CLASSIFICATION OF TWO KINDS OF ALMOST SIMILAR SIGNALS WITHIN THE FRAMEWORK OF SONAR INTERCEPTION

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1 - INTRODUCTION

Sonar transmitters can generate complex signals, composed of wave trains whose features can be changed from an emission to another.
Every wave-line is called "stage" of emission. The wave train duration, the time between two stages, and the number of stages are changeable. Stage is a very narrow band signal that can be modulated slowly (There are several types of modulation: linear, hyperbolical...).
It seems to be interesting to identify the transmitters by analysing the emissions. This job is entrusted to an acoustical recognition expert, that, from listening signal in sonar context, gives a decision. The expert valuation leads to a data bank where signals are ranged into type one or type two family.
The aim is to find out an analysis method able to provide the same prediction as the expert. Numerous methods have been developed [1,2], and two of them that seem the more promising, are presented here.

The first uses the wavelets transform [3 to 9] of transient part of the non-modulated stages, corresponding to the emission raising power phase.
The second compares the steady state to a narrow band pattern, obtained by filtering a white noise by a second order system.

2 - ANALYSIS OF RAISING POWER PHASE OF NO MODULATED STAGE

The chosen wavelet is Morlet's kind [3, 7]: $g(t, f) = e^{-\alpha t^2} e^{2i\pi f t}$ (1)
The parameter f changes around central frequency f_1 of permanent rate: $0{,}8 < f / f_1 < 1{,}25$.
The coefficient α depends on the choice of f. Experimental studies and sampling period have shown that a good choice of α corresponds to wavelet life equal to 5/f. This leads to relation,

$$e^{-\alpha\left(\frac{2,5}{f}\right)^2} = \frac{1}{100}, \quad \text{so} \quad \alpha = \frac{f^2}{1,3} \qquad (2)$$

If we call x(t) the signal, his transformation corresponds to the convolution product:

$$d(t, f) = \int_{-\infty}^{+\infty} x(v)\, g(v - t, f)\, dv,$$

that can be written

$$d(t, f) = \int_{-\frac{2,5}{f}}^{\frac{2,5}{f}} x(u + t)\, g(u, f)\, du \qquad (3).$$

The energy of the function g(u,f) changes with f. The energy of x(t) into interval [-2,5/f , 2,5/f] changes also in the transient phase, corresponding to the raising power. So it is desirable to replace d(t,f) by the coherence function defined by $C(t, f) = C_1(t, f) + i\, C_2(t, f)$, where

$$C_1(t,f)=\frac{\displaystyle\int_{-\frac{2,5}{f}}^{\frac{2,5}{f}} x(t+u,f)\, e^{-\alpha u^2}\cos 2\pi f u \; du}{\sqrt{\displaystyle\int_{-\frac{2,5}{f}}^{\frac{2,5}{f}} x^2(t+u,f)\; du}\;\sqrt{\displaystyle\int_{-\frac{2,5}{f}}^{\frac{2,5}{f}} e^{-2\alpha u^2}\cos^2 2\pi f u\; du}} \qquad (4)$$

$C_2(t,f)$ is the same formula where $\cos 2\pi fu$ is replaced by $\sin 2\pi fu$.

The chosen graphic representation, shows in form of contour lines, the evolution of modulus of C(t,f) during the time.

Experimental results are easy to interpret :
For type one signals, one can note an important frequency drift corresponding to the raising or the decreasing power of the non-modulated stages *(cf fig 1, 2)*.
But then, the type two signals don't generally present these frequency drift *(cf fig 3, 4)*.

