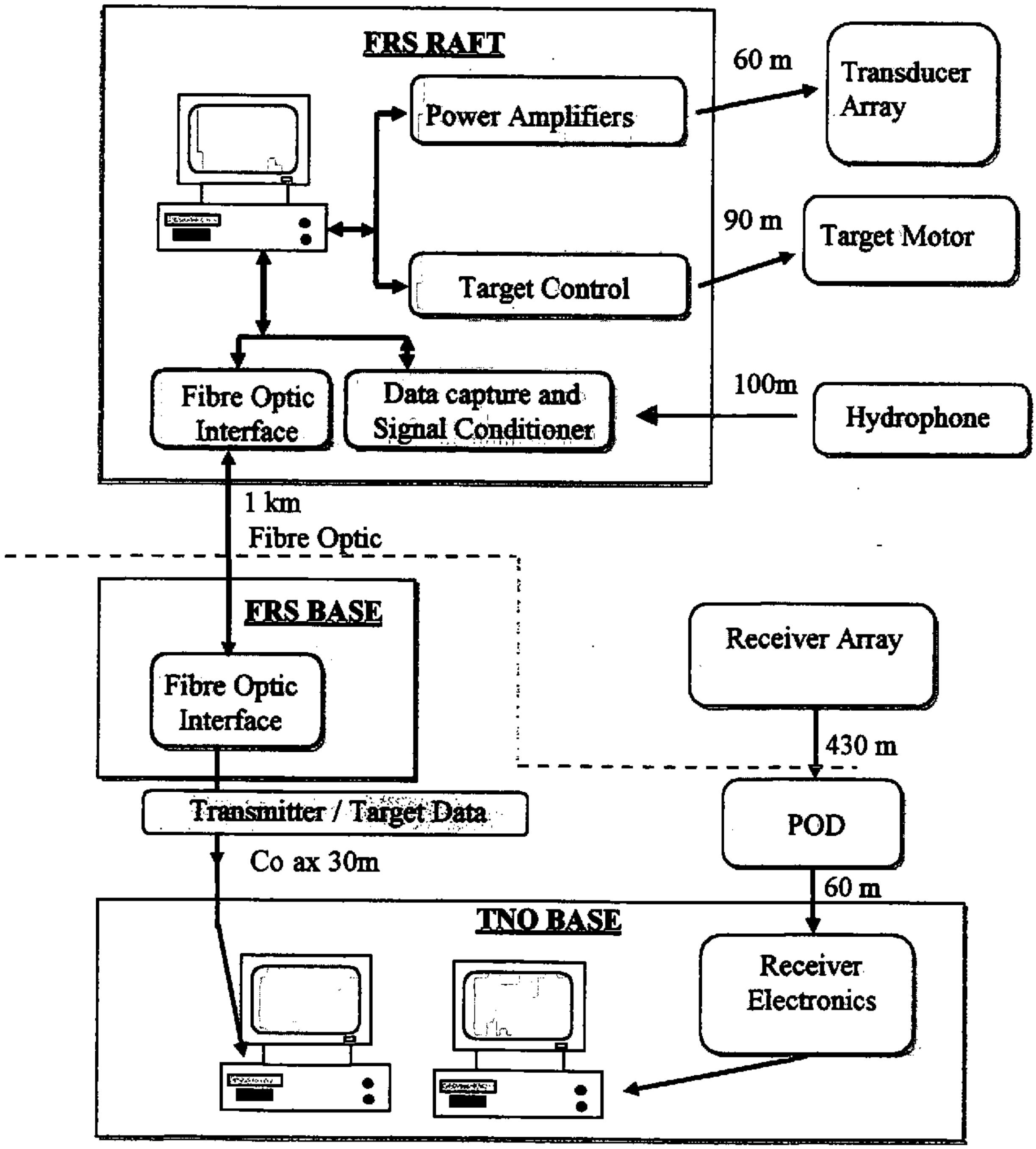

Fig.1 Complete transmitter-receiver system for DEO project trial Loch Duich

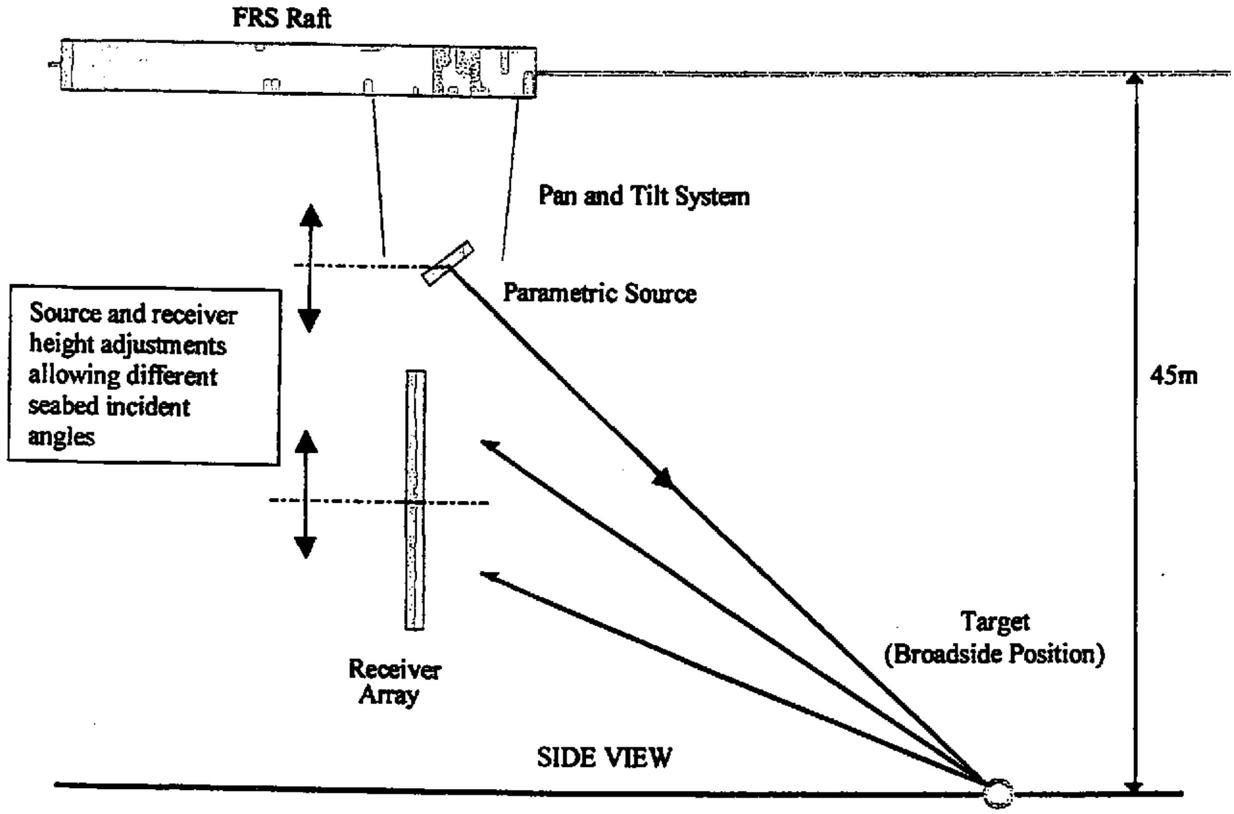

