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SUB-BOTTOM PROFILERS USING PARAMETRIC SOURCES

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(FOR AFFILIATION SEE BELOW)

Use of low-frequency acoustic waves in obtaining information about the geological structure of the earth is well established. High energy 'impulse' sources (such as explosives, air guns and 'boomers') for sea operations are being used successfully for sub-bottom operations, especially for deep-penetration work. In particular, 'boomers' have been developed to provide a compact package, giving good resolution for shallow-penetration work as well.

With increasing activity in the various aspects of off-shore engineering, the need for high-resolution sub-bottom profilers (for various specific tasks) has become quite clear. In addition to establishing the nature of the first few meters of the sediment for various purposes, one may consider the location and the measurement of the depth of buried pipes. A particular problem of interest in the control of dredging operations, for example, is the accurate measurement of the thickness of silt in harbour areas.

A parametric source has particular advantages for use in a high resolution sub-bottom profiler. These advantages were probably first demonstrated in open literature by Walsh[1].

The main attributes of a parametric source particularly useful for high-resolution echo-sounding and sub-bottom profiling are as follows:-

(i) A narrow beamwidth at a low frequency can be achieved using a relatively small transducer;

(ii) The low-frequency used can be varied over a wide range with ease and simplicity, to suit the particular purpose for which the system is to be used;

(iii) Wide-bandwidth signals can be used in order to obtain high range resolution;

(iv) The primary-frequency returns can be used to provide a high-frequency narrow-beam echo sounder which determines the position of the sea bottom accurately, even for soft sediments.

Characteristics of Parametric Sources

The properties of the low-frequency waves radiated by parametric sources have been studied extensively, and are fairly well understood.

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SUB-BOTTOM PROFILERS USING PARAMETRIC SOURCES

To obtain a high degree of resolution within the first few meters of the sediment (even with a narrow beam system) it is important to work with the transducer close to the sea bottom. This often results in 'truncating' the parametric source within the virtual-source volume. Hence, the near-field effects in parametric sources become of significance. (There is experimental evidence to suggest that the truncation of the parametric array by the sediment interface does produce additional effects. This is the subject of another paper in this Conference.)

In the study of the near fields of parametric sources it is easier to ignore the attenuation of high-frequency waves, either due to small-signal absorption or resulting from higher-order interactions. Then, for a circular transducer, by assuming collimated plane-waves (of the same cross-section as the aperture) the sound-pressure level along the acoustic axis can be determined in a straightforward manner. This result is applicable particularly in the vicinity of the transducer.

For longer ranges, it is more useful to extrapolate Rolleigh's results[2] which are strictly applicable for interactions in the far-field of the transducer (at the primary frequencies).

These two results can be combined to produce a formula (which is simple to use) to estimate the sound pressure level (SPL) at the difference frequency.

$$SPL = -36.2 + 40\log F_- - 60\log C + 20\log W_o + 20\log|Q| \quad \text{dB rel 1 Pa (r.m.s.)}$$

where F_- is the difference-frequency in kHz, C is the sound velocity in km/s, W_o is the geometric mean of acoustic powers transmitted for the two primary waves, in watts.

Q is used to represent either of the two normalised expressions, Q_1 and Q_2, discussed below. As will be seen, Q_1 and Q_2 are functions of a normalised range parameter.

In the vicinity of the transducer, we obtain

$$Q_1 = r\sin(1/r) - Ci(1/r) - j\{r[1-\cos(1/r)] + (\pi/2) - Si(1/r)\}$$

with $r = R/R_{o-}$, R being the range and $R_{o-} = \pi a^2/\lambda_-$, 'a' the transducer radius and λ_- the wavelength at the difference frequency. The functions Ci(x) and Si(x) are related to the exponential integral.

$$\int_x^\infty (dv/v)\exp(-jv) = Ci(x) - j[(\pi/2) - Si(x)].$$

In the vicinity of the near-field/far-field transition, Rolleigh's result can be reduced to give

$$Q_2 = -0.318 + 0.853y - 0.88\ln(y/2) + j\{1.285 - y[0.30+0.121\ln(y/2)]\},$$

where $y = R/r_o$,

with $r_o = (\pi a^2/\lambda_o)(F_o/F_-)$,

F_o being the arithmetic mean of the primary frequencies (in kHz) and λ_o the wavelength at that frequency.

