NEAR-FIELD MEASUREMENT USING A PARAMETRIC SOURCE

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1. INTRODUCTION

Underwater acoustic characterisation using panel measurements is now a well established technique. Measurements may be made at single points both in front and behind the panel to obtain the reflection and transmission coefficients. It has been shown that when spherical radiation corrections are taken into account, this method can be extremely accurate at normal incidence [1].

Recent effort has focused on the measurement of these properties at oblique angles where the single point method is less reliable. A variety of techniques have been suggested. Picquette has generalised the onion method [2, 3], however this method is only useful for materials with a low shear modulus. Many authors have used methods based on two dimensional Fourier transforms and it is these which are concentrated on here [4-7].

This paper demonstrates an implementation of the method of Tamura [4]. Section 2 contains a review of the basic principles of the method and is followed by a description of the particular implementation used at DERA Farnborough. Focus is given to reflection coefficients, although transmission coefficients may be treated in a similar manner. After some sample results are presented, the paper concludes with a discussion of possible extensions of the method to periodic systems.

2. THEORY

The method of Tamura is based on the principle that an arbitrary, steady state acoustic pulse can be decomposed into a superposition of plane waves: consider a set of Cartesian co-ordinates (x, y, z) and a impulse travelling in an acoustic medium with wave speed c. It is a simple matter to show that the acoustic pressure field, p(x,y,z), maybe expressed in the form

$$p(x,y,z) = \int\frac{dk_x}{2\pi}\int\frac{dk_y}{2\pi}\,\hat{p}(k_x,k_y)\,e^{i(k_x x+k_y y+k_z z-\omega t)}\,, \tag{1}$$

where

$$k_z = \sqrt{k^2 - k_x^2 - k_y^2} \tag{2}$$

and $k = \omega/c$ is the wave number in the medium. Equation (1) essentially states that the impulse consists of an (infinite) sum of plane waves travelling at different angles with complex amplitudes $\hat{p}(k_x,k_y)$. These maybe obtained by simply taking the Fourier transform of (1):

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$$\hat{p}(k_x,k_y,z) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} p(x,y,z)\, e^{-i(k_x x+k_y y)}\, dx\, dy\,. \qquad (3a)$$

$$= \hat{p}(k_x,k_y)\, e^{ik_z z}\,, \qquad (3b)$$

were the second equality is only true for a forwards travelling wave.

Suppose that the panel to be measured , which for the moment will be considered infinite in extent, lies in the x-y plane. Further suppose that measurements are to be taken on the planes $z = z_1$ and $z = z_2$ lying in front of and behind the panel respectively.

At the point z_1 the acoustic field maybe considered to consist of an incident and scattered field

$$p(x,y,z_1) = p_i(x,y,z_1) + p_s(x,y,z_1)\,, \qquad (4)$$

while at z_2 the field is purely the transmitted component

$$p(x,y,z_2) = p_t(x,y,z_2)\,. \qquad (5)$$

If one takes the two dimensional Fourier transform of (4), using the definition of the amplitudes (3) one obtains

$$\hat{p}(k_x,k_y,z) = \hat{p}_i(k_x,k_y)\, e^{ik_z z_1} + \hat{p}_s(k_x,k_y)\, e^{-ik_z z_1}\,. \qquad (6)$$

The two parts of (6) have different dependencies on z, a property that Tamura exploited to separate the incident and reflected signals. If one where now to perform a second measurement at a slightly further distance away from the panel, one would obtain a second equation of the form (6) which could be used to solve for the amplitudes $\hat{p}_i(k_x,k_y)$ and $\hat{p}_s(k_x,k_y)$. This has the advantage of involving very little disturbance to the system between measurements; in particular one would expect any systematic errors to be unaffected. However, for simplicity, it is assumed in the sequel that the separation into incident and scattered components is achieved by the simple expediency of removing the panel and measuring $p_i(x,y,z_{1,2})$ directly.

Once p_i has been obtained, and using the fact that incident and scattered signals must have the same phase on the panel, the reflection co-efficient is simply given by

$$R(k_x,k_y) = \left(\frac{\hat{p}(k_x,k_y,z_1)}{\hat{p}_i(k_x,k_y,z_1)} - 1 \right) e^{2ik_z d}\,. \qquad (7)$$

Here d is the distance between the measurement plane and the panel.

Similarly the transmission coefficient is given by

$$T(k_x,k_y)=\frac{\hat{p}(k_x,k_y,z_2)}{\hat{p}_i(k_x,k_y,z_2)}e^{-ik_z\delta}, \tag{8}$$

δ being the thickness of the panel.

So far everything has been considered only for infinite panels and arbitrary large measurement planes. In practice it is only possible to perform measurements over some finite area. This introduces a window function, $W(x,y)$, into the measured pressures. The finite size of the panel also introduce extra diffraction effects which perturb the results away from the infinite panel values. These effects have been studied, [4, 7], with the view of altering the source characteristics to reduce these sources of error. Needless to say the best results are obtained with more directional sources: the smaller the incident and transmitted signals are at the edge of the window function, the smaller the error is due to truncation at this point. Similarly it seems physically reasonable that diffraction effects due to the edge of the panel can be reduced by minimising the amount of energy falling on these parts.