Fig. 2. Experimental configuration

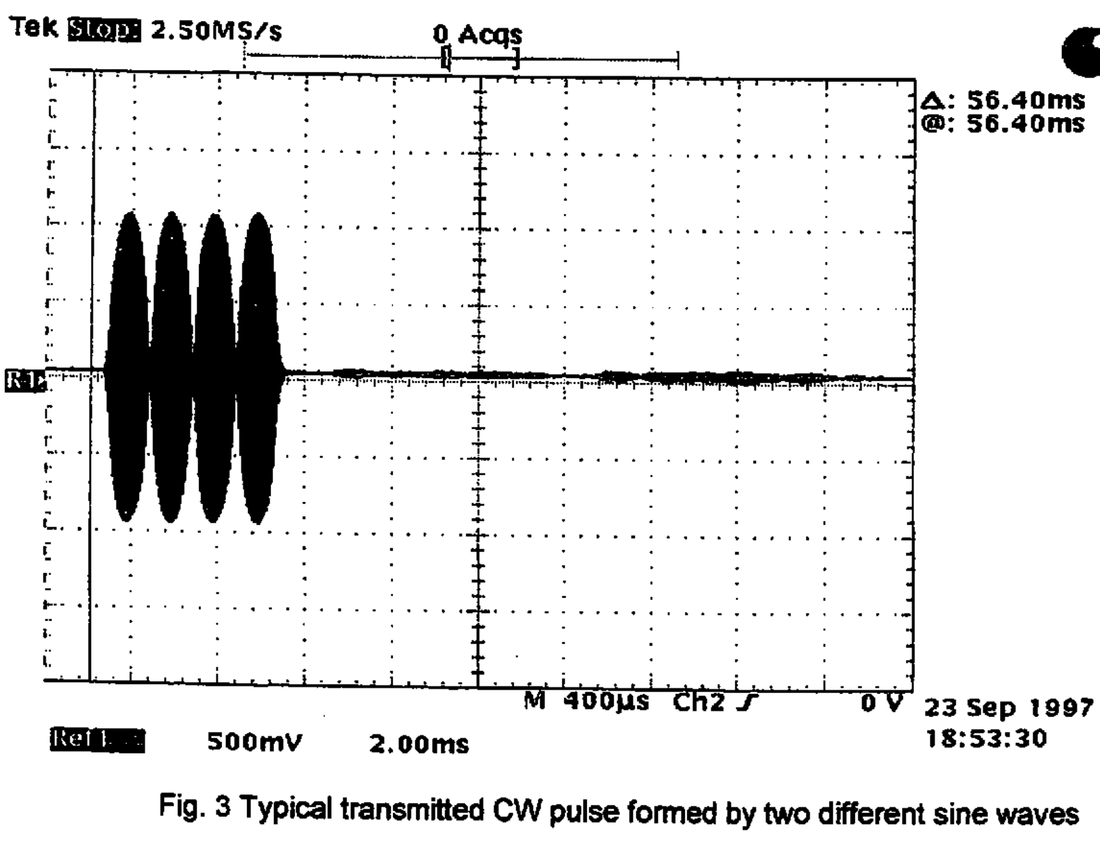

Fig. 3 Typical transmitted CW pulse formed by two different sine waves

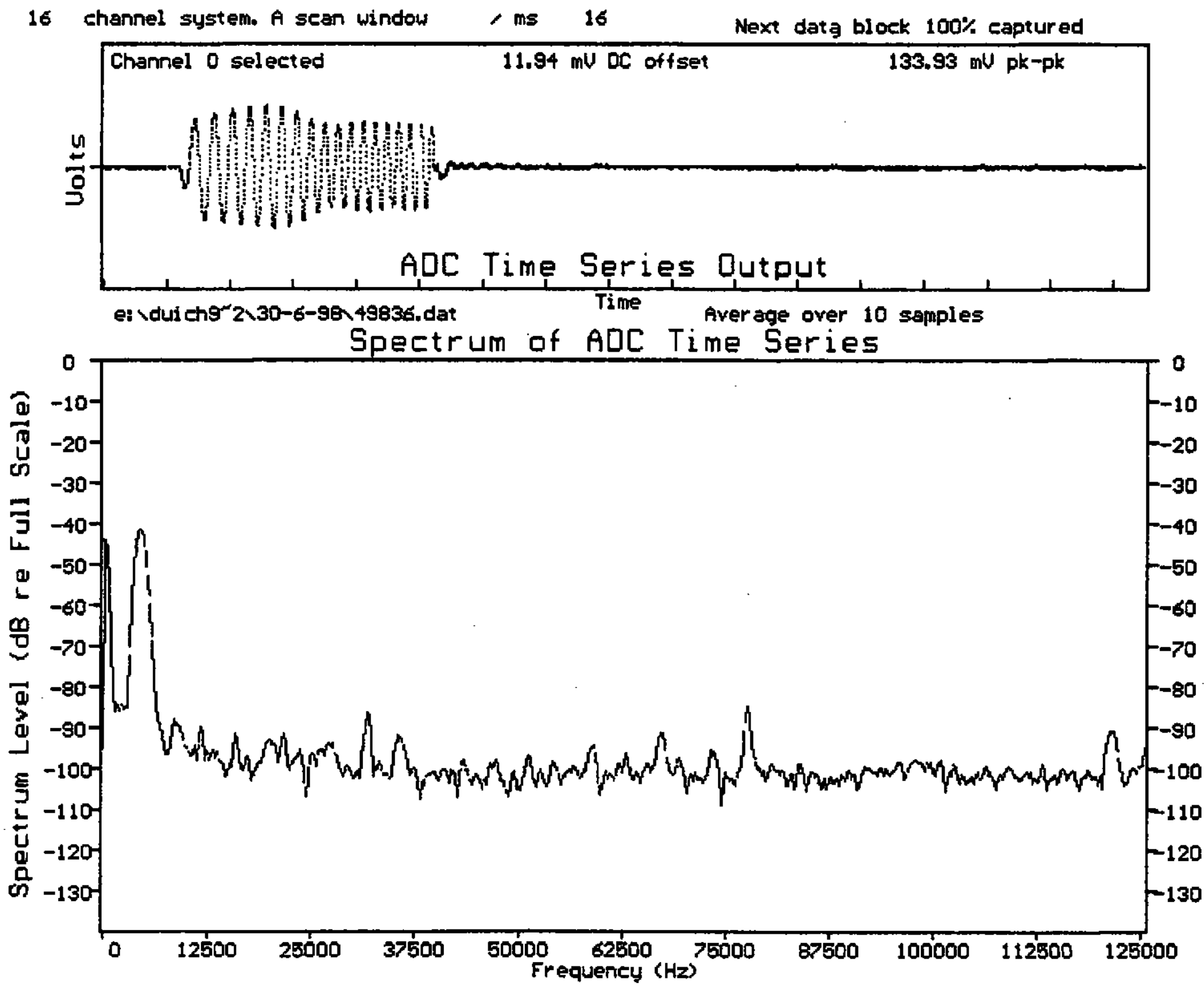

