TRANSMITTING RESPONSE MEASUREMENT OF LOW FREQUENCY PROJECTORS IN CONFINED ENVIRONMENT WITH MAXIMUM LENGTH SEQUENCES AND HOMOMORPHIC SIGNAL PROCESSING

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1. INTRODUCTION

IFREMER is involved in long range oceanography experiments, such as acoustic tomography, using very low frequency transducers (200 Hz - 400 Hz). Thus, the possibility to measure in tank or in pool the transducer Transmitting Voltage Response (TVR) is a real need for reliability controls after several months deployment at sea.

Because of large wavelengths, usual methods are unsuitabled to tank measurement. The use of Maximum Length Sequences (MLS) allows the fast determination of the impulse response of the system made up of the projector and its environment. MLS generation and signal cross correlation calculation using Fast Hadamard Transform are achieved by a software called MITAS. The separation between transducer contribution and environment effect is made easier with a homomorphic signal processing in which windows are applied in the cepstral domain preferably to the time domain.

In this paper, parameters of this processing (signal length and window shape in both domains) have been optimized for two configurations : a low-Q 2 kHz ring projector in a tank and a higher-Q 200 Hz Janus-Helmholtz transducer in a pool. Results are compared to free-field measurements of both transducers.

2. TRANSDUCERS, TANKS AND MEASUREMENTS

To reach 1000 km ranges with autonomous instrumentation, the working frequency is always lower than 1 kHz. For oceanography applications such as acoustic tomography, the central frequency is 250 or 400 Hz. IFREMER uses Janus-Helmholtz transducers made up of a double-ended piezoelectric driver and a Helmholtz cavity (Fig. 1) which allows a large bandwidth (Fig. 2) required to distinguish multipath arrivals [1].

This kind of instrumentation is usually 1 year deployed at sea in the sound channel and the possibility to verify the good behaviour of the transducer after sea trials is necessary. IFREMER has two acoustic test facilities : a small tank (4 m length, Fig. 3) and a large pool (50 m length, Fig. 4).

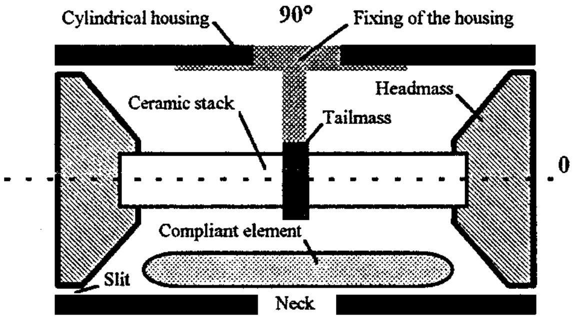

Fig. 1 : section of the Janus-Helmholtz (JH) transducer

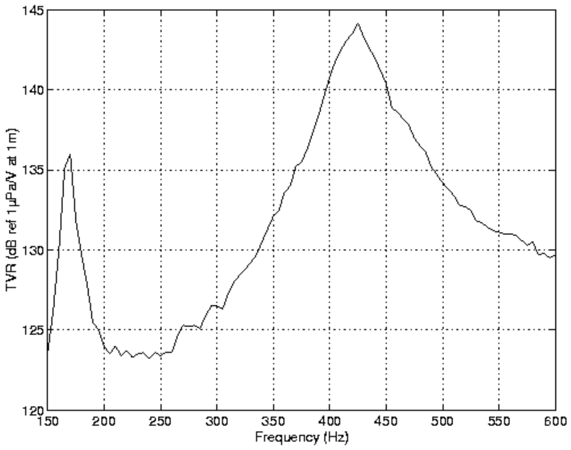

Fig. 2 : TVR of the JH transducer

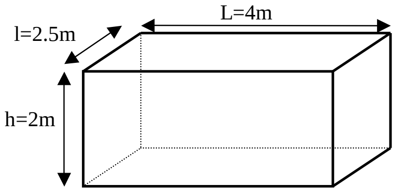

Fig. 3 : IFREMER acoustic tank

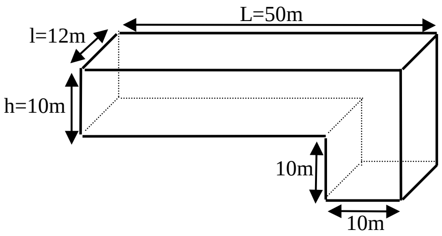

Fig. 4 : IFREMER pool

Usual methods devoted to medium or high frequency (sinusoidal burst excitation or spectral method) are unsuitabled to tank measurements because of large wavelengths (λ = 6 m at 250 Hz). Thus, the lowest frequency for acoustic measurements is 10 kHz in the small tank and 1 kHz in the pool.