In [1] it was shown that a parametric array behaves in a similar way to a truncated line array and is principally directed along the array axis. By altering the spacing between the array and panel one can adjust the beam size to obtain the optimum arrangement. In the next section an implementation of the above technique using a parametric source is described.

3. IMPLEMENTATION USING PARAMETRIC SOURCE

The parametric array facility at DERA Farnborough consists of parametric array source together with a computer controlled positioning system. Panels may be placed in the tank and then transducer measurements made at arbitrary positions around them. It is ideal for an implementation of the near field measurement previously described (figure 1).

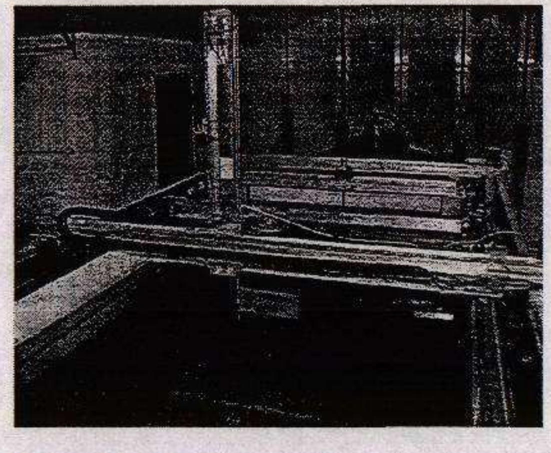

Figure 1: Parametric array facility at DERA Farnborough.

Even with the automatic positioning system, the method described in section 2 is extremely time intensive due to the presence of the two dimensional scans needed to achieve this. However if the panel is isotropic, and the panel and measurement plane are sufficiently far from the source, it is possible to obtain sufficient information by only scanning along a line (the measurements are close to normal in the y direction and providing the reflection and transmission coefficients only vary slowly with angle at normal incidence, the errors introduced by this approximation are only of the order of 1 or 2 dB [1]). However this necessitates measuring close to the panel and care must be taken to avoid extra errors due to multiple reflections between the measuring hydrophone and the panel for highly reflective materials [8].

Measurements are made using an impulsive signal to enable spurious reflections from the sides of the tank to be windowed out. First a measurement of the incident signal is made by sampling along a line with no panel present. Then the panel is inserted into the tank and the measurements are repeated to obtain the total signal. In [9] it was shown that the sampling criterion is given by

$$\frac{2\pi}{\Delta x} > k + k_{max} \tag{9}$$

were Δx is the sampling interval and k_{max} is the largest non-zero wave number in the measured field. In practice measurements are restricted to the geometrical beam width. Figure 2 shows a schematic diagram of the measuring apparatus.

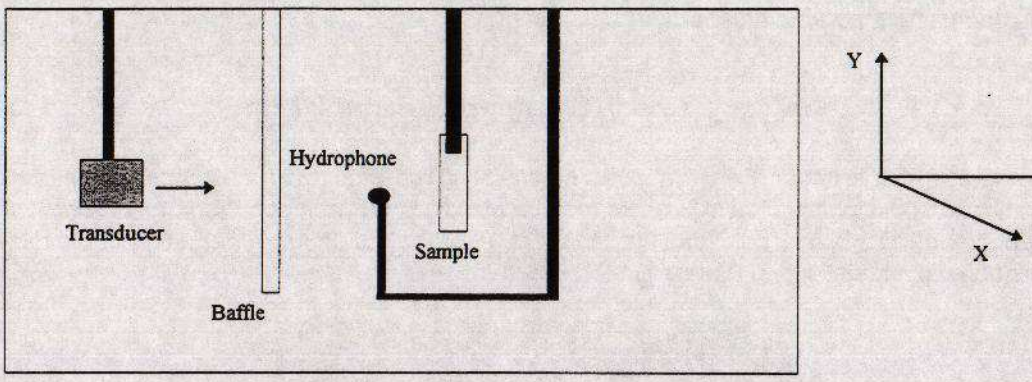

Figure 2: Measuring arrangement.

Once the measurements have been obtained a frequency fast Fourier transform is performed to transform the results to the frequency domain. This results in a set of frequency data for each point in the scan. A spatial FFT is then performed on this data to provide a discrete approximation to $\hat{p}$, $\hat{p}_t$ and $\hat{p}_i$. These may then be used in (7) and (8) to obtain the angular reflection and transmission coefficients.

The data presented in figure 3 corresponds to the echo reduction at normal incidence for a 14mm thick PTFE panel. It is plotted as experimental data and modelled data as a function of frequency. The model data was taken from standard sources, and thus may be slightly inaccurate for the panel measured. The reasonable agreement of theory and experiment is an indication of the success of this method. The results obtained by scanning across the surface of the panel reduce the effects of edge diffraction that are present in single point measurements.