The magnitudes of Q_1 and Q_2 are shown plotted (in dBs) in Figure 1 for ease of use. These results have been checked against the results of a number of experiments, quite successfully. There is obviously a cross-over region from Q_1 to Q_2 which (depending on the frequency ratio F_o/F_-) occurs at a range of about 0.6 to 0.8 times the near-field distance of the transducer (i.e., of $\pi a^2/\lambda_o$). It has been found that 'free hand' smoothing of the curves of Q_1 and Q_2 (for a given set of parameters) produces acceptable agreement with experimental data over this range as well.

The estimation of the difference-frequency beam patterns (particularly in the vicinity of the transducer) is more difficult. The difficulty appears to arise from the fact that contribution from the sources in the vicinity of the field-point become more significant. Hence, a simple model for the primary fields is insufficient to obtain an accurate estimate of the off-axis field.

System Considerations

(a) Signal Generation

The signals applied to the transducer in a parametric source can be obtained by modulating a sine wave at the centre frequency to be used. (If the power amplifier is to be operated in switching mode, the carrier could be a square wave.) Such a system provides flexibility in that the carrier frequency can be changed to suit that of the transducer to be used, while the modulating waveform (which controls the sonar signal) can be selected quite independently.

For a 'two-frequency' system, for example, the modulating signal would be a sine wave at half the required difference frequency, which is multiplied with the centre-frequency waveform. If the frequency of the modulating signal is 'swept' linearly with time, a linear-F.M. (i.e., 'chirp') pulse can be obtained.

Alternative amplitude-modulation techniques (other than the double-sideband, suppressed carrier system mentioned) have also been used successfully.

A limitation of sinusoisal modulation techniques is the requirement they place on the linearity of the power amplifier, as any envelop distortion would result in more energy being transferred to the harmonics of the difference frequency. From this point of view, it may be more advantageous to use a form of square-wave modulation.

If the transmission is in the form of a short burst of carrier, the low-frequency component which results from nonlinear acoustic interactions is in the form of a short pulse of wide spectrum. (The width of the spectrum of this pulse would be controlled, essentially, by the bandwidth of the transmitting transducer.) If this pulse is repeated at the required difference frequency, the spectrum of the pulse train would consist of specular lines at the harmonics of the repetition frequency, the envelop of the lines being the spectrum of a single pulse.

To obtain a 'chirp' transmission, it is then sufficient to modulate the carrier by a swept-frequency square wave.

In a parametric source, in addition to the difference-frequency its harmonics are also generated. Therefore (in order to avoid signal distortion due to an overlap of information bands) it appears advisable to restrict the signal bandwidth to less than the difference-frequency used.

(b) Signal Processing

For high resolution work, the wide bandwidth capability of a parametric source needs to be utilised. When the signal bandwidth approaches (numerically) the signal frequency, to avoid serious signal distortion, any filters used in the receiver must be designed with care. The frequency characteristics of such filters must be arithmetically symmetrical about a centre-frequency, and the group-delay introduced must be constant over the pass-band.

Particularly, if the signals received from immediately below the interface are of interest, the dynamic range of the component parts of the receiver need to be considered carefully.

Because of the wide dynamic range of the signals expected in a sub-bottom profiler, the type of normalisation used has been found to affect significantly the effective use of the system for different shallow-penetration applications. For example, for locating specific objects (such as a buried pipeline) an automatic gain control system has been found to be very effective. On the other hand, for obtaining information regarding the sub-bottom strata, time-varied gain (triggered from the bottom return) provides best results. By using the bottom return at the primary frequency, it has been found possible to delineate the water/sediment interface accurately even over very 'soft' sediments, when the returns at the difference-frequency do not show a clear demarcation.

