

Optically Driven Wireless Earplug for Communications and Hearing Protection

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Abstract

Electronic earplugs with embedded receivers provide for quality communications capability and effective double hearing protection in high noise environments. With the addition of ear canal microphones in the earplug greater hearing protection can be achieved using active noise reduction (ANR) in the ear canal. Current communication earplugs must be connected by wire to the outside world or must carry an onboard power source. The wire connection makes don and doff difficult, and presents a snag hazard and the connectors and wires pose possible problems in high EMI and EMP environments. Batteries in the earplug cause maintainability issues.

The optically driven earplug described in this work eliminates the need for wire interconnects and earplug battery energy sources. Both the power to drive the earplug electronics and signals to and from the earplug are delivered optically through a free-space optical link to the outer layer of the double hearing protection.

The optically driven earplug has been demonstrated to match the performance of a wire interconnect in both a listen-only earplug configuration and in two-way communication earplugs that can include ear canal Active Noise Reduction (ANR) with the addition of an ear canal microphone also driven through the optical interconnect.

Objective

The objective of this work was to develop a wireless link to active electronic earplugs used for communication and active noise reduction for hearing protection in high noise environments. The wireless link was designed to be a local link to the individuals hearing protection or communications earmuff in a double hearing protection situation. The wireless link is to replace the wired link needed for other active earplug implementations so as to improve ease of don and doff of hearing protection while maintaining a reliable two-way link to an active electronic earplug including an ear canal microphone without addition of energy sources in the earplug.

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Summary

A local wireless link using a power-by-light optical link between the earmuff and the active electronic earplug was developed. LED light sources and detectors in the circumaural earmuff couple to detectors and LED sources in the earplug to provide a two-way signal link between the earmuff and the earplug. The light transmitted to the earplug also provides electrical power for the earplug circuitry through photovoltaic conversion of the light to electricity. Thus it is not necessary to have any energy sources such as batteries in the wireless earplug.

The optically driven earplug was developed in two configurations:

1. A one-way, listen only earplug was developed as a wireless alternative to the CEP communications earplug.
2. A two-way communication earplug including both a receiver and microphone in the earplug was developed to enable active noise reduction (ANR) in the ear canal using the ear canal microphone for residual noise sensing in the ear canal. This configuration, a power-by-light earplug (PBLEP), can also extract speech from the ear canal microphone signal as an alternative to an external boom mike.

In this briefing we describe the earplugs developed for these two implementations and show some examples of implementations of both types of the optically driven wireless earplug systems.

Listen-Only Optical Communications Earplug (OCEP)

Benefits of an active earplug

Active earplugs provide a communication speaker/receiver inside a noise reducing earplug delivering the sound directly to the ear canal. An active earplug used under double hearing protection provides high speech intelligibility in high noise environments.

The wire link from the active earplug to the communication source for most active earplug systems makes for difficulty of don and doff of the earmuff or helmet. Typically the wire connection to the active earplugs must be made to a terminal outside the earmuff or helmet.

In addition to creating difficulty in don and doff, the connecting wire creates a snag hazard for the user.



Figure 1. OCEP earplug implementation

The **OCEP** earplug provides quality communication under double hearing protection with no need for the cumbersome wire connection and resultant snag hazard of wired active earplugs. Figure 1 shows an implementation of the OCEP listen-only communications earplug in a David Clark headset. Three different earplug implementations differing in type of ear canal seal are shown. Also seen are the drive LEDs for the optical drive system shown as replacements for the conventional ear cup speakers.

The **OCEP** earplug uses an optical, power-by-light method to deliver the communication signal and the driving power wirelessly to an active earplug. The optical link is made through a free space optical link from the earmuff interior to the earplug.

The user inserts the earplug as he or she would with their normal hearing protection earplug. Once they slip on their earmuff or helmet they are immediately connected to receive incoming communications with the clarity and high signal-to-noise that can be delivered by an active earplug.

The optical drive of the earplug speaker is delivered by infrared light originating in the earmuff or helmet. Once the earplug is inserted no further action needs to be taken by the user.

Benefits

- Simple to use. No user actions or training needed beyond insertion of an earplug.
- No wire connection to the earplug to act as a snag hazard or source of EMI noise in high field and EMI environments.
- Low maintenance earplug. No batteries or other energy source required in the earplug.

- Optical link does not create a broadcast frequency conflict with other equipment as may exist with other wireless earplug methods. The signal link also does not radiate RF energy and thus creates no TEMPEST concerns.

Earplug Options

The power-by-light earplug drive system can be implemented for multiple earplug styles.

- **Custom mold earplug.**
Custom molded earplugs provide exceptional damping of external noise because of their quality fit to the ear. The **OCEP** system can be readily incorporated into active earplugs built as custom molded earplugs.
- **Generic earplug.**
The **OCEP** earplug is available with several standard earplug seal systems.