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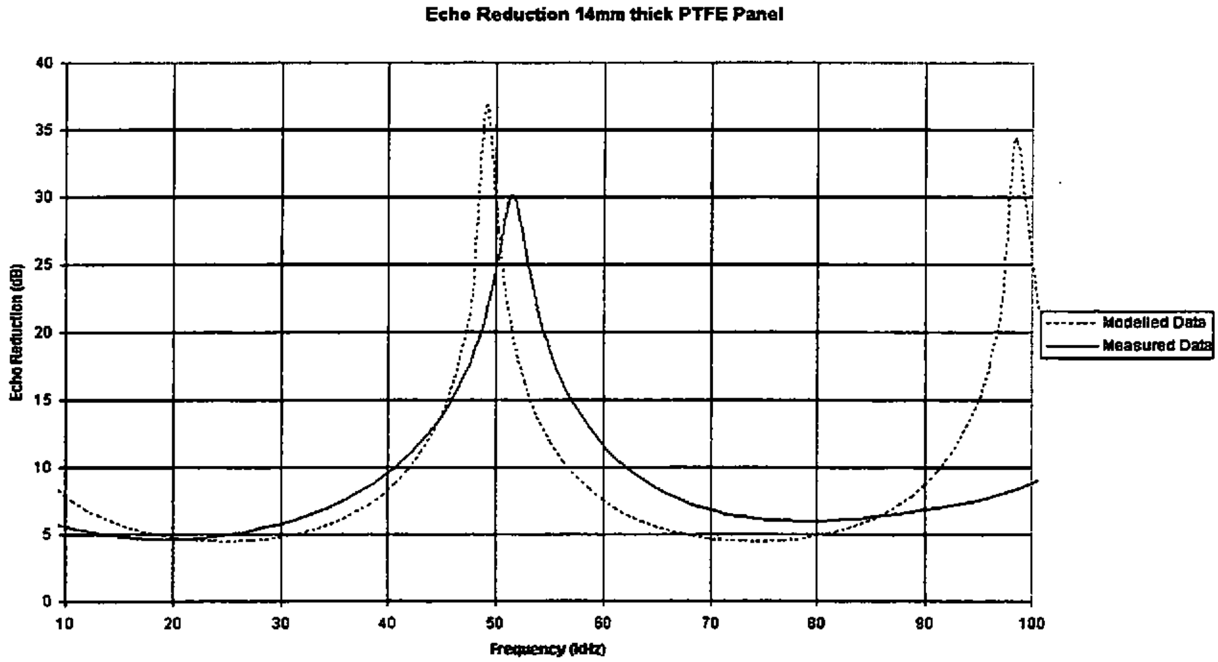

Figure 3: Echo reduction at normal incidence.

Figure 4 displays the angular distribution of the incident and reflected signal at 40 kHz. This gives an indication of the beam size. The amplitude of the signal can be seen to fall to noise levels rapidly with increase in angle.

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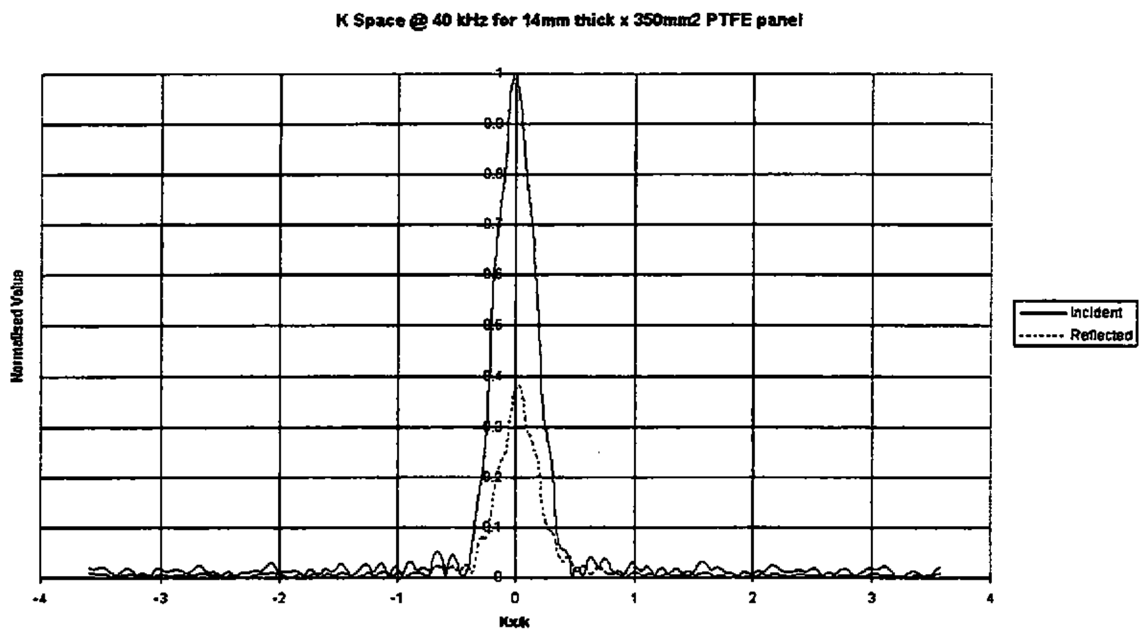

Figure 4: K_x spectrum of incident and reflected signals.

