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LOW FREQUENCY STANDARD HYDROPHONE FOR CALIBRATING LINE HYDROPHONE ARRAYS (SEISMIC STREAMERS) AND MARINE SEISMIC SOURCES

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SUMMARY

The design of a standard hydrophone having a maximally flat (Butterworth) response in the frequency range 8.0 Hz to 1.0 kHz is described. The standard hydrophone has been developed primarily for calibrating line hydrophone arrays (seismic streamers) and marine seismic sources.

The standard hydrophone has been used successfully during the past eight years for monitoring the output of a single air-gun. The use of the standard hydrophone for calibrating a marine seismic streamer is discussed.

INTRODUCTION

The marine seismic source and streamer are essential parts of a highly complex seismic data acquisition system used in offshore oil prospecting. Therefore, proper quality control of their performance is an important consideration in ensuring high data quality standards. An effective quality control can only be achieved by using a reliable calibrated hydrophone.

The purpose of this paper is to present the design and construction of a low frequency standard hydrophone and to discuss its use in monitoring the output of a single air-gun and in calibrating a marine seismic streamer.

DESCRIPTION OF THE HYDROPHONE

A sectional view of the hydrophone is shown in Fig. 1. The sensitive element consists of a stack of three 30mm diameter x 3.0mm thick PZT-5H discs. The PZT-5H is chosen because of its high permittivity. The three PZT-5H discs are cemented together with a mixture of Araldite and Tungsten powder and are connected in parallel by means of 0.5mm thick copper foils which are inserted between the discs. One side of the stacked discs is clamped by means of a 25.0mm thick stainless steel disc, while the other side, which is exposed to the incident acoustic pressure, is isolated from the water by a 6.0mm thick perspex disc. The edge of the stacked discs is shielded from the incident acoustic pressure by having an air-gap between the edge and the discs housing. The output voltage of the stacked discs is connected to the hydrophone cable via a step-down transformer.

THE DESIGN OF THE LOW FREQUENCY STANDARD HYDROPHONE

It can be shown that the equivalent circuit of the standard hydrophone sensitive element, for the case when the highest frequency of interest is less than 1000 Hz, consists of a voltage source E_h in series with a capacitance C_h. The standard hydrophone sensitive element open circuit receiving sensitivity M and the capacitance C_h are shown to be given by

$$M \simeq A \left[N^2C_m/(C_o + N^2C_m)\right] \left[(\rho_s t_s + 3\rho_c t_c/2) \;/\; (\rho_s t_s + 3\rho_c t_c + \rho_w a/2)\right] \quad (1)$$

$$C_h = 3(C_o + N^2C_m) \quad (2)$$

The sensitivity M and the capacitance C_h computed after substituting the appropriate values into eqns. (1) and (2) are 5.0 μV/μb and 0.037 μF respectively whereas the measured values are 7.0 μV/μb and 0.034 μF. The standard hydrophone sensitive element open circuit receiving sensitivity M is measured using the impulse method which involves the measurement of the electric charge produced by the sensitive element when subjected to a sudden drop in the static pressure. The difference between the computed and measured values of the sensitivity M could be due to the fact that the steel block is not air-backed.

The complete equivalent circuit of the standard hydrophone is shown in Fig. 2. The transformer, the resistance R_h and the capacitance C_d are required for producing a hydrophone response which is the same as a two-pole Butterworth high pass fitter. It can be shown(Safar and Hosken 1980) that when neglecting the coupling transformer primary and secondary resistances, the approximate low frequency transfer function of the standard hydrophone is given by

$$E_o/E_h \simeq \left[\frac{C_h/n}{C_h + C_d} \right] \left[\frac{(j\omega/\omega_o)^2}{1 + 2j\omega h_s/\omega_o - \omega^2/\omega_o^2} \right] \qquad (3)$$

where

$$\omega_o = 1/\left[L_p \ (C_h + C_d) \right]^{\frac{1}{2}} \qquad (4)$$

$$h_s = \left[L_p/(C_h + C_d) \right]^{\frac{1}{2}}/2R'_h \qquad (5)$$

$$R'_h = n^2 R_h R_1/(n^2 R_1 + R_h) \qquad (6)$$

In order that the standard hydrophone response is maximally flat (Butterworth) we make $h_s = 1/\sqrt{2}$. Consequently, the standard hydrophone 3 dB cut-off angular frequency ω_c and the resistance R'_h are given by

$$\omega_c = 1/\left[L_p(C_h + C_d) \right]^{\frac{1}{2}} \qquad (7)$$

$$R'_h = \left[L_p/2(C_h + C_d) \right]^{\frac{1}{2}} \qquad (8)$$

Given the values of L_p, C_h and ω_c then the values of R_h and C_d can be determined from eqns. (5), (7) and (8). The standard hydrophone design parameters R_h and C_d obtained as indicated above, for the case when the 3 dB cut-off frequency f_c is 8.0 Hz and when the hydrophone is driving an amplifier with input impedance R_1 equal to 1200 Ω are 120.0k Ω and 0.15 μF respectively.