Operational Results

A system was developed at the University of Birmingham, in collaboration with the Vickers Oceanics Ltd., to be fitted to manned submersibles operating near the bottom of the sea. With this in mind, the system was developed around a 300kHz transducer with an active surface of about 15cm x 15 cm.

The transmitted signal could be selected to be either a short pulse (of about 160μs duration) or a 'chirp' pulse with a swept band of about 6.6 kHz and of duration 1.65ms. The centre frequency could be selected to be 5, 10 or 15kHz.

For the reception of the chirp signals, a matched filter consisting of a band-pass filter and a lumped-circuit dispersive delay network was used.

Experience in the field showed that the use of 15 kHz centre frequency did not provide any advantages. Significant differences were observed between the results (obtained over similar areas) at 5 kHz and at 10 kHz, in stratified sediments. Whereas the returns at 10 kHz brought out a great deal of detail, at 5 kHz only significant highlights could be seen.

Figure 2 shows a trace obtained in the Norwegian Trench. From observation, the bottom consisted of compacted sand and hard rock.

Figure 3 shows four different traces showing the returns from a buried pipe in different circumstances.

Conclusions

Experience gained so far in using a high-resolution sub-bottom profiler indicates that such a system, mounted on a stable platform, can be a very useful tool, particularly in applications involving shallow penetration into sediments.

References

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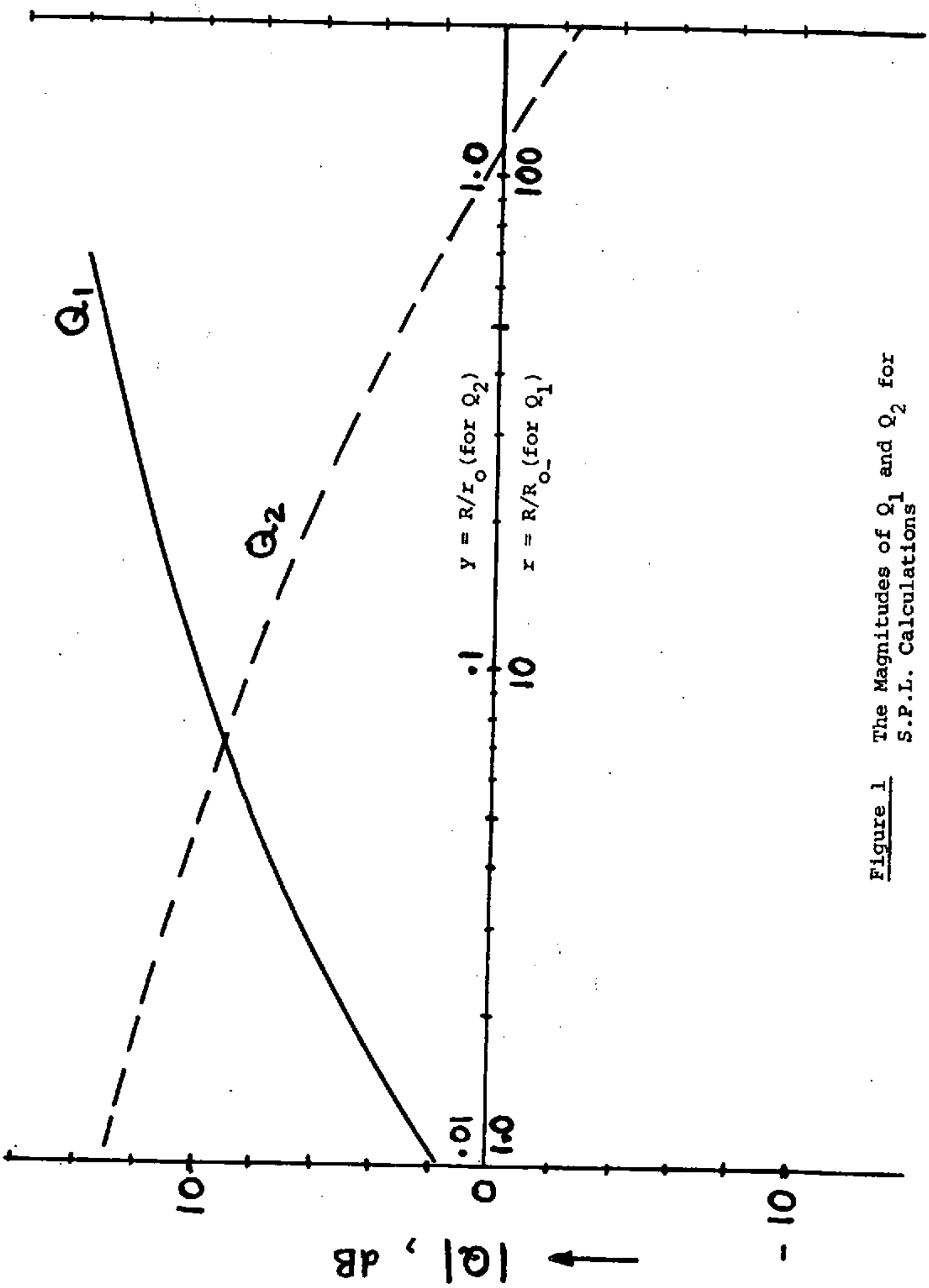