Figure 5 compares the measured TVR of a low frequency free-flooded ring projector ([2, 5 kHz]) in free space and in the small tank with a 1.5 ms Hanning windows applied in the time domain. First echo appears after 1.3 ms, although the impulse response of the ring is approximately 5 ms long.

One can see that even if the ring projector is a low mechanical Q transducer, the beginning of the TVR is badly softened with a 5 dB difference around 2 kHz, because low frequency informations take place at the end of its impulse response. From 2.5 to 6 kHz, tank measurements are close to free space results.

The following method based on Maximum Length Sequences and Homomorphic Signal Processing will be applied to the Janus-Helmholtz in IFREMER pool and to the ring projector in the small tank. Acoustic behaviour of both transducers are similar but the mechanical Q of the Janus-Helmholtz at its first resonance is much higher.

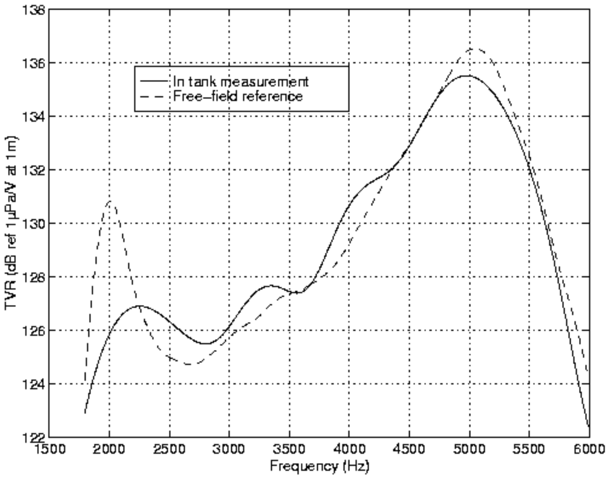

Fig. 5 : effect of a time domain windowing applied to a ring projector in IFREMER tank

3. MAXIMUM LENGTH SEQUENCES AND *MITAS* SOFTWARE

A Maximum Length Sequence (MLS) is a pseudo-random distribution of binary values (Fig. 6). The number of samples is 2^N and N is the degree of the MLS.

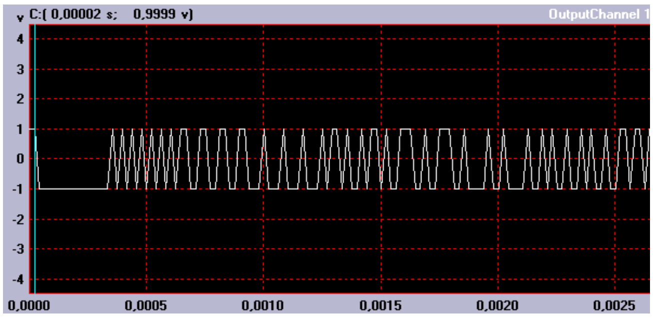

Fig. 6 : exemple of a MLS with a 48 kHz sampling frequency

Major properties :

- The autocorrelation of a MLS is a Dirac distribution around the origin with a 2^N magnitude.
- The magnitude of a MLS spectrum is equal to 2^N on a wide frequency band.
- The impulse response h(τ) of a system subjected to a MLS is :

$$h(\tau) = \frac{\phi_{xy}(\tau)}{2^N} \qquad \phi_{xy}(\tau) \text{ is the cross-correlation function}$$

Thanks to the MLS binary values, the cross-correlation calculation can be achieved with a Fast Hadamard Transform (FHT).

MITAS Software :
MITAS (Mesure Impulsionnelle de Transducteurs Acoustiques Sous-marins) is a software designed by CTTM (Centre de Transfert de Technologie du Mans [2]) which allows the generation of MLS, the synchronous acquisition of the output signal and the calculation of the cross-correlation $\phi_{xy}(\tau)$ made with FHT.

4. HOMOMORPHIC SIGNAL PROCESSING

The separation between transducer contribution and environment effect is made easier with a homomorphic signal processing in which windows are applied in the cepstral domain.