Fig. 3 shows the amplitude response of the standard hydrophone when the sensitive element is simulated by a voltage source in series with a capacitance equal to C_h. It can be seen from Fig. 3 that the standard hydrophone system has a flat response in the frequency range 12-1000 Hz and a sensitivity of 0.089 $\mu V/\mu b$. It can also be seen from Fig. 3 that the low frequency cut-off is 12.0 Hz instead of 8.0 Hz. This indicates that the transformer primary inductance L_p is about 1000 H which differs from the assumed values of 2100 H. Of course, the low cut-off 3 dB point may easily be altered by changing C_d, so to obtain the value of 8 Hz originally aimed for it should be increased to 0.36 μF.

THE USE OF THE STANDARD HYDROPHONE

Monitoring a single air-gun output pressure

A low frequency wide-band hydrophone is required not only to provide zero time reference but also to monitor the acoustic source performance during the well velocity and vertical seismic profiling surveys. A typical marine well velocity survey involves the measurement of the time taken by the acoustic waves to travel from the acoustic source to a particle velocity sensitive wall-coupled detector. The acoustic waves are radiated by an air-gun situated at a certain depth below the sea surface.

The standard hydrophone has been used in several marine well velocity surveys in the North Sea over the past eight years. Typical pressure waveforms measured by the standard hydrophone are shown in Fig. 4. In measuring the pressure waveforms shown in Fig. 4, the standard hydrophone was placed 1.5 metres below the Par 0.65 litre air-gun. The air-gun was fired at a depth of 18.5 metres for various values of air-gun chamber pressure.

Calibrating a marine seismic streamer

In a marine seismic reflection survey acoustic pressure signals are sensed by the seismic streamer, which in the interest of facilitating maintenance and repair work usually consists of a number of interconnected sections, typically of 100 metres length. Total streamer length often extends to 3km. Each section contains 2, 4 or perhaps 8 linear arrays of hydrophones depending upon the seismic application, together with stress members and conductor cables, the entire assembly being contained in an oil-filled plastic sheath. Hydrophone arrays are coupled to the seismic amplifiers either through step-down transformers within the streamer or via a charge amplifier on the seismic vessel.

It has recently been shown (Safar and Hosken 1980) that the equivalent circuit of the transformer coupled seismic streamer is the same as that of the standard hydrophone so that when the hydrophone and streamer have the same cut-off frequency their impulse responses should be identical to within a scale factor.

Checking the performance of a seismic streamer poses considerable practical difficulties because of the physical size of the streamer and the length of the individual arrays. In-situ testing is further complicated by the proximity of reflecting boundaries at the upper and lower surfaces of the water layer. Nevertheless, a valid test can be made by comparing the responses of coiled streamer hydrophone arrays with one another and with that of a calibration hydrophone located at the centre of the coil. For such a comparitive test to be meaningful it is necessary to employ a broadband seismic source impulse.

Fig. 5 shows a set of responses obtained in this way from a calibration hydrophone, at the top of the figure, and from three coiled 25 metre groups of hydrophones, beneath. These responses are normalised for display purposes to have a common peak amplitude, the normalisation factors providing a means for estimating the relative sensitivities of the different sensors. For the purpose of this experiment the streamer groups, each comprising 16 individual hydrophones, were tied in a coil of approximately 1 metre diameter and suspended at 5 metres depth in the sea. The signal was provided by a single 20 cubic inch air-gun operated at 500 psi air pressure and mounted in a special steel bell to suppress bubble oscillation. Responses were recorded through conventional digital seismic instruments with a sample rate of 2ms, low cut filters 8 Hz 18 db/octave, high cut 124 Hz, 18 db/octave. Residual air bubble oscillation accounts for the low frequency undulation that follows the initial impulse in Fig. 5. The principal difference between streamer group and calibration hydrophone responses is seen in the phase of this undulation. The streamer groups have a response that extends nominally to 5 Hz, whereas the calibration hydrophone is characterised by a 12 Hz low frequency cut-off, as was seen in Fig. 3.

