A New Nonlinear Earplug for Use in High Level Impulse Noise Environment

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Abstract: A nonlinear earplug allows speech communication, detection and localization of acoustic sources, and prevents hearing hazard from high peak pressure impulses. In this paper, we explain how we improved the physical characteristics of a nonlinear earplug: nonlinear attenuation starting with relatively small level (110 dB peak), improvement of nonlinear attenuation for high levels. Such an earplug is especially designed against weapon noises (up to 190 dB peak). The study is based on experimental approach. Moreover a theoretical model has been developed to explain the experimental results and to optimize the acoustic nonlinear filter dimensions and configuration. The nonlinearity of such a filter is due to one (or several) little hole(s) the acoustic impedance of which is essentially a viscous resistive one and depends on the particle velocity in its center.

INTRODUCTION

Because the impulse noises produced by weapons are frequently the cause of acoustic trauma (1), we start to improve the nonlinear characteristics of an earplug. This earplugs allow speech communication, detection and localization of the acoustic sources in about the same conditions as for unprotected ears (2). We transformed the geometry of the nonlinear filter insert in the RACAL Gunfender earplug and optimize its nonlinear behavior.

IMPROVEMENT OF THE NONLINEARITY

The RACAL Gunfender earplug is made nonlinear by means of a metallic plate which is inserted inside the earplug perpendicular to its axis and perforated in its center by a hole. The acoustic resistance through the orifice increases with the peak level (3), (4). An expression for orifice resistance \( R_o \) might, as a first approximation, be a linear combination of kinetic and viscous terms as follow: 

\[ R_o = R_v + \frac{k u}{2S} \]

where \( R_v \) is a viscous resistance, \( k \) a real constant, \( u \) the particle velocity in the orifice, \( \rho \) the air density and \( S \) the orifice area. This earplug has been proven to act as a nonlinear mechanism allowing the attenuation to increase with the stimulation level beyond 120 to 140 dB (5).

We decided to look for a new nonlinear earplug design with better performance and better ergonomics. Given the original RACAL Gunfender earplug, we modified the dimensions of the metallic plate (the nonlinear component) and measured the corresponding changes in Insertion Loss. Systematic variations in thickness of the plate, in diameter, shape and position of the hole, in the number of holes... led us to an optimized configuration. The best nonlinear characteristics were obtained with a plate of 0.10 mm in thickness and one hole of 0.30 mm in diameter. As it seemed impossible to get better performances with a single plate arrangement, we decided to study the characteristics of small cylindrical cavities terminated by two perforated plates. Extensive measurements allowed to determine the influence of the dimensions of the cavity, the thickness of the plates, the diameter of the holes..., on the nonlinear performance. All measurements are performed with the help of the ISL ATF (6).

FIGURE 1. Schematic representation of the ISL "filter" (overall length: 3.7 mm, outside diameter: 3.0 mm, inside diameter: 2.0 mm). The thickness of the perforated plates is 0.10 mm and the diameter of the holes is 0.30 mm.

The "filter" which is represented in figure 1 corresponds to the best dimension/performance compromise. In its final version it is made by plastic injection moulding (in two parts). As it is necessary to get precise and
reproducible dimensions of the plates and of the holes as well as sharp edges and even surfaces to ensure good and uniform performances, the factory limits must be very strict. Figure 2 presents the IL of the nonlinear ISL-EAR Ultrafit earplug as a function of frequency for impulses of 110, 130, 150, 170 and 190 dB peak (A-duration: 2 ms). We can note the increased nonlinear performances compared to the original RACAL Gunfender. The frequency range for which the nonlinearity is significant goes from 0.025 to 10 kHz. The nonlinearity begins at 110 dB and increases by about 0.4 dB/dB around 0.3 kHz. The NR peak increases by 17 dB from 110 to 190 dB.

![Graph showing insertion loss for different levels of impulses and earplugs](image.png)

**FIGURE 2.** Insertion Loss afforded by the ISL-EAR Ultrafit [(1) to (5)] and RACAL Gunfender [(6) to (10)] earplugs for different levels (110, 130, 150, 170 and 190 dB) of the impulses (1/3 oct. bands). Insertion Loss afforded by the original EAR Ultrafit earplug when measured with a pink noise at 120 dB [(11)]. All measurements are performed with the help of the ISL ATF (6).

**CONCLUSION**

The new nonlinear earplug design afford a protection adapted to occasional exposure to impulse noise such as those produced during training or combat. It allows speech communication, and detection and localization of acoustic sources in about the same conditions as an unprotected subject, thus avoiding problems of overprotection. The final design of these plugs will also allow to get a full attenuation even at moderate levels in the case of exposure to continuous noise (by manually plugging the sound passage between the two ends). These new earplugs, which represent a good compromise between the so far opposed requirements: hearing protection and operational capabilities, will be used by the French infantrymen in the near future.

**REFERENCES**