Definition : the cepstrum $c(\tau)$ of a signal $s(t)$ is

$$c(\tau) = FT^{-1}\{ \ln (FT [s(t)]) \} \quad \text{(FT = Fourier Transform} \qquad \text{ln = natural logarithm)}$$

Major properties :

- In the cepstral domain, due to the effect of the logarithm on the spectrum, the low spectral variations are gathered around the origin, whereas the fast spectral variations do not move.
- The cepstrum of the convolution of two signals is the sum of the cepstrum of each signal.

Exemple [3] :
$s_1(t)$ = damped sinusoidal signal → cepstrum $c_1(\tau)$ (Fig. 7)
$s_2(t)$ = impulse signals at the origin t = 0 and at t = 100 → cepstrum $c_2(\tau)$ (Fig. 8)

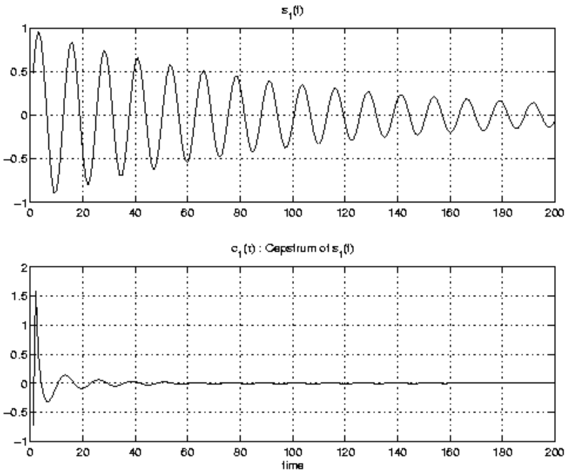

Fig. 7 : $s_1(t)$ and $c_1(\tau)$

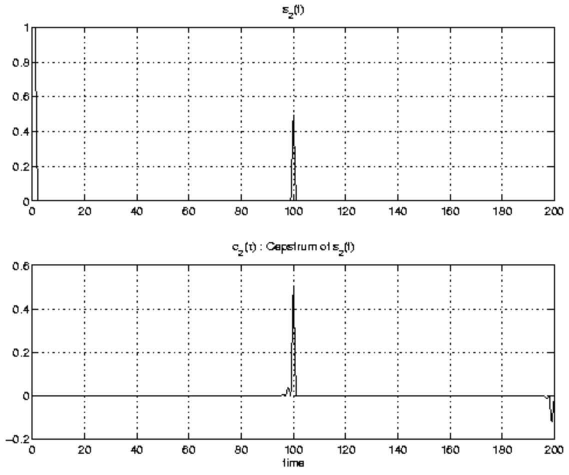

Fig. 8 : $s_2(t)$ and $c_2(\tau)$

$s(t) = s_1(t) \otimes s_2(t) \rightarrow \text{cepstrum } c(\tau) = c_1(\tau) + c_2(\tau)$ (Fig. 9)

By windowing the cepstrum $c(\tau)$, in order to cancel the contribution of $s_2(t)$, i.e. $c_2(\tau)$, the initial signal $s_1(t)$ can be rebuilt from the windowed cepstrum $c'(\tau)$, thanks to the following inverse homomorphic calculation :

$s_1(t) = FT^{-1}\{ \exp (FT [c'(\tau)]) \}$ (Fig. 10)