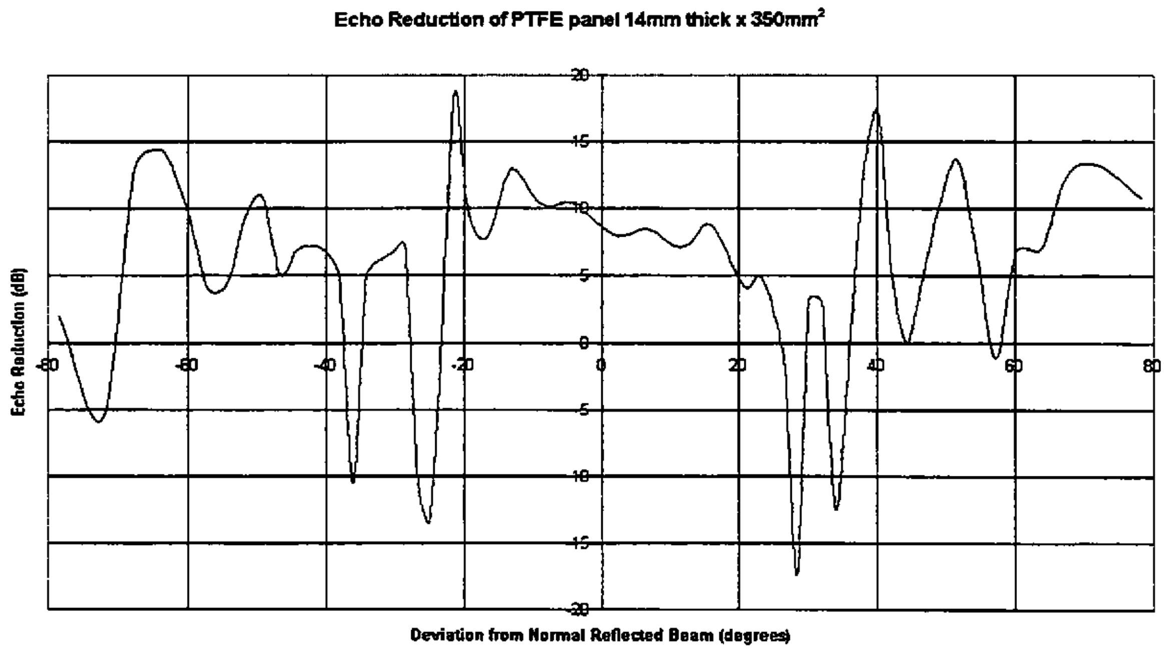

Figure 5: Angular dependence of echo reduction.

The Echo reduction obtained from the incident and reflected signals, (figure 5), displays some asymmetry. This is attributable to misalignment of the panel. The data for echo reduction is only valid for ~±20° since data outside these angles is dominated by noise. Comparison with Figure 4 shows that this corresponds roughly to the geometrical beam width of the incident signal.Also present within the data are edge effects due to the finite size of the panel, e.g. edge diffraction, and panel vibration modes.

4. EXTENSIONS OF METHOD

The method presented above though useful for flat planar panels is useless for materials with internal structure. An example of such a coating would be the German Alberich coating used during WW2. This consists of a periodic array of resonance cavities. For simplicity, here we consider only periodicity in one direction (the x- direction).

In such a system a plane wave with an indent wave number whose x component is k_x, on reflection is mapped onto a set of diffracted orders with x components given by

$$k_x \mapsto k_x + \frac{2n\pi}{L} \qquad (10)$$

were n is an integer and L is the periodicity. Previously this problem has been treated by assuming that the 0th order (specularly reflected) component dominates all others and the just using the standard echo reduction and transmission loss formulae [7]. However an alternative would be to use (10) as a criteria to mapping plane waves in the incident spectrum to points in the reflected k- space spectrum. This mapping would be unique providing

$$k_{\max} > \frac{2n\pi}{L} \qquad (11)$$

where $k_{\max}$ is the largest wavenumber in the incident k spectrum. This then provides a constraint on the beam width of the source: providing the source is not too narrow, the resulting data can be interpreted in a sensible fashion. This constraint must then be combined with the constraints caused by the windowing function to give the range of angles which may be measured. Further angles would then have to be obtained by rotating the panel.

5. CONCLUSION

It has been shown that methods now exist to enable one to obtain the reflection and transmission coefficients at oblique angles. Such a method has been implemented at DERA Farnborough with a reasonable degree of success. In addition suggestions have been made on how the method might also be used to obtain a limited amount of data about periodic coatings in their diffraction regime, something which is not possible with more traditional methods.

6. ACKNOWLEDGEMENTS

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ACOUSTIC POWER CALIBRATION IN REVERBERANT TANKS

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1. MEASUREMENTS IN REVERBERANT ACOUSTIC FIELDS

Acoustic output measurements can be made in a free field without reverberation, or in the short time between the receipt of the direct transmission and the arrival of the first echo. However, there are practical circumstances where it is useful to make measurements in reverberant fields, with multiple echoes creating many waves, travelling in all directions.

The work described has been driven by the need to measure the noise of ROVs (Remotely operated vehicles) in relatively small tanks, but has led to other circumstances where a reverberant field is the best choice. A significant feature of a reverberant tank is that the measurements are insensitive to position, an advantage when testing a mobile object. This uniformity has also been used in the simulation of ocean ambient noise where the omnidirectionality is often a virtue.

For all but the simplest omnidirectional devices the output will vary with direction and this data forms the basis for a polar plot of its directivity. Where a wide band of frequencies is of interest a large amount of data is required to characterise the device. It is then useful to measure the total power emitted in all directions as a means of making simple comparisons. This can be done in a reverberant tank.