Figure 1 : Coherent Wavelets Transform of Aa11

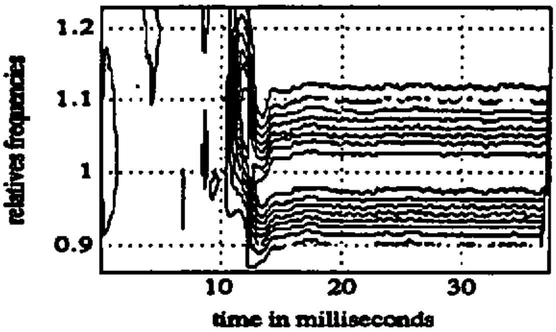


Figure 2 : Coherent Wavelets Transform of Ab1

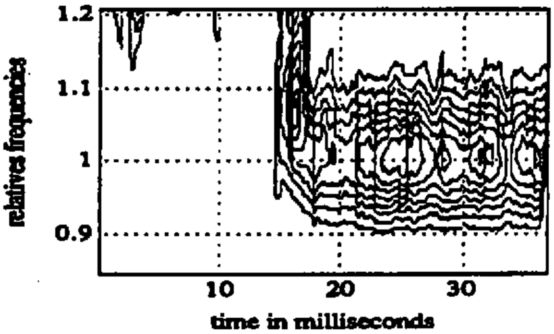


Figure 3 : Coherent Wavelets Transform of Ba1

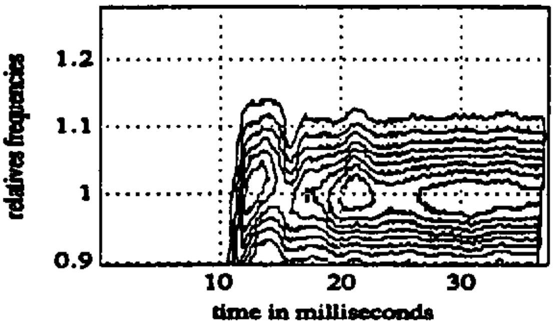
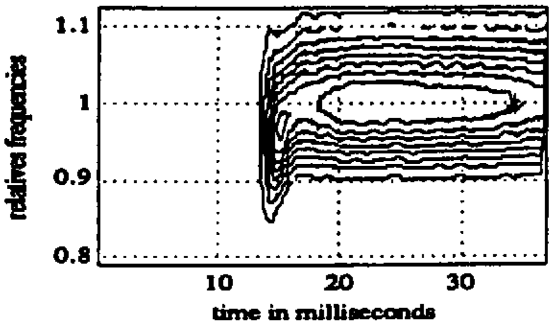


Figure 4 : Coherent Wavelets Transform of Bb1



3 - STUDIES OF PERMANENT RATE STAGES

3.1 Estimation of Q-factors

In first approximation, the steady state of non-modulated stage is equivalent to a narrow band signal, quasi-sinusoïdal. So the idea is to compare it to a pattern, resulting from filtering a white noise, by a second order system. More exactely, the comparison is realised between the modulus of spectrum S(v) of the steady state and the modulus of the transfer function T(v) of the second order system :

$$| T(v) | = \frac{1}{\omega_o^2} \frac{2\sqrt{\omega_o^2 - \omega_1^2}}{\sqrt{(1-(\frac{\omega}{\omega_1})^2)^2 + 4(\frac{\omega}{\omega_1})^2(1-(\frac{\omega_1}{\omega_o})^2)}} \quad (5)$$

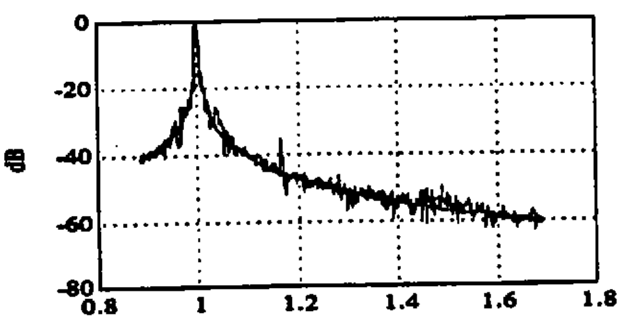
In this formula, ω_1 is the central pulsation of the steady state of non-modulated stage and ω_o is a parameter used to minimize the difference between |S(v)| and |T(v)| *(cf fig 5)*.

The Q – factor is then calculated according to the formula: $Q = \frac{1}{2\sqrt{1-\left(\frac{\omega_1}{\omega_o}\right)^2}}$ (6).

Numerical results can be summarized as follow:
- the assumption of second order system is quite confirmed for the type one emissions.
- This assumption is not always confirmed for type two emissions, where some transmitters seem to have choice of Q-factor.
- Generally speaking, the selectivity of type one emissions is lower than the selectivity of type two emission (see below) .

type one :	$310 \le Q \le 400$,
type two :	$280 \le Q \le 5000$.

Figure 5 : Spectrum of Ac 2° stage and transfer function of pattern q=353



3.2 Presence of spectrum lines and their time-variation

Trying to superimpose the two curves |S(v)| and |T(v)| by adjusting the value of the parameter ω_o, it can be noted the presence of spectrum lines symetrical with regard to the central frequency *(cf fig 6)*.

If it is supposed that these lines are dependant on the emissions, then the assumption that a white noise excites an unvarying second order system is not valid. So come the idea to whiten the signal to enhance the visualisation of these lines whose level is comprised between -20 and -40 dB with regard to the central peak *(f fig 7)* [1].