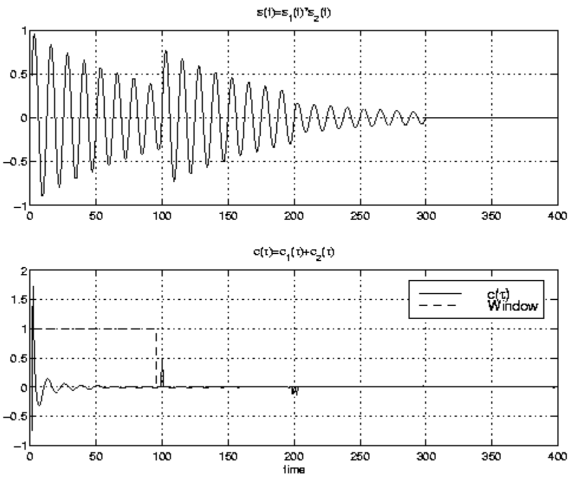

Fig. 9 : $s(t) = s_1(t) \otimes s_2(t)$ and $c(\tau)$

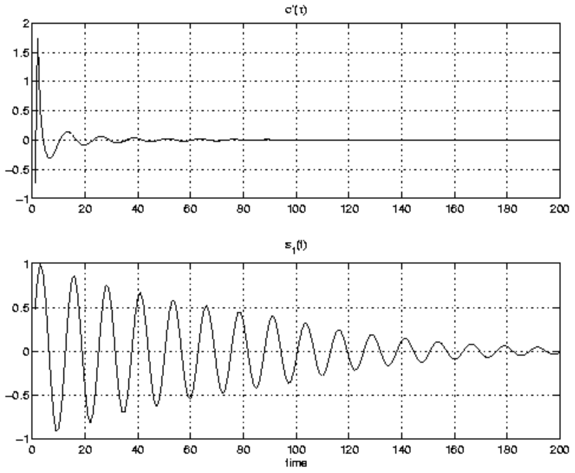

Fig. 10 : $c'(\tau)$ and reconstruction of $s_1(t)$

$s(t)$ can represent a signal coming from a transducer with a wall effect at $t = 100$ and, thanks to the homomorphic processing, the initial signal $s_1(t)$ has been rebuilt. This method can now be applied to our transducers in various confined environment. Frequency ranges are respectively [1.8, 6 kHz] and [150, 600 Hz] for the ring projector and for the Janus-Helmholtz transducer. Four parameters have to be optimized :

- the signal length in the time domain.
- the window shape in the time domain.
- the signal length in the cepstral domain.
- the window shape applied to the cepstrum.

5. RESULTS

5.1 Free-flooded Ring (FFR) projector in IFREMER tank

In the case of the FFR transducer in the small tank, the length of the impulse response is approximately 5 ms and the first echo appears after 1.3 ms. The length of the signal in the time domain is not a very important parameter if all the transducer impulse response is taken into account : a length of 20 ms is then choosen.

The window shape in the time domain is one of the most important parameters to have a good TVR accuracy. The use of Hamming windows (not presented) does not allow a good separation between transducer contribution and wall effect because of the remaining echo in the cepstrum due to the maximum phase of the reflection burst. The use of an exponential window ($F(n) = \alpha^n$ with n = sample number and $\alpha = 0.985$ [4]) can solve this problem. Fig. 11 shows the cepstrum when an exponential window (20 ms) is applied to the time response. All the non-causal area is then only relative to the source because of the minimum phase of the reflection burst. The cepstral window (Fig. 11) is rectangular for negative time and a half-Tukey window ($\beta = 0.7$) for positive time [5].

The end of the half-Tukey window at 1.5 ms has been optimized [3] to have the best compromise between the accuracy of the TVR magnitude and the limitation of the wall effect. The full suppression of the echoes is not possible if a 2 dB accuracy on the TVR is required near the first resonance. Fig. 12 shows the comparison between the FFR TVR in free space and in IFREMER tank with a cepstral windowing stopping at $T_{end} = 1.5$ ms. One can see that this processing allows a good estimation of the first resonance. The perturbation coming from the wall effect is still existing between 3 and 4.5 kHz but is very well softened (1 dB magnitude).