Foam earplugs shown in Fig. 2 provide a high quality seal to the ear canal in disposable, single use earplug. The **OCEP** earplug can be configured to accept replaceable Comply™ type disposable foam ear tips. A replacement foam ear tip simply screws onto the **OCEP** earplug body.



Figure 2. OCEP earplugs with foam canal tips

OCEP earplugs with reusable, flanged ear tip styles were also developed. These are shown in Fig. 3. Ear tips of this type have somewhat reduced passive hearing protection compared to the foam ear tip styles but in some cases provide superior comfort.



Figure 3. OCEP earplugs with reusable silicone ear seals.

Two-Way Communication Power-by-Light Active Earplug

A wireless active earplug for communication and active noise reduction in the ear.

Benefits of an two-way active earplug

Active earplugs provide a communication speaker/receiver inside a noise damping earplug delivering the communication directly to the ear canal. Addition of a microphone sensing residual noise inside the ear canal allows for implementation of active noise reduction algorithms to maintain acceptable noise levels in the ear even for ambient noise of 150dBspl.

The power-by-light two-way earplug (PBLEP) maintains the advantages of a wireless earplug link of the OCEP active earplug for one-way, listen-only applications. The PBLEP earplug uses a similar optical link to the helmet or earmuff to provide ease of on and doff. Like the OCEP active earplug the two-way PBLEP earplug does not require a connection wire and thus also eliminates a snag hazard caused by a connection wire.

The PBLEP earplug provides quality two-way communication under double hearing protection with no need for the cumbersome wire connection and resultant snag hazard of wired active earplugs. Figure 4 illustrates an implementation of the PBLEP two-way optical interconnect system in a commercial walkie-talkie headset. Shown are PBLEP earplugs in a custom ear mold configuration (L) and a generic ear bud type earplug (R).

The PBLEP earplug uses a optical, power-by-light method to deliver a communication signal to the earplug and transmit back from the earplug the output of a microphone sampling the sound in the ear canal. The microphone signal can be used as a voice microphone, eliminating the need for an external boom mic, or as part of an active noise reduction operation within the ear canal.
Active noise reduction in the ear canal

The user inserts the earplug as he or she would with their normal, hearing protection earplug. Once they slip on their earmuff or helmet they are immediately connected to receive incoming communications and/or connection to an active noise reduction system for ANR in the ear canal.

Benefits

- ANR in the ear canal reduces hazardous noise in very high noise environments
- Wireless earplug simple to use. No user actions or training needed beyond insertion of an earplug.
- No wire connection to the earplug to act as a snag hazard or source of EMI noise in high field and EMI environments.
- Low maintenance earplug. No batteries or other energy source required in the earplug.
- Optical link does not create a broadcast frequency conflict with other equipment as may exist with other wireless earplugs. The signal link also does not radiate RF energy and thus creates no TEMPEST problem.



Figure 4. Two-way PBLEP earplugs in a walkie-talkie headset

Earplug Options

The power-by-light earplug drive system can be implemented for multiple earplug styles.

- **Custom mold earplug (Fig. 5).**
Custom molded earplugs provide the best ANR in the ear canal because they create a small and reproducible trapped ear canal volume on repeated insertions. They also provide exceptional passive noise damping because of their quality fit to the ear. The PBLEP system can be readily incorporated into active earplugs built as custom molded earplugs.
- **Generic earplug (Fig. 6).**
The PBLEP earplug is available with several standard earplug seal systems.

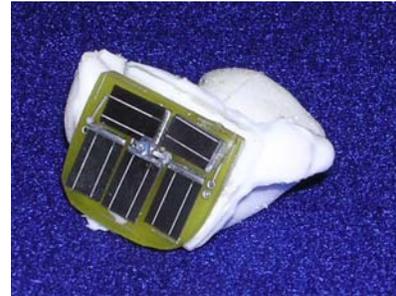


Figure 5. Custom ear mold PBLEP earplug

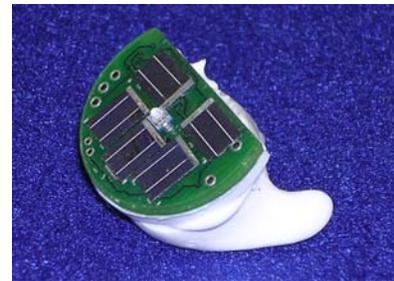


Figure 6. Generic ear bud type PBLEP earplug.

Required Earmuff and Helmet Modifications

It is required that the surrounding earmuff or helmet be modified to include the optical drive for the OCEP and PBLEP earplugs. This optical drive modification can usually retrofit to existing communication headsets. Shown below is a David Clark headset with a M/A-COM HYDRA radio set shown modified for an OCEP, listen-only configuration. The optical drive circuitry and light sources replace the earcup speakers. The earmuff speakers could also be retained for redundancy if desired. In the photo below the speaker has been replaced and only the two LED light sources of the OCEP optical drive are visible in