2. MEASUREMENTS IN THE DIRECT FIELD.

The output of an underwater acoustic projector is usually described as a source level. This convenient parameter assumes that the r.m.s (root mean square) acoustic pressure P diminishes as the inverse of the range R from the source, which is true for the region of spherical spreading. This region has an inner bound when close to a projector, but the effects of its finite diameter D can be ignored when $R \gg D^2/\lambda$, where λ is the wavelength. There is also an outer bound when the diminishing direct field becomes comparable with the reverberation, also creating departures from the simple spherical spreading law.

The sound pressure P is measured by a hydrophone at range R, and the P·R product is then constant in the direction determined by the hydrophone position, provided spherical spreading is obeyed. This P·R product with S.I. units of Pa·m (pascal·metres) is usually presented as a source level SL in decibels.

$$SL = 20\log_{10}(PR) \quad \text{dB re 1 μPa @ 1m} \qquad \text{or} \quad \text{dB re 1 μPa·m}$$

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For use in the sonar equations, the decibel reference level can be the P·R product of 1 μPa·m, or the pressure in μPa measured at a 1 m range, for small sources for which this range is within the spherical spreading region ($D^2/\lambda << 1$m).

In the work described here decibels are inappropriate, since we need to add the direct and reverberant field. The linear P·R product can usefully be referred to as a "source potency" S_p, since conventional "source strength" has a different meaning. P·R can be considered as the dependent variable in the spherical wave equation discussed by Kinsler et al [1] (p112), and S_p is then the amplitude of the outgoing harmonic wave solution. For a known fluid the source potency is also a measure of the output power per unit solid angle in a specified direction.

$$\text{Power per unit solid angle} = \frac{P^2 R^2}{\rho\, c} = \frac{S_p^2}{\rho\, c} \text{ (watts /steradian)}$$

The product of density ρ and sound speed c is the specific acoustic impedance of the fluid. The power W, emitted by an omnidirectional source into all directions (4π steradians) is then $4\pi\, S_p^2/\rho\, c$. In sea water (ρ = 1030 kg/m^3, c = 1500 m/s), $\rho\, c/4\pi$ gives a 123,000 Pa²·m²/W conversion factor, which is more familiar as the 170·9 dB re 1 μPa·m source level emitted by an omnidirectional source of 1 watt. For a directional source this becomes $D_f\, \rho\, c/4\pi$, where D_f is a directionality factor, the ratio of S_p^2 in the measured direction, to its average over all directions. Then

$$W = \frac{4\pi\, S_p^2}{D_f\, \rho\, c} = \frac{4\pi\, P_d^2\, R^2}{D_f\, \rho\, c} \quad \text{where } P_d \text{ refers to the direct field pressure}$$

D_f can be used to calculate the sonar directivity index, DI = 10 log D_f.

3. THE COMBINED DIRECT AND REVERBERANT FIELD

The distribution of wave directions in the reverberant field means that the wave pressures are incoherent, and that their energies are additive. The mean square pressures associated with the direct P_d^2 and reverberant P_r^2 pressure fields can thus be added to give the total P_t^2 (Kinsler et al [1], pp 314-326). For steady state circumstances the power of the source W equals the losses at the walls (ignoring absorption in the water). The energy density E in a uniform reverberant field is given by

$$E = \frac{P_r^2}{\rho\, c^2}$$

and the rate of loss for a tank with an absorbent wall area of A (m²) can be shown to be

$$\frac{E\, c\, A}{4} = \frac{P_r^2\, A}{4\, \rho\, c} = W$$

The total field $P_t^2 = P_d^2 + P_r^2$ can now be related to source power W

$$P_t^2 = W \rho\, c \left(\frac{D_f}{4\pi R^2} + \frac{4}{A} \right) = S_p^2 \left(\frac{1}{R^2} + \frac{16\pi}{A\, D_f} \right)$$

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or more simply $$P_t^2 = S_p^2\left(\frac{1}{R^2}+\frac{1}{R_e^2}\right) \qquad \text{if } R_e^2 = \frac{A}{16\pi} \text{ and } D_f=1$$

This relationship can be used to analyse the results of measurements of the distribution of total pressure P with range from the source R. The equivalent range R_e is an alternative measure of the tank absorption, the range at which the two terms are equal if the source is omnidirectional (D_f =1). To measure P_t, an omnidirectional hydrophone will be required, with the same sensitivity to the direct and reverberant pressure fields.

4. TECHNIQUES TO DETERMINE THE TANK ABSORPTION CONSTANT

The techniques for measuring the acoustic power level in air using reverberant chambers are well established, (e.g ISO 3741), but water has an impedance almost 4000 times larger and a rather different approach has been found effective. Work has been done in the past year to validate these techniques, both at N.P.L. and at Sonardyne's factory.

4.1 Characterisation by Reverberation Time

The usual method pioneered by Sabine is to measure the reverberation decay time. If the source is impulsive or turned off suddenly, the pressure will decay as the walls absorb the sound. If all modes are absorbed at the same rate an exponential decay can be plotted, and the time T taken to decay by 60dB recorded. The tank absorption A then depends on its volume V and is given by

$$A = \frac{60}{10\log_{10} e} \times \frac{4\,V}{c\,T} = \frac{55.26\,V}{c\,T}$$

Note that A still has units of m², sometimes referred to as metric sabins. However, the absorption of different tank modes or standing waves can depend on their direction, with those that travel farthest between reflections lingering longer. This gives rise to a departure from the ideal exponential decay and some consequent error. Reflections depend on the mismatch of acoustic impedance between fluid and wall, and it is more difficult to isolate water from a tank than air from a room. This may explain the less satisfactory decay curves observed in tanks.