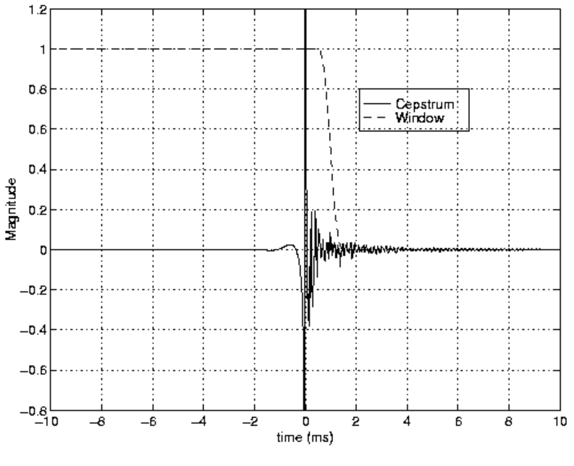

Fig. 11 : FFR cepstrum after time domain exponential windowing

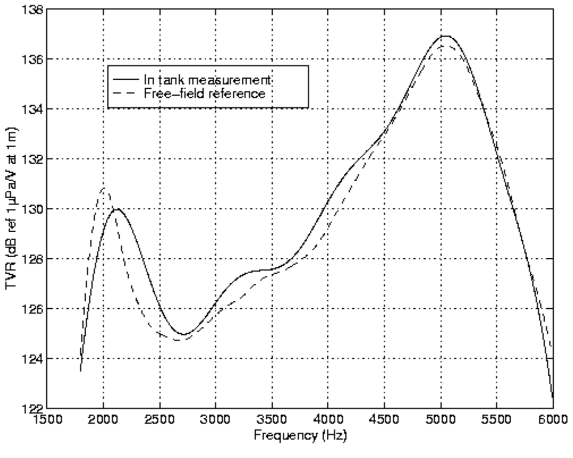

Fig. 12 : FFR TVR after cepstral rectangular and half-tukey windowing ($T_{end} = 1.5$ ms)

5.2 Janus-Helmholtz (JH) transducer in IFREMER pool

In the pool, the first echo appears after 8 ms and the length of the JH time response is approximately 40 ms. A 60 ms exponential window is then applied to this response. Fig. 13 and 14 shows the cepstrum and the JH TVR obtained with a half-Tukey window stopping at T_{end} = 30 ms [3].

When a 30 ms cepstrum is taken into account, both resonances of the JH transducer are estimated with a very good accuracy (1 dB difference on the TVR values), but pool effects are still existing between 200 and 350 Hz with a 2 dB maximum magnitude (Fig. 14). This effect can be reduced with a half-tukey window stopping at 15 ms (not presented), but the value of the TVR at the first resonance is then 6 dB lower than the TVR in free space and 3 dB lower for the second resonance.

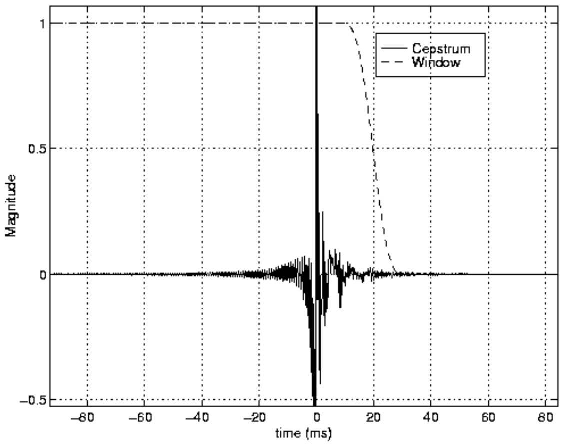

Fig. 13 : JH cepstrum after time domain exponential windowing

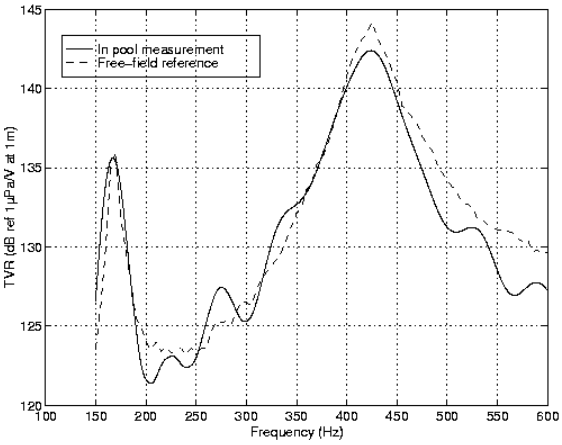

Fig. 14 : JH TVR after cepstral rectangular and half-tukey windowing (T_{end} = 30 ms)

6. CONCLUSION

The MITAS software has the possibility to generate Maximum Length Sequences and to calculate cross-correlation functions thanks to the Fast Hadamard Transform. The Homomorphic Signal Processing applied to the ring projector in tank and to the Janus-Helmholtz transducer in pool has given good results, even if perturbations coming from the wall effect are still existing in the case of the higher-Q transducer, due to the large length of the cepstrum to take into account.

The window shape has been optimized in time and cepstral domains, and the hardest parameter to adjust is certainly the length of the cepstral window, to have the best compromise between the accuracy of the TVR magnitude and the limitation of the wall effect.

An improvement of this very fast method could be obtained by making measurements in various areas of the tank and averaging the obtained frequency responses.

7. REFERENCES

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