Are Electromagnetic Receivers Suitable for ANR Earplugs?

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Introduction

Communication and hearing conservation are essential for the crews using modern weapon systems. However, in many situations the noise levels becomes so high, that the standard hearing protectors (e.g. ear plugs) are not any more effective enough. Moreover, in order to allow communication underneath the hearing protection the speech has to be displayed at levels that may be harmful.

In order to overcome this problem, more effective hearing protection has to be developed. A solution, that may be acceptable for the exposure to such high level noises, is the use of deep inserted ANR (Active Noise Reduction) earplugs. This type of device is suitable if the ANR adds at least 5 dB of attenuation up to a frequency of 4 kHz.

Ear-plugs with different Transducers

"Walkman" type transducers

The first prototype earplugs made at the ISL [1] and their contributions to the ANR are presented on figure 1. These

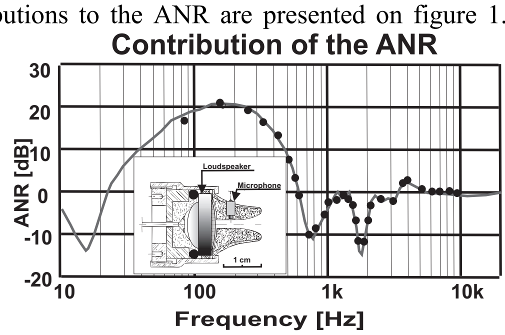

Figure 1: Experimental ANR ear-plug and the contribution of the ANR provided by the device.
Solid line - simulated (predicted) values
Dots - measured values

first experiments have shown, that it is possible to reduce the size of the ANR device and that the use of a digital filtering system in the feedback loop is possible. However the earplug equipped with a "walkman" type transducer did not exhibit a larger ANRbandwidth than a good ANR ear muff.

Piezo-ceramic transducer

Different types of piezo-ceramic transducers have been developed in collaboration with the LAUM [2][3]. The bandwidth of the contribution of the ANR (figure 2) of this type of plugs was extended up to 4 kHz when accepting a lower ANR (e.g. 7 dB). However, this technology is, presently, unable to produce enough acoustic pressure in the ear canal to allow its use in high level noise environments.

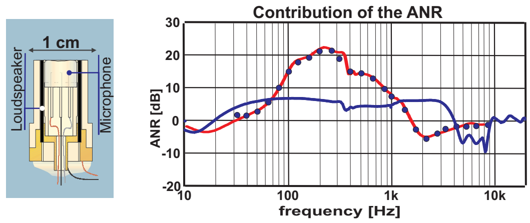

Figure 2: Experimental ANR ear-plug using a piezo-ceramic transducer and the contribution of the ANR using different filter functions. (solid line – simulation; dots – measurement).

Electromagnetic "hearing aid" receivers

Receivers small enough to fit in an ear-plug, and effective enough produce high anti-noise levels are used for hearing aids. An experimental plug has been developed. Figure 3 shows this plug. It can be observed, that the acoustic distance between the microphone and the outlet of the receiver is about 2.5 mm. Accepting another 5 mm for

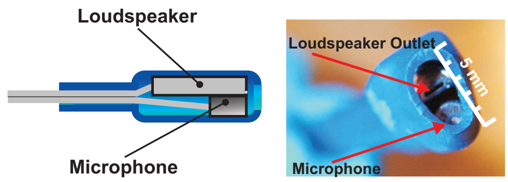

Figure 3: Experimental ear-plug using a miniature electromagnetic receiver and a miniature microphone.

hidden paths (inside microphone and receiver) a maximum delay (due to an acoustic "distance") of 22 µs may be estimated. This delay is usually the limiting factor for the ANR if the other parts defining the transfer function are minimum phase. As the estimated acoustic delays of the piezo-electric and electromagnetic earplugs are close, the ANR bandwidth of both assemblies should be the same. In

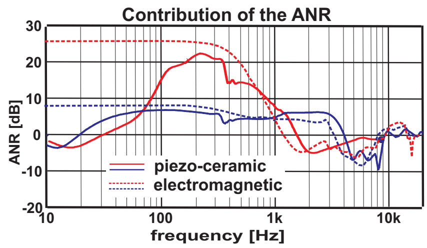

Figure 4: Comparison of the ANR bandwidth of electro-magnetic (broken lines) and piezo-ceramic (solid lines) transducers.

figure 4 a comparison between the ANR bandwidths for comparable configurations is shown. It can be seen, that the obtainable ANR bandwidth is broader with piezo-ceramic transducers (In order to show the maximum bandwidth for the high frequencies, the low frequency response of the receiver has been flattened). Comparing the transfer functions of a receiver with its analog (figure 5) we observe an extra delay corresponding to about 10 mm for which we have no explanation (if the receiver behaves as a minimum phase system). When implementing an ANR earplug, it seems that this supplementary phase shift (delay) represents