4.2 Characterisation By Spatial Distribution

An alternative method of measuring absorption is to plot P^2 versus $1/R^2$, whilst applying continuous psuedo random noise. This noise excites a large number of tank modes to provide a uniform reverberant field, and is similar to the nature of the noise generated in real systems.

Whilst the hydrophone must be omnidirectional, a known directivity D_f of the projector can be used as a correction factor. Unless D_f =1, the transducer orientations must be held fixed whilst changing the range R, to achieve a straight line. The figure below shows some results from Sonardyne's reverberant tank, analysed using an Excel spreadsheet. The in-band voltages were measured with an H.P. 35660A dynamic analyser, but equally good results have been obtained using a band pass filter and true RMS meter. Wide band white noise was created with a 20 bit psuedo random binary sequence, clocked at 1 MHz, but the pressure spectrum is shaped by the projector response.

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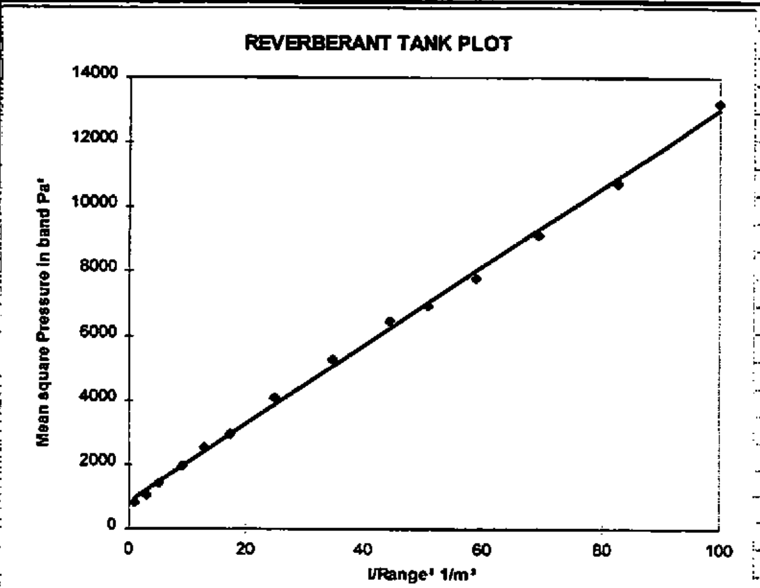
REVERBERANT TANK CALIBRATION	02-Dec-97	Tank description	16' * 12' * 12'	Volume	65.4 cubic metre
Hydrophone description	Type 7910 sphere	Projector description	Type 7752 "MF omni" - tube and baffle		
Hydrophone sensitivity	-205 dB//V/uPa	Best fit gradient	121.6 Pa².m²	SL in band	140.8 dB//uPa.m
Bandwidth Lower bound kHz	18	Tank absorption area (sabins)	9.7 m²	Sound speed	1481 m/s
measured Upper bound kHz	36	Reverb correction factor AL	-7.2 dB//m	Reverb time	0.25 seconds

Range R	1/R²	Band noise	Pressure²
m	1/m²	dB//V	Pa²
0.1	100	-43.8	13182.57
0.11	82.64463	-44.7	10715.19
0.12	69.44444	-45.4	9120.108
0.13	59.1716	-46.1	7762.471
0.14	51.02041	-46.6	6918.31
0.15	44.44444	-46.9	6456.542
0.17	34.60208	-47.8	5248.075
0.2	25	-48.9	4073.803
0.24	17.36111	-50.3	2951.209
0.28	12.7551	-51	2511.886
0.33	9.182736	-52.1	1949.845
0.44	5.165289	-53.5	1412.538
0.56	3.188776	-54.8	1047.129
1	1	-55.9	812.8305
Reverberant		-57.2	
field data		-56.5	
Ranges > 2m		-57.2	
		-57.1	
	Average	-57	630.9573



The gradient of the least squares best fit line is the square of the source potency

$$\text{Gradient} = \frac{W\,\rho\,c\,D_f}{4\pi} = S_p^2 \qquad \text{Pa}^2\cdot\text{m}^2$$

The mean reverberant pressure P_r^2 can be found from the best fit intercept, or from a separate average of a set of P_r^2 measurements made in the reverberant field (large R). The absorption A can then be calculated

$$A = \frac{16\pi\,S_p^2}{P_r^2\,D_f} = 16\pi\,R_e^2 \qquad \text{m}^2$$

The disadvantage of the best fit intercept is that equal weighting is given to all results in Pa² rather than the more appropriate proportional weighting in dB.