Figure 6 : Spectrum of Aa10

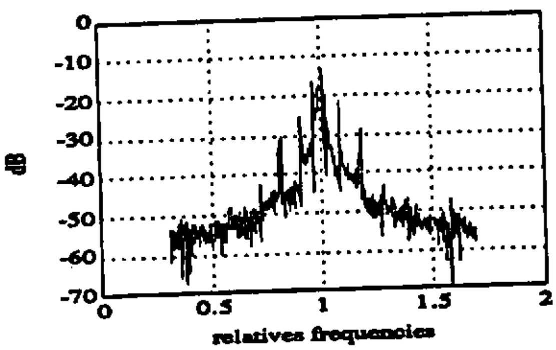
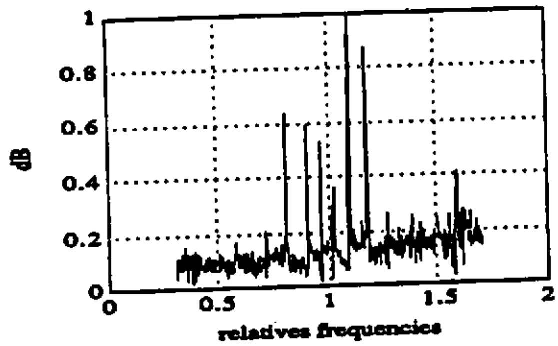


Figure 7 : Aa10 whitened



The whitening of emission sonagram is performed according to the following:
Every 6,52 milliseconds, one realises a spectrum (by FFT) of the signal, of a duration of 33,41 milliseconds. On the other hand, one simulates a sinusoïdal wave train of the same duration, and with a central frequency corresponding to the estimated frequency of the signal. (This assumption is acceptable as the frequency modulation of the stages are low enough to remain undetected during the duration involved in the analysis) . The whitening consists in dividing the spectrum modulus of signal by the spectrum modulus of the simulation.

Results

No modulated stages

The comparison affects type one and type two signal having approximatively the same central frequencies.

a - First frequency family

Among all the spectrum-lines of type one signal, one can note the existence of a common line at a distance of about 100 Hertz away from the central frequency *(cf fig 8,and fig 10 3° stage)* , whereas there is not really a common lines for the type two signals *(cf fig 9 2° stage)*.

b - Second frequency family

The common spectrum-lines of type one signals are separated about 110 and 540 Hertz away from the central frequency *(cf fig 10 2° stage)* . However, for the type two signals, one notes either the absence of lines, either the presence of lines distant of about 120,700,1300 Hz away from the central frequency *(cf fig 11 2°stage)* .

Linearly modulated frequency stage

Frequency modulations are very typical: the spectrum-lines evolution is suffisant to their identification.
For type one signals the frequency distance between the considered line and the central frequency keeps practically unvarying with time (equal to 300 and 600 Hz) *(cf fig 10)*, except for one case where the distance has been found to change by $\Delta f/\Delta t$ =-1,3 Hz/ms *(cf fig 12)* .
For type two signals, the distance changes such that : 2,1≥$\Delta f/\Delta t$ ≥0,6 Hz/ms *(cf fig 9,11)* .

Figure 8 : TYPE 1 sonagram of Aa10 whitened

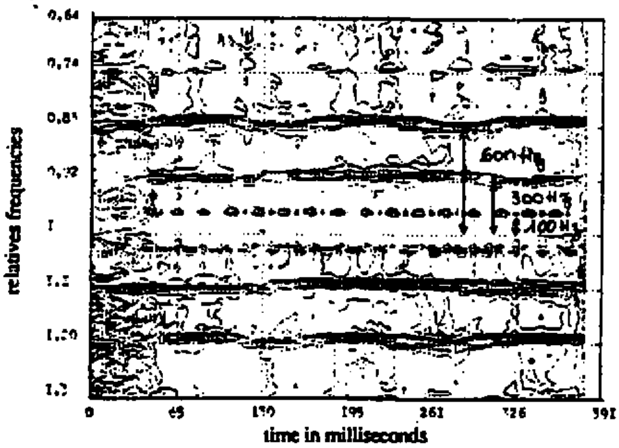


Figure 9 : TYPE 2 sonagram of Ba1 whitened (2 stages)