Figure 1 The Magnitudes of Q_1 and Q_2 for S.P.L. Calculations

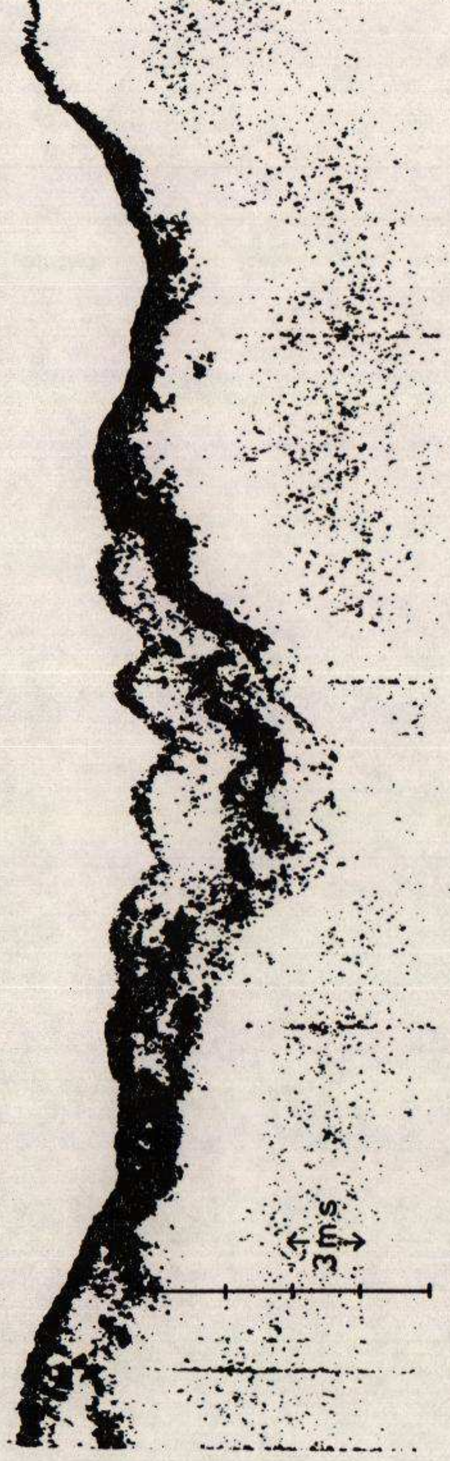
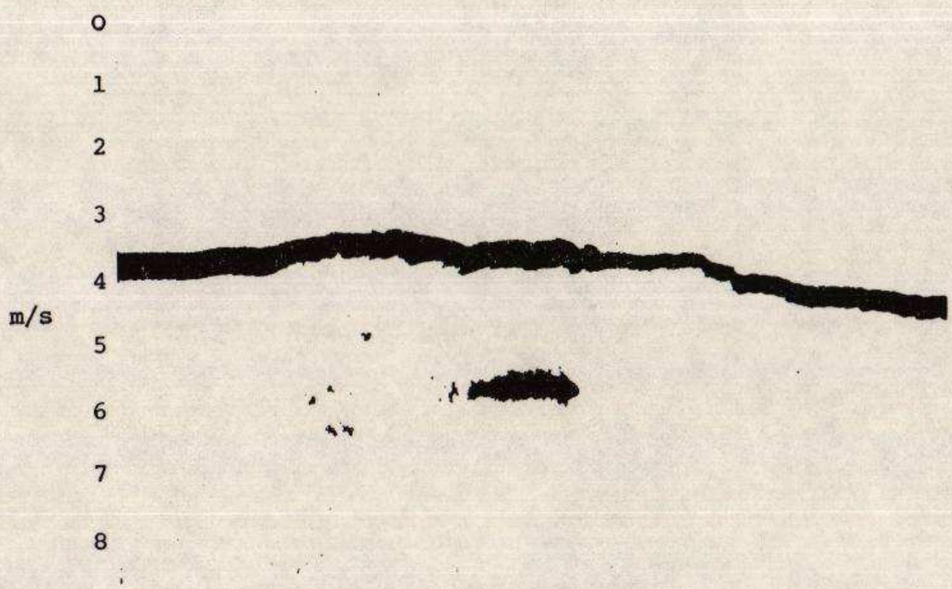