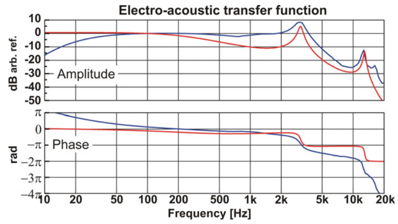

Figure 5: comparison between the measured electro-acoustic transfer function of a electro-magnetic receiver (blue) and its mecano-electric analog (red). The measured phase is compensated for length of the acoustic path between receiver and microphone.

the main limitation of the ANR bandwidth. Figure 6 shows, the difference in bandwidth that can be obtained when using the transfer function of the analog. We observe that if this phase shift could be compensated, the bandwidth of the ANR earplug would be improved by a factor of 2 with a higher ANR contribution at high frequencies. In order to

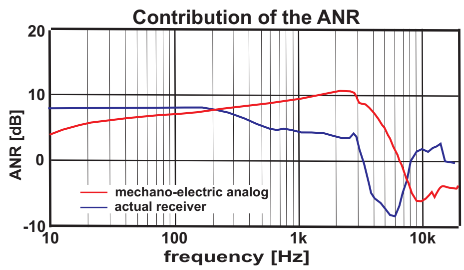

Figure 6: Comparison of the simulated ANR using the transfer function of the real receiver (blue) and this of the mechano-electric analog (red).

understand the reason of the difference between the measured data and the data from the receiver analog, different investigations have been made. None of them were able to point to the source of this effect. As the piezo-ceramic transducers did not show this effect, we suspected at that time, that there may be ferromagnetic effects (not included in the receiver model) the source of the phase shift.

An ideal Ear-Plug with digital ANR

As it seems that the electromagnetic receivers are (at least

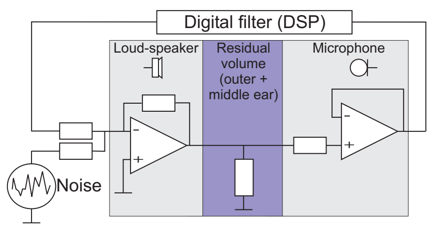

Figure 7: Schematic of the “ideal ear-plug”

presently) the only possible system to be used, we have to make sure, that the other parts of the feedback loop are not limiting the ANR bandwidth. In order to show this, an “ideal ear-plug” (electronic) has been made. The schematic in figure 7 shows the electrical implementation of the “ideal” earplug. The electro-acoustic of this ANR earplug is unity for all frequencies. To show the ANR behaviour, an electrical noise may be added in the loop. The feedback loop is controlled by a recursive (IIR) digital filter. Using this experimental design, the limitation due to the digital filtering can be shown. Figure 8 shows the maximum ANR bandwidth possible with this “ideal” digital ANR ear-plug. The overall delay due to the digital filter is 12 µs. Figure 8 shows, that this configuration allows an ANR of more than 20 dB with a bandwidth of more than 10 kHz. These data show clearly that, at this moment, the digital implementation

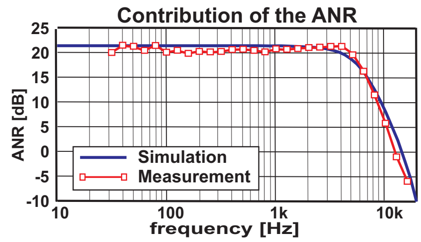

Figure 8: Contribution of the ANR to the attenuation of an “ideal” active ear-plug

of the filter in the feedback loop is not a limiting element as far as the ANR bandwidth is concerned.

Conclusion

At that time, only two types of transducers seem to be suitable for the use in ANR earplugs.

The piezo-ceramic transducers have electro-acoustic properties that are favourable for the use in ANR systems. Unfortunately, the use of this type of transducers is limited by their output and the high voltage (up to 100 V) needed to obtain ANR at the required levels. For these reasons, the use of this type is actually restricted to experimental designs. The electromagnetic “hearing aid” type transducers (receivers) have a very good efficiency. Their electro-acoustic transfer functions give good ANR up to a frequency of 1 to 2 kHz. ANR at higher frequencies is limited by a phase behaviour that can not been explained at this time. However, at this moment, there is no other available transducer on the market that could be used for an ANR earplug. An important effort has to be made to explain and decrease the phase lag inherent to this type of transducer.As far as the other elements of the feedback loop are concerned, there is none that can be shown to be critical. Especially the influence of digital filtering is not a major limiting factor.

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