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ANC HEADSET : THE SECOND GENERATION

Ch. Carme, D. Derrien, P. De Man

TechnoFirst S.A., Parc Technologique et Industriel de Napollon
399, Avenue des Templiers, 13676 AUBAGNE Cedex-FRANCE

ABSTRACT

In 1981, we started a development of active noise control headsets. The new filtering developed for this technology was able to improve the bandwidth and the level of noise reduction. Today, we have continued the development and the purpose of this paper is to present a headset with a feedback control which avoid an increase of noise in high frequencies when active noise control is on.
Keywords : hybrid control, headset, nonlinearity, stability, technical application

1. INTRODUCTION

This experimentation requires to use an earmuff with active noise control : NoiseMaster™ produced by TechnoFirst®. The feedback controller uses colocated microphone, speaker and an analog fixed compensator developed for this specific application of Active Noise control [1]. This feedback controller is installed inside each earcup.
Different performances of noise reduction are given by a panel of different NoiseMaster™ application. For this experimentation, we have chosen to use one of the middle of the range. This NoiseMaster™ #1010 provides an active noise reduction about 20 dB from 50 Hz to 500 Hz. Nevertheless a noise increasing appears from 650 Hz to 1500 Hz. We can easily explain this phenomenon which appears for any kind of feedback loop control.
When we want to control a mechanism, the feedback control has to combine two antagonistics parameters:

- or a rapid control with a very sensitive stability,
- or a slow control with a strong stability.

At any time, if we increase one of these two parameters, it is against the second one. So, the good engineer has to determine, according to the needs of his application, if it is better to penalize the magnitude of the gain or the stability of the system.

2. WHY A FEEDBACK CONTROL CREATES UNSTABILITIES?

We have already spoken about the weakness of feedback control [2]. For a feedback application we can write the system behavior as follows :

$$\boxed{\frac{s(j\omega)}{e(j\omega)} = \frac{T(j\omega)}{1 + H(j\omega)}} \qquad (1)$$

where:

- s and e represent the output and the input of the system,
- T is the direct transfer function,
- H is the feedback loop transfer function.

The numerator and denominator are compound polynomials with real coefficients. When the denominator is equal to zero for different values of jω, the feedback loop system becomes unstable.
We can describe this phenomenon by using the Nyquist criterion [3] for closed loop system. According with the Nyquist criterion, we just have to draw the compound path of the open loop system ; if this open loop diagram does not crossover the real axis beyond the real number (-1, 0), the system is stable when the loop is closed.
For instance, Fig. 1 represents a stable closed loop system and Fig. 2 an unstable one.

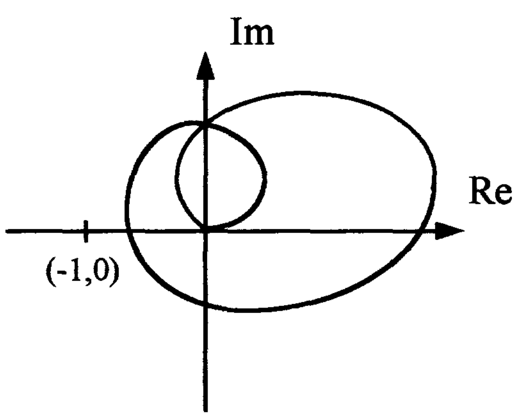

Figure 1 : Nyquist diagram - stable closed loop system -

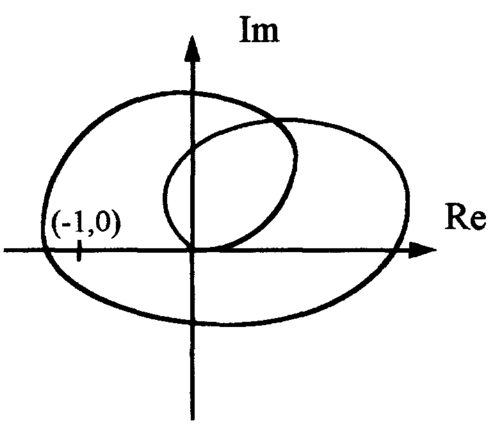

Figure 2 : Nyquist diagram - unstable closed loop system-

Nevertheless, when the closed loop system is stable, if the compound path is too closed to the critical point (-1 ,0), a pumping phenomenon appears and increases the level of noise outside the frequency bandwidth controlled by the feedback loop.
Equation (1) may be written for an active noise control earmuff [4] as :

$$\boxed{\frac{s(j\omega)}{e(j\omega)} = \frac{a}{1+k.F(j\omega).H(j\omega)}} \quad (2)$$

To obtain the maximum active noise reduction, the parameter k has to be very high. To control the stability and to increase the gain control, we have developed a specific filtering [5]. This filtering allows already to optimize the compromize between gain and stability and can provide a good active noise control result increased in comparison with standard filtering. This optimum result is given in Fig. 3.