A more critical appraisal of these same responses is afforded by displaying their amplitude spectra as in Figure 6. Thus, the fine detail in the spectra of the response is virtually identical between groups, whereas the reduced response of the calibration hydrophone to a spectral peak at 13 Hz is clearly shown. These results confirm that valid comparative response tests can be made at seismic frequencies and under field conditions if streamer groups are bunched so as to occupy a space that is dimensionally small compared with seismic wavelengths in water.

CONCLUSION

We have shown that the low frequency standard hydrophone, which has served for many years as a reliable monitor of the output pressure of a single air-gun, can also be used successfully for calibrating marine seismic streamers.

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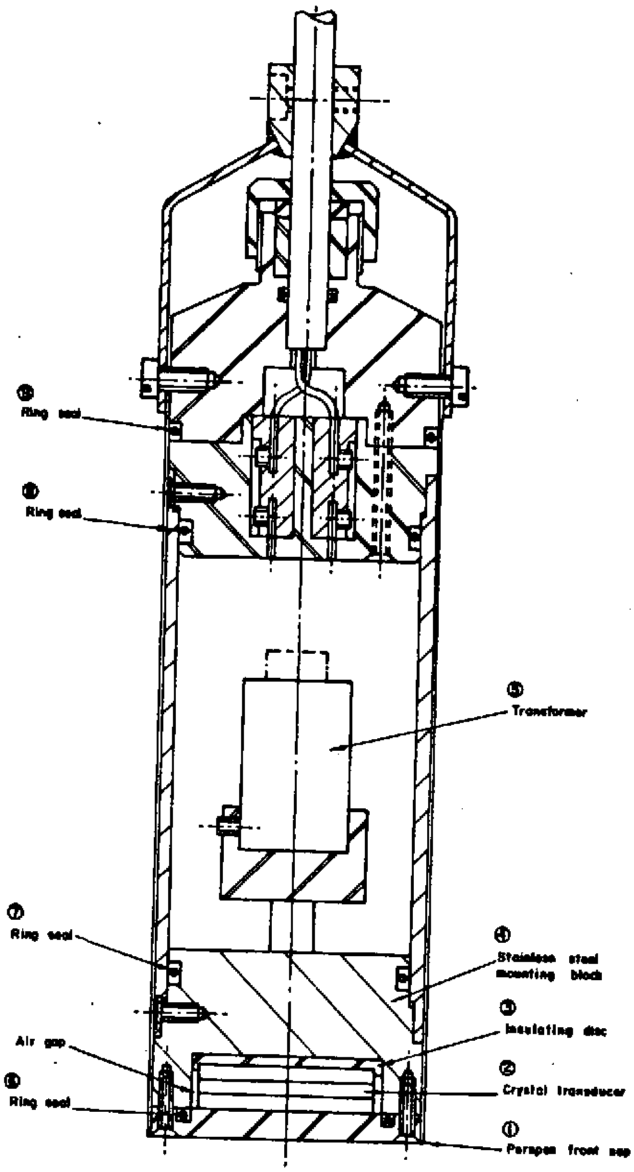