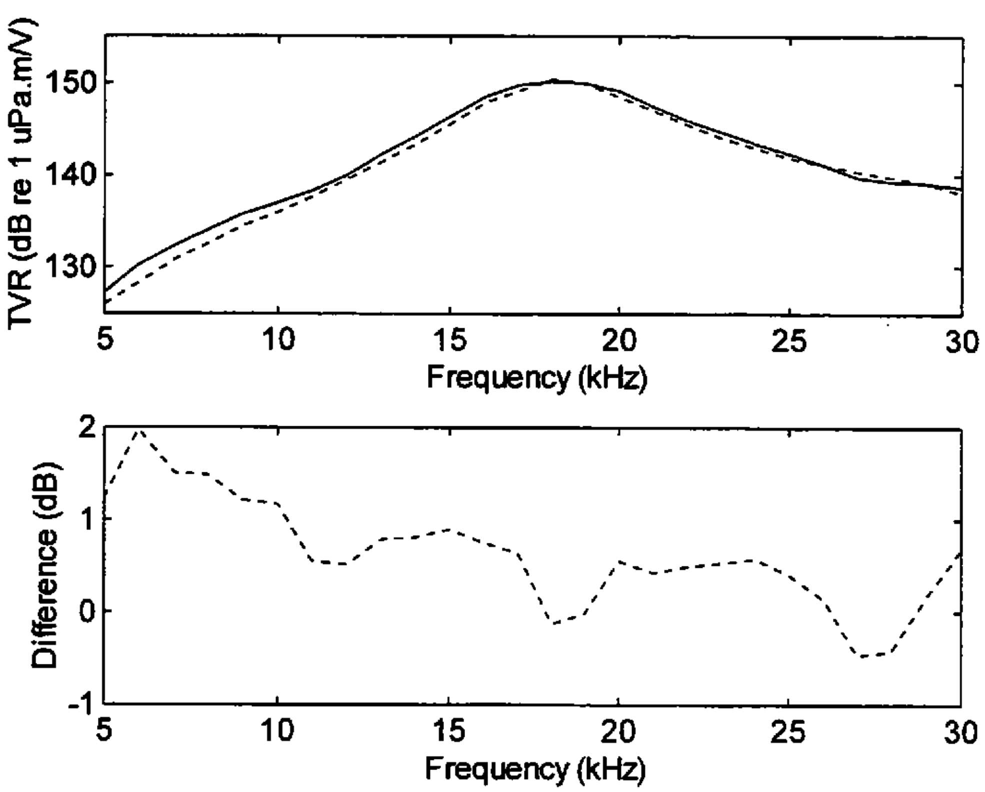
5. DETERMINATION OF THE TRANSMIT VOLTAGE RESPONSE (TVR)

Results using an ITC 1001 spherical projector have been analysed in detail and compared with results from a free field calibration at NPL. This 18 kHz resonant projector was driven by a B&K 1405 white noise source through a B&K 2713 amplifier, and the signals from the Reson TC4034 hydrophone were fed to an HP 89410A signal analyser.

An automatic analysis routine written in the Matlab environment plotted results from a succession of 2kHz wide bands to give the gradients of the best fit lines. These gradients were used to compute the source potencies Sp, which were divided by the measured noise voltage V in the same band, to give

$$TVR = 20\log_{10}\left(\frac{S_p}{V}\right) \quad \text{dB re 1 }\mu\text{Pa}\cdot\text{m/V}$$

The second graph shows the differences between the reverberant and free field results, less than ±1dB at frequencies above 10 kHz where the TVR is largest.



6. COMPARISON OF RESULTS WITH DIFFERENT PROJECTORS

The ideal projector for this work would be small, omnidirectional ($D_f = 1$), and exhibit a TVR over a wide frequency band. Rather more practical compromises have been investigated in this work, including a baffled tube and various spherical projectors. The table below gives the Sonardyne tank reverberation measured with two different hydrophones, and four different projectors on two occasions. Results for octave bandwidths are given, as absorption A in m² (sabins), reverberation time T in seconds and as a reverberation correction factor AL = 20 log R_e or 10 log (S_p^2 / P^2) in dB re 1m. The latter is the correction to be added to a measured reverberant sound pressure level to predict the source level of the projector in a free field. This correction is seen to vary by less than ±1dB.

Date	Projector type	Hydrophone type	Bandwidth	A m²	dB//m	T secs
Dec 97	ITC 1001 sphere	Reson 4034	12-24 kHz	13.8	-5.6	0.17
Dec 97	ITC 1032 sphere	Reson 4034	22-44 kHz	14.5	-5.4	0.17
Dec 97	Sonardyne 7752 tube	Sonardyne 7910	18-36 kHz	9.7	-7.1	0.25
Apr 98	Sonardyne 7752 tube	Sonardyne 7910	18-36 kHz	9.4	-7.3	0.26
Apr 98	" (rotated by 180°)	Sonardyne 7910	18-36 kHz	11.5	-6.4	0.21
Apr 98	Sonardyne 7765 sphere	Sonardyne 7910	30-60 kHz	10.5	-6.8	0.23
Apr 98	" (rotated by 180°)	Sonardyne 7910	30-60 kHz	10.3	-6.9	0.24

7. APPLICATIONS - MEASURING ROV NOISE

Remotely operated vehicles (ROVs) are being used in increasing numbers particularly in the construction and servicing of deep sea oil and gas wells. The larger "work class" ROVs are electrically powered but convert the energy to hydraulic pressure to operate the numerous tools and thrusters fitted. Hydraulic pumps are a potent source of noise, even in air. Underwater, the acoustic energy is even better coupled and radiated away into the sea water.

