Did you say "bionic" ear?

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Introduction

For decades, Hearing Protection Devices (HPDs) have been used to protect wearers against noise-induced hearing loss (NIHL). HPDs are available under various shapes and forms, from roll-down foam earplugs to cap-mounted earmuffs (see Fig. 1 for illustrations of common hearing protectors and their common classification). Until recently, HPDs have acted simply as passive acoustical barriers intended to prevent sound from reaching the ear canal. With the increasing miniaturization of electronic components and consolidation of consumer electronic goods, new electronic HPDs have come onto the marketplace. Thus, entirely new communication devices are being developed such as Hearing Aids that are also a wireless cellphone earpiece. The convergence of hearing protection devices, hearing aids and communication earpieces appears to be the next step and this technology is sometimes referred to as a "bionic" ear.

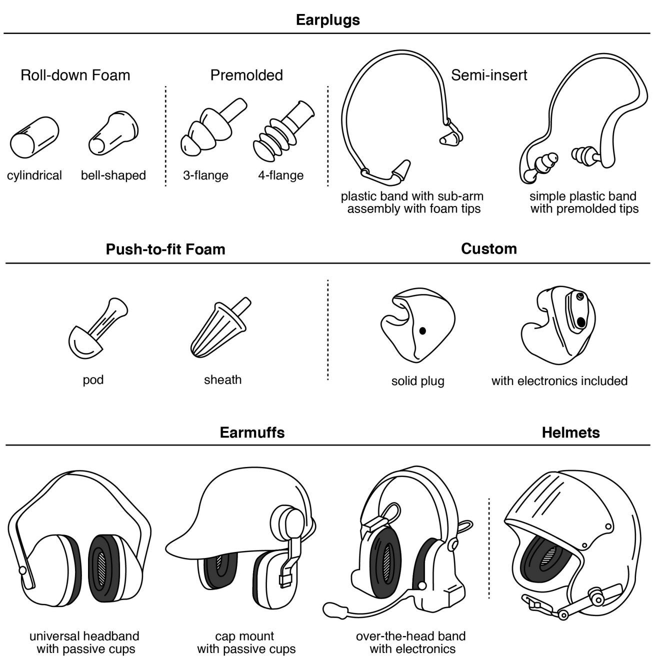

Figure 1: Illustrations of typical hearing protectors and their common classification.

1 Combining hearing protection, hearing aid and communication into one digital device

HPDs reduce the sound energy reaching the wearer's eardrum and -in their passive linear form- cannot distinguish between noise and useful signals, such as speech and warning signals. This issue can now be addressed using electronic HPDs that use an external microphone a -preferably- digital signal processor and an internal loudspeaker. The electronic HPD could be an earmuff-type, while it could also be a custom earplug, such as the one illustrated in Figure 1 middle-right. Figure 2 illustrates the electro-acoustical components and equivalent schematic of a digital version of a custom electronic earplug.

1.1 Digital Hearing Protection

Many electronic HPDs have already been developed for the industrial and military workplaces, but only a few feature digital signal processing. Some of our current research efforts are oriented towards the detection of speech [1] and warning signals [2] in noisy environments, the denoising and enhancement of the speech signals [3], as well as the protection of musicians [4] [5] [6] and other special wearers [1].

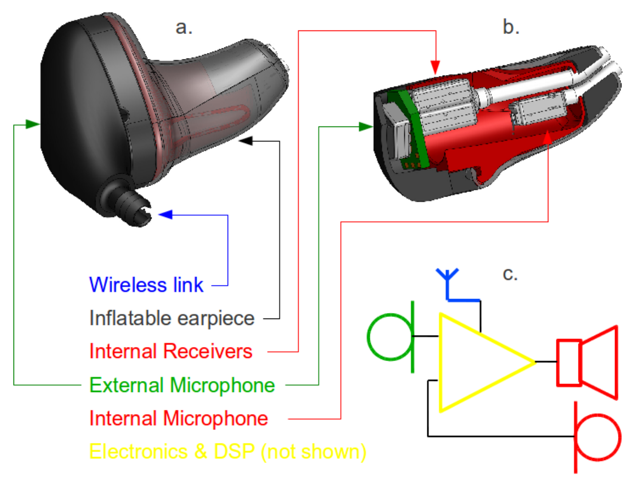

Figure 2: Overview of a digital custom earpiece (a), its electro-acoustical components (b), and equivalent schematic (c).

1.2 Digital Hearing Aid

Hearing Aids are considered in most jurisdictions as medical devices and usually require hearing specialists to dispense them. Nevertheless, the sound amplification they provide is very beneficial for speech perception and relatively easy to use in low-noise environments, giving use to a wide range of consumer products, sometimes referred to as Personal Sound Amplification Products (PASPs), ranging from by integrating revival of so-called *body-aids* with the use of modern smart phones to digital in-ear devices featuring a pre-programmed hearing aid. It should be noted that the use of hearing-aids or combined use of hearing aid and HPD in noisy environments are still challenging topics for hearing conservationists [7] and hearing-impaired workers in noisy environments would definitively benefit from a digital in-ear device combining hearing protection and hearing aid.

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1.3 Digital Communication Device

With the widespread adoption of cell phones and smart phones, earphones and communication earpieces are now ubiquitous in their wired and wireless versions. Despite intense research efforts in speech noise reduction algorithms and in multi-/noise-canceling speech capture microphones, communication in noise is often less than satisfactory. Many consumers find it difficult to hold a phone conversation on a busy street. Business travelers cannot comfortably join teleconference while in the ambient noise of an airport and it is still nearly impossible for many workers in noisy industrial environments to communicate safely over their personal radios without overexposing their hearing either to ambient noise or to a communication signal. To address these communication in a noise issues, the superior sound isolation offered by a custom-fitted in-ear device, illustrated in Figure 2, enables quieter playback, reducing the chances of overexposing the wearer's hearing [8]. Also, the in-ear microphone, illustrated in Fig. 2, could be used to capture the wearer's speech under the HPD with a favorable signal-to-noise ratio, and further spectral expansion techniques could be used to enhance the quality and intelligibility of the picked-up speech [9]. Finally, a Radio-Acoustical Virtual Environment (RAVE) could be created in civilian and military environments, where teams equipped with such digital communication in-ear devices could speak to each other on personal radios, while the speech signal of the wearer would only be broadcasted to receivers within a given radius, just like in normal open-air acoustic communication [10].

2 The earcanal : a nice place to be for "wearable" technologies

While integrating all the above-mentioned audio applications could already open a new realm of technologies and products for consumers, medical and military applications, the earcanal is still probably the ideal location -currently underestimated- for many more technologies in years to come. The growing field of "wearable technologies" aims at developing electronic devices that -broadly defined- interconnect the human body to the machine. Proof-of-concepts have been made to collect acoustic bio-signals -such as the heart beat and breathing rate- within the earcanal, for health and fitness monitoring applications. Miniature electrodes have recently been embedded on in-ear devices to enable portable and non-invasive electroencephalography (EEG) monitoring of brain-wave and other evoked responses. One could possibly foresee that a truly light and non-invasive Brain-Computer-Interface (BCI) could be developed by integrating acoustical and electro-physiological sensors. Interestingly, the earcanal may be one of the best places, to harvest energy to power -at least partially- all future "bionic ear" and other "wearable" devices, as recently demonstrated in a study on harvesting energy from earcanal deformation by jaw-joint movement [11].

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