Sectional view of the Standard Hydrophone Fig. 1

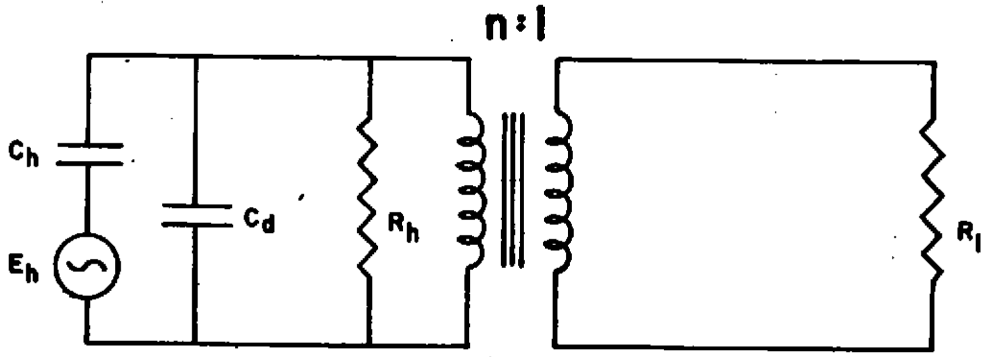


Fig. 2 Complete equivalent circuit of the standard hydrophone system

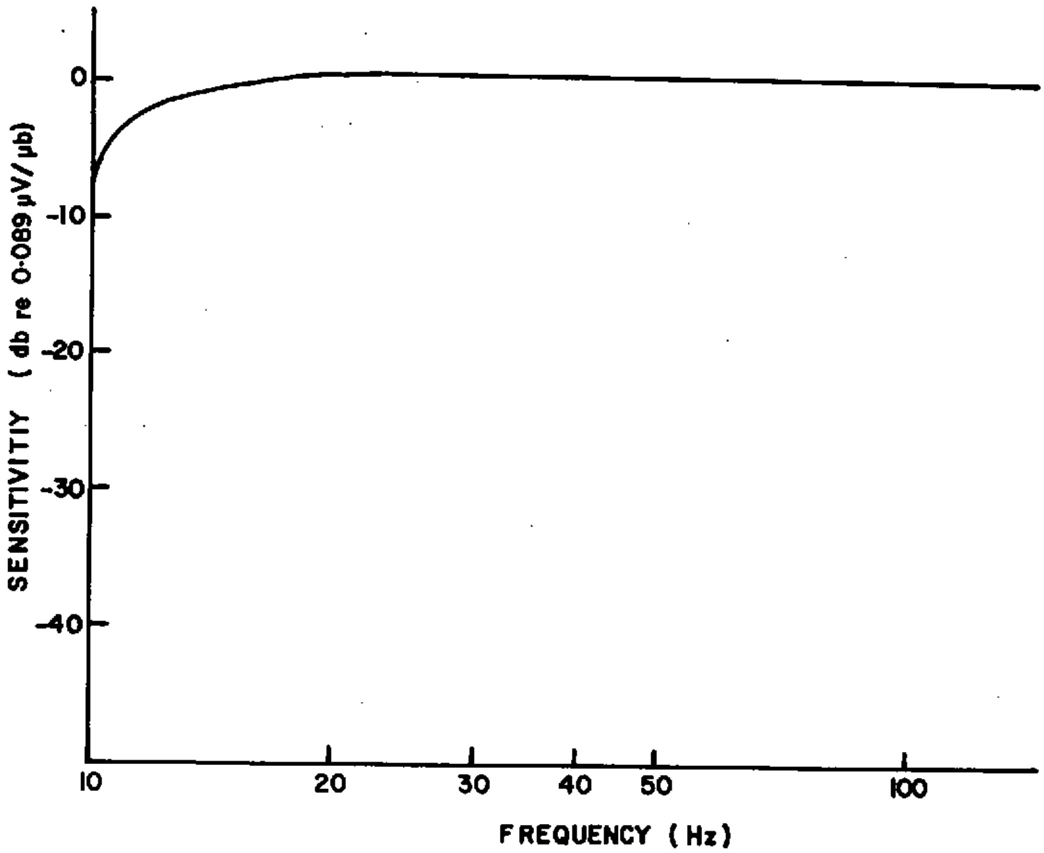
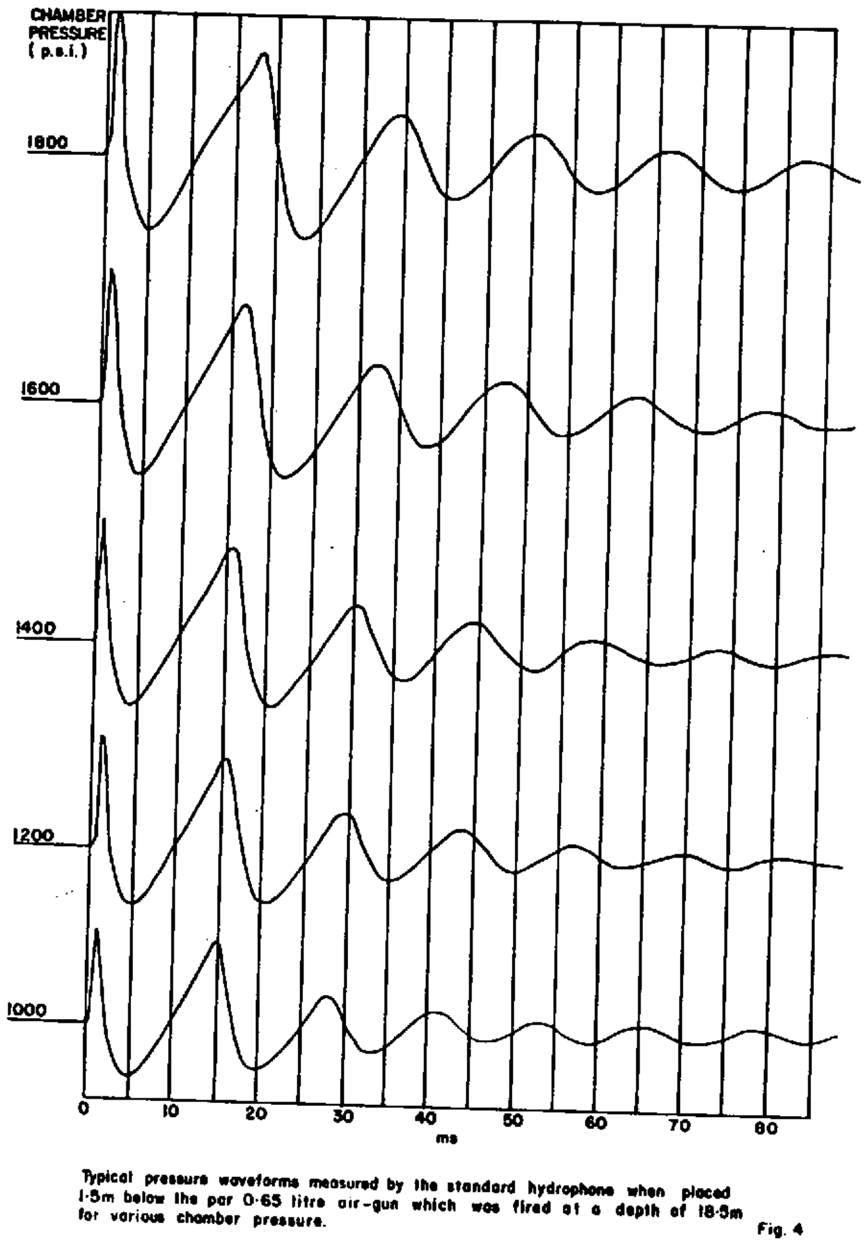