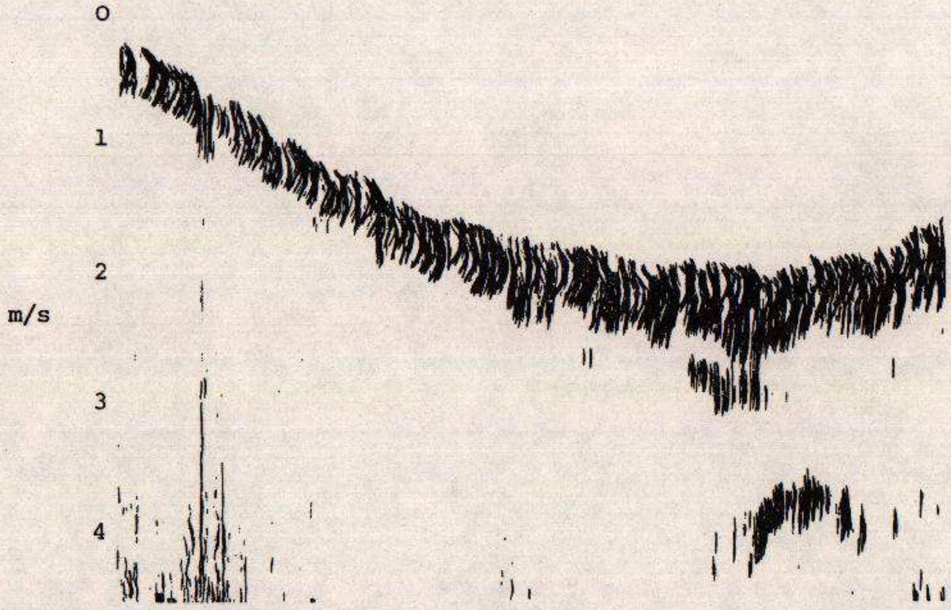
Fig 2



Water filled 36" diameter pipe

Oil filled 36" diameter pipe

Figure 3



Gas filled 36" diameter gas pipe

Figure 3

36" diameter gas filled pipe