Acoustic positioning is often essential to overcome the limited underwater range of electromagnetic waves (radio and light). The most accurate form of acoustic positioning uses fixed sea bed transponders which, after calibration to determine their position, provide a set of fixed reference points. Two way ranges from a transducer mounted on the ROV provide enough data to determine the ROV position. Excess data is usually available to allow a best fit analysis and determine the quality of the positional fix.

The reception of the signal return over ranges which can exceed 1 km is usually limited by the self noise of the ROV, and system planning should be done with knowledge of this noise. Sonardyne International has made measurements of a variety of such ROVs over more than a decade of work in this field [2]. To compare one ROV with another it is essential to reduce the data to manageable proportions and noise power has proved useful in this endeavour.

8. COMPARISON WITH A STANDARD NOISE SOURCE

The simplest use of a reverberant tank is to compare the total power emitted by an unknown noise source (e.g. an ROV) to that from a known noise source. The validity of this test can be assessed by the effects of a change in geometry on the measured pressure. In suitable tanks, excited by a random noise source of adequate band width, the variation of measured pressure is less than 1 dB over most of the tank, thus providing adequate reproducibility for many applications.

This insensitivity to position is particularly important when testing the effects of ROV thrusters because the ROV can then be allowed to move. Provided both the ROV and the hydrophone are kept away from each other and the tank walls, reliable measurements can be made. The known source can be calibrated in the factory tank, or calibrated at the time in the ROV test tank. The power radiated by a source can also be calculated with a knowledge of the conductance G over the band. If the mean square voltage over the band is measured, the power absorbed equals $V^2 \times G$. However, G usually varies over the wide bandwidth required by the tests. In early work the type 7752 tube and baffle projector was used which has a flat region of G between 20 and 25 kHz. However, the output power will depend on the efficiency of the projector which introduces some error. This difficulty was overcome by using the spatial distribution technique described above.

The equivalent range R_e can be presented as a reverberation correction factor or absorption level AL given in the spreadsheet in dB//m (a concise form of dB re 1m)

$$AL = 20\log_{10} R_e = 10\log_{10}\left(\frac{A}{16\pi}\right)$$

AL provides a convenient way of specifying the tank reverberation. When added to the measured tank reverberant pressure level PL, the expected source level SL when the ROV is deployed in the open ocean becomes

$$SL = PL + AL = 20\log_{10} P_r + 20\log_{10} R_e = 20\log_{10}(P_r\ R_e)$$

SL has no directional information, being an average over all directions ($D_f = 1$). This is nevertheless useful in the assessment of operational limits, when the ROV attitude is not specified.

9. EFFECTS OF TANK SIZE AND NOISE BANDWIDTH

A determination of the range of acceptable tank and bandwidth parameters has not been undertaken and it is hoped that some of these issues can be addressed by others in the future. However, considerable experience with the octave band 18-36 kHz (Sonardyne "MF" band) in tanks with dimensions in excess of 2·4 m has shown that the technique can be valuable. The wavelength λ of the geometric mean frequency of 25 kHz is 6cm. Whilst ROV test tanks are usual larger, even the reverberant tank at Sonardyne's factory is 4.9 × 3.7 × 3.6 m, (81 λ × 61 λ × 60 λ) with a volume of 67 m^2 or 300,000 λ^3. There will then be over one million normal modes in the 18 - 36 kHz band. This provides considerable statistical smoothing of the reverberant spectrum.

This bandwidth is of particular significance to battery operated subsea transponders (e.g Sonardyne "Compatt"). The octave wide band is typically subdivided into over 24 narrow bands, and signal detection occurs if the spectral energy density in one narrow band significantly exceeds that of the wide band. For reliable detection in this design, the signal needs to be 5dB greater than the noise in the wide band. Wide band noise measurements are thus useful for predicting the critical signal strength and operational range between source and receiver. Other octave bands are also used by equipment designed for longer range ("LF" 7.5 - 15 kHz), or more accurate positions ("EHF" 50 - 100 kHz). Provided the spectrum is reasonably smooth, the total noise in the appropriate band provides a good prediction of performance.

10. APPLICATION TO HYDROPHONE CALIBRATION

Whilst a full set of polar plots is often useful in precise tank work, measurements made in the ocean may not have sufficient control of the measurement geometry. At the same time a robust guard is often more important than ultimate precision, and such guards are prone to more complex polar responses at higher frequencies. The measurement of a directional average response is then of practical benefit when the hydrophone attitude is uncontrolled. A reverberant tank calibration can provide such an average response, with considerable savings in time and effort. Sonardyne's type 7773 noise hydrophone systems are regularly checked in this way before, and where necessary after, every job. The hazards of deployment under ships and oil rigs means that it is important to check on any loss in sensitivity due to damage. Whilst internal calibrations can be used for regular checks of the amplifier and cabling system, acoustic testing is required to check the transducer.

11. CONCLUSIONS

Measurements of noise power in reverberant tanks have been found useful over the past decade, and the techniques developed have been further investigated to check the repeatability of the measured absorption, and the agreement of derived projector characteristics with measurements made by other more conventional means.

12. REFERENCES

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