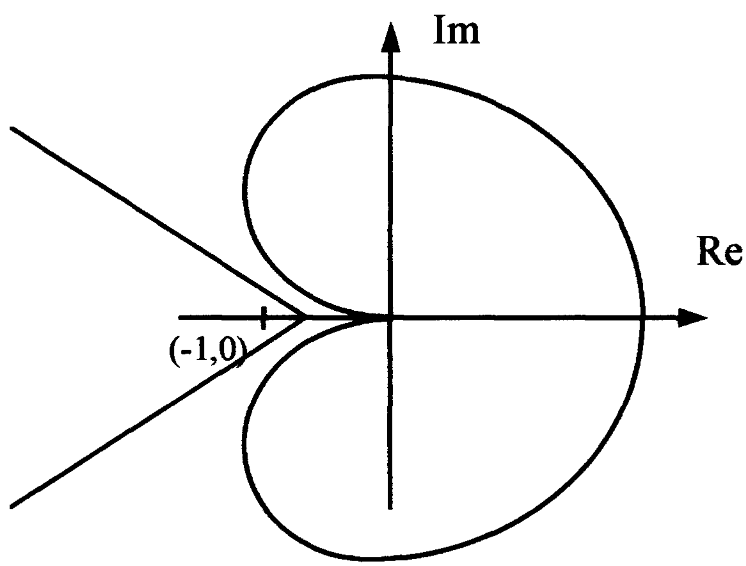

Figure 3 : Nyquist diagram of the optimum filtering

We can see on this Nyquist diagram that, except a conical sector with a vertex located at the point: $(-1+\varepsilon, 0)$, avoided by this specific filtering, we can increase the parameter k in all compound plan quadrants. So all vectors for which $j\omega_i$ is near the point $(-1+\varepsilon, 0)$ inside the conical sector give an amplification of noise which is represented at Fig. 4 ; the frequency response starts to be increased from 650 Hz instead to be the same as the passive frequency response.

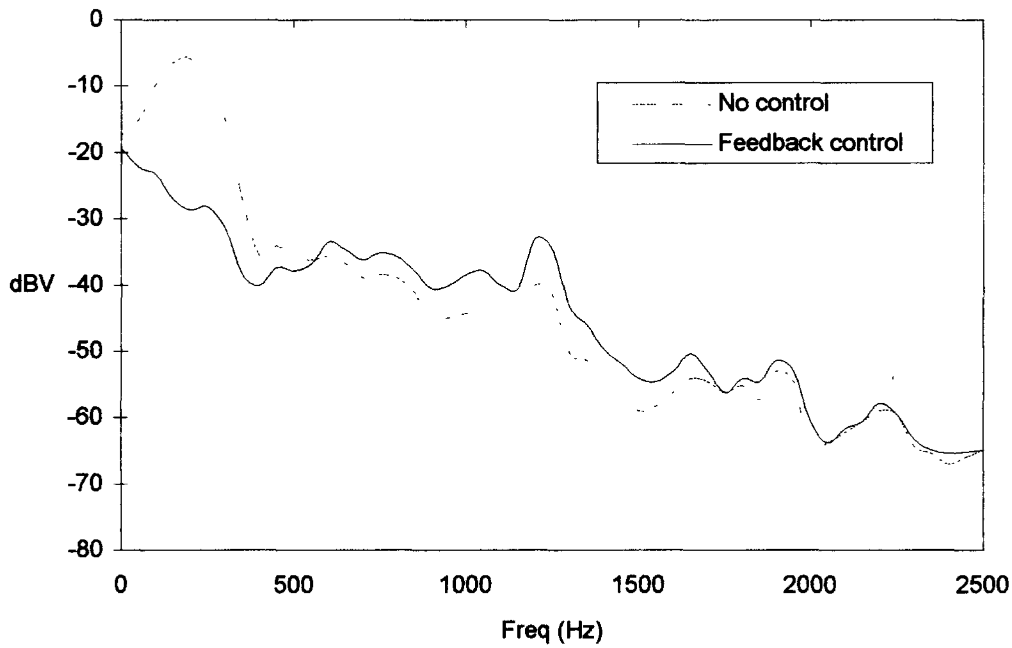

Figure 4 : ANC wide-band noise reduction using feedback control

3. BENEFIT OF COMBINING FEEDBACK AND FEEDFORWARD CONTROL

In the previous section, we saw that feedback control shows disturbance amplification beyond the bandwidth of the controller. As a consequence, any perturbation in this range decreases the overall performance of the system by bringing undesirable noise. With the aim of cancelling this noise, a feedforward control has been joined to the existing analog feedback controller, forming what we could call now a hybrid feedback/feedforward control.