Fig. 4 Typical secondary frequency CW pulse and its spectrum

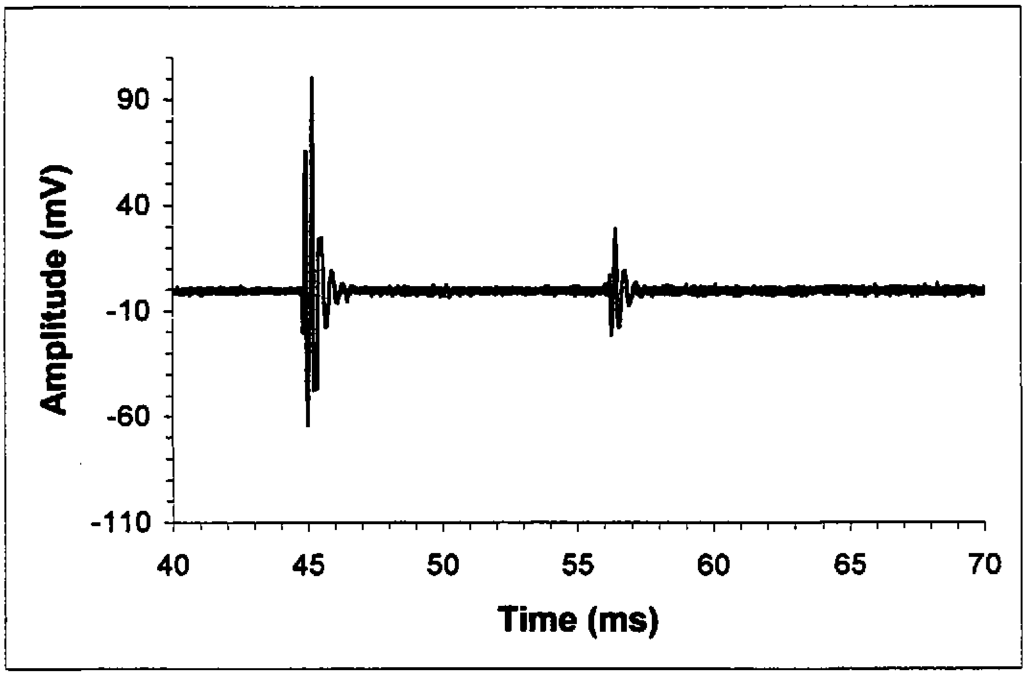

Fig. 5 NLA Ricker pulse (7 kHz band-passed secondary) showing incident signal and signal scattered from the end-cap of the water-filled cylindrical target

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