Fig. 3 Amplitude response of the standard hydrophone system



Typical pressure waveforms measured by the standard hydrophone when placed 1·5m below the par 0·65 litre air-gun which was fired at a depth of 18·5m for various chamber pressure.

Fig. 4

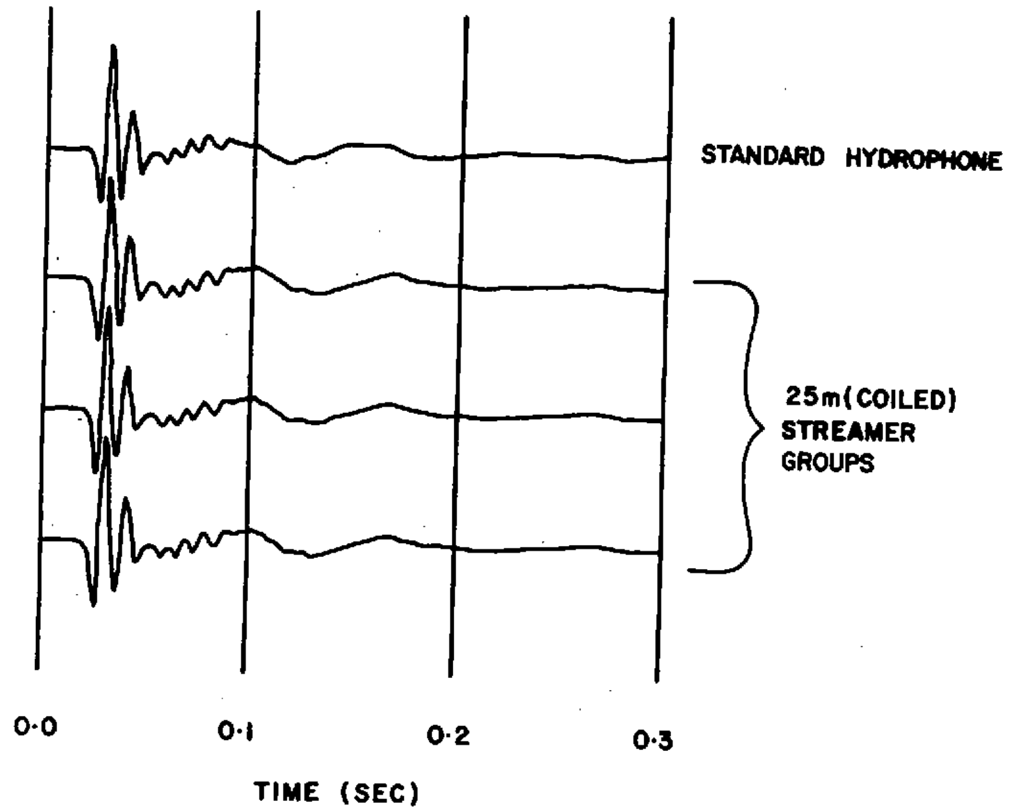
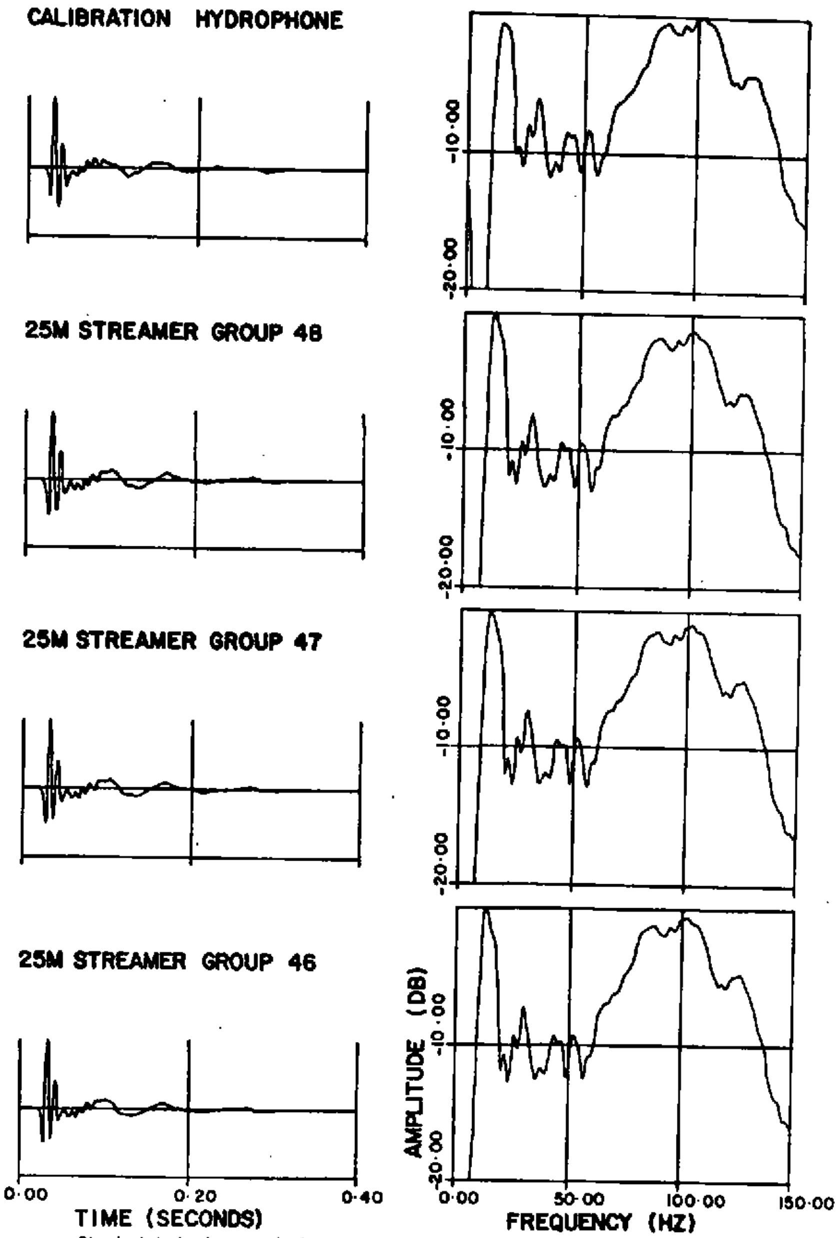


Fig. 5

Standard hydrophone (top trace) and three coiled 25m streamer groups (lower traces) normalised responses to seismic air-gun source. Time scale in seconds.



Standard hydrophone and three streamer groups responses and their normalised amplitude spectra. Fig 6