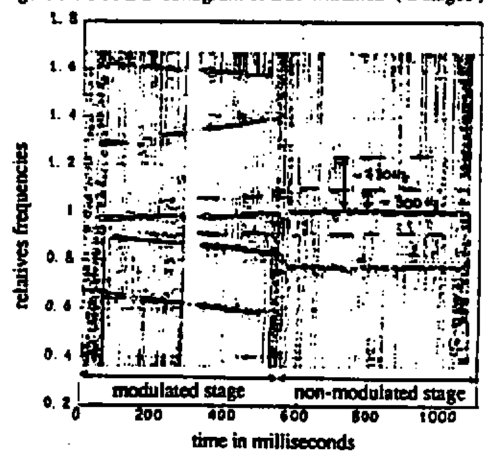


Figure 10 : TYPE 1 sonagram of Ac whitened (3 stages)

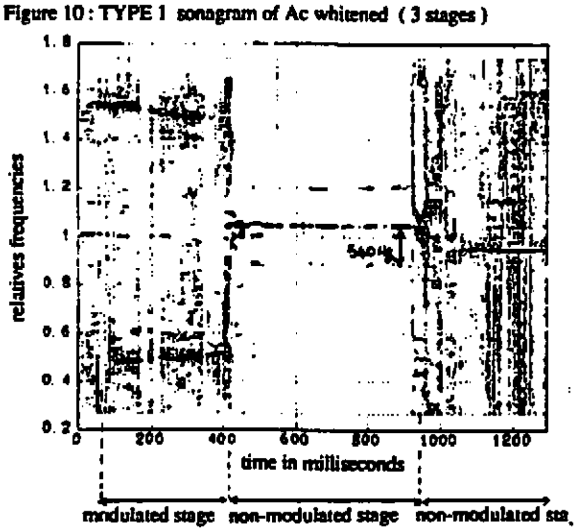


Figure 11 : TYPE 2 sonagram of Bc whitened (2 stages)

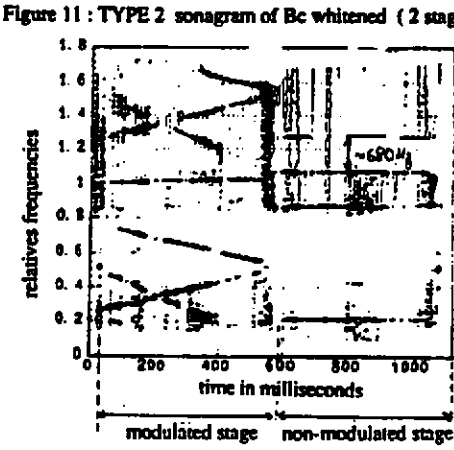
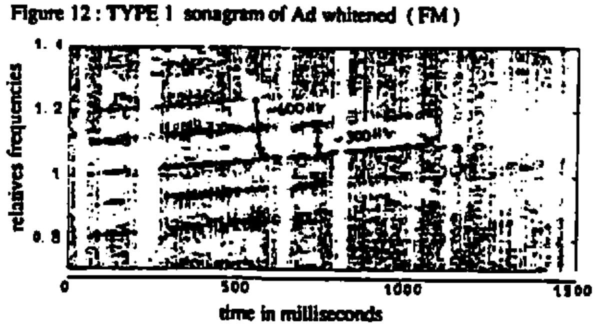


Figure 12 : TYPE 1 sonagram of Ad whitened (FM)



4 - REFERENCES

[1] A.C. PIGNOL-PEREZ 'Identification expérimentale de signaux acoustiques par des décompositions sur des fonctions à support borné' Université de Toulon thèse 1991.
[2] C. BERNERDINI 'Méthodes expérimentales de détection et d'identification de signaux acoustiques à bande étroite,basée sur une interprétation des fréquences instantannées' Université de Toulon thèse 1991.
[3] R. KRONLAND-MARTINET, J. MORLET, A. GROSSMAN 'Analysis of sound patterns through wavelets transforms' Centre de Physique théorique, CNRS Luminy Marseille, Janvier 1987
[4] B. TORRESANI 'Wavelet analysis : a tool for signal processing mathematics and physics '
Centre de physique théorique CNRS Luminy 1989
[5]Y. MEYER , S. JAFFARD , O. RIOUL 'L'Analyse par ondelettes' .Pour la science, Septembre 87 ,pp 28 - 87
[6] I. DAUBECHIES 'The wavelet transform, Time-frequency localization and signal analysis' IEEE 1990
[7] A. GROSSMAN , M. HOLSCHNEIDER , R. KRONLAND-MARTINET , J. MORLET
'Detection of abrupt changes in sound signal with the help of wavelet transform'
Centre de Physique théorique , CNRS Luminy , Marseille
[8] Y. MEYER 'Les Ondelettes' CEREMADE, Université de Paris-Dauphine et Ecole Polytechnique .
[9] I. DAUBECHIES , A. GROSSMAN , Y. MEYER 'Painless nonorthogonal expansion'
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