Each type of controller keeps its own properties and the joined system has some advantages.

- feedforward control can deal with noise outside the bandwidth of the feedback control.
- feedback control provides a short impulse response to the system, and enables feedforward control to react and converge faster.

By using this hybrid controller, we stabilize the feedback control near the critical point (-1, 0) and reduce the pumping phenomenon in the frequency bandwidth [650 Hz, 2000 Hz].

4. EXPERIMENT

In order to evaluate the performance of this hybrid controller, an experiment was carried out involving an active earmuff NoiseMaster™. The principle of the standard headset is described fig 5-a. Active sound attenuation performances have been shown fig.4.

The feedforward controller, joined to the system to form the hybrid controller, consists in a NOVACS™ system developed by TechnoFirst®. NOVACS™ is a ready-to-use platform allowing digital real-time control. In this application, X-filtered LMS algorithm is used.

Fig. 5-b describes the implementation of the hybrid controller. The same control microphone and speaker are used for both feedback and feedforward. An external reference microphone is needed for feedforward control. The outputs of each controller are summed before entering the audio amplifier.

The feedback control allows a very fast control even for an impulse noise. The transfer function between the control microphone and the earphone is measured throught the existing feedback control. The result is a shorter impulse response, and means less datas and time computing for the Novacs™.

Fig. 6 shows the active noise attenuation of the hybrid controller, when a strong harmonic noise is present at a frequency outside the bandwidth of the feedback controller. This disturbance (700 Hz) which is sligthly amplified when the feedback control is used alone, is now attenuated by 15 to 20 dBV. Actually, we can observe this result for each frequency included in the hybrid bandwidth processing [50 Hz, 2000 Hz].

5. CONCLUSION

The hybrid feedback-feedforward controller gives the addition of both positive performances of feedback and feedforward control and increases quality of these technologies according to the following points:

- for the feedback, no more pumping effect outside the frequency bandwidth controlled by the feedback,
- for the feedforward, a faster control.

By using the combination of the two standard technologies of active noise and vibration control we demonstrate that it is possible to increase performances of this active control got only by each separate technology.

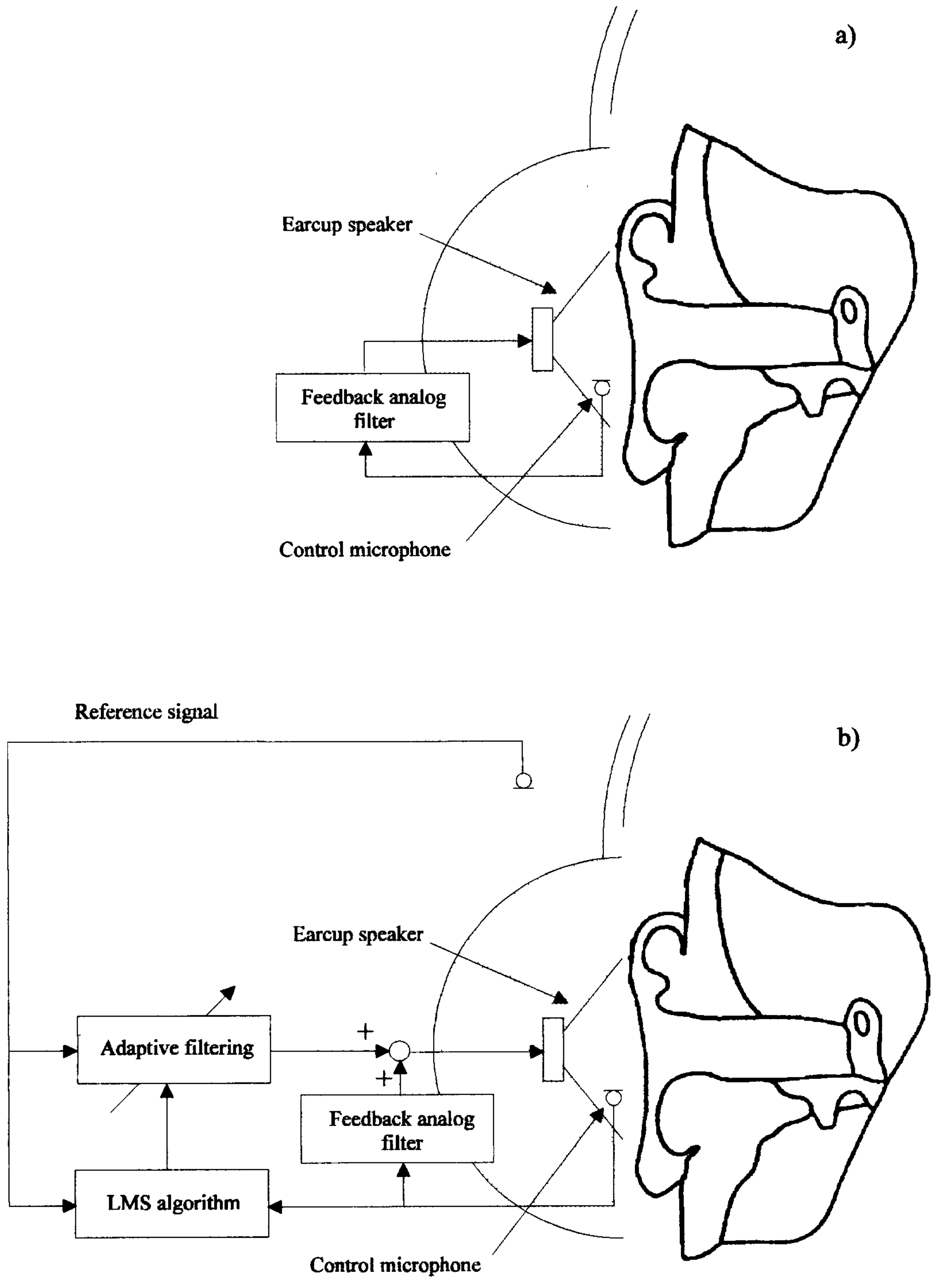

Figure 5 : NoiseMaster™ ear protection
a) with feedback control
b) with hybrid control

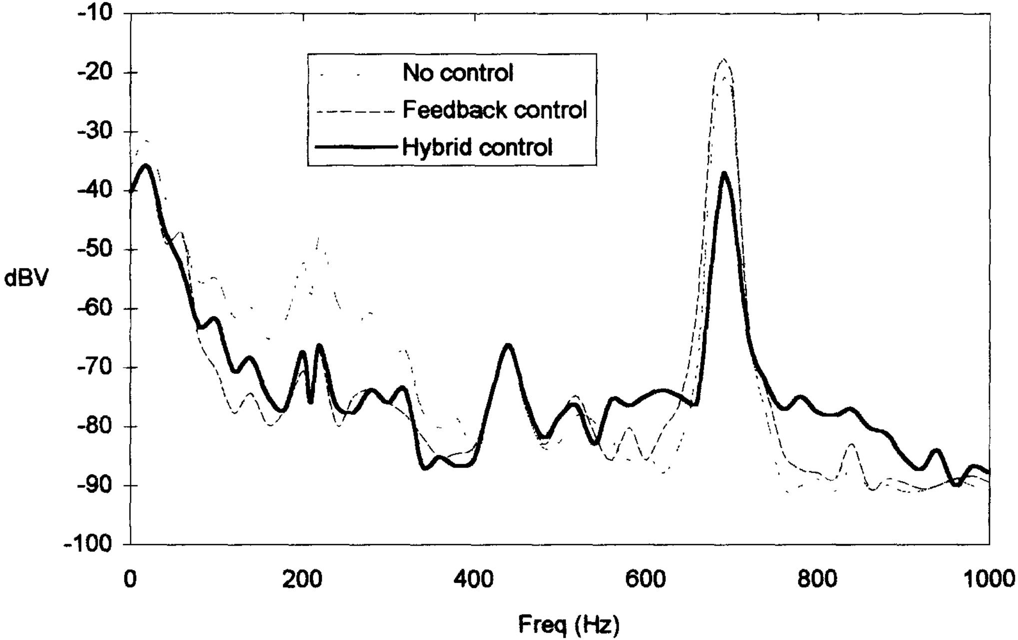

Figure 6 : ANC narrow-band noise reduction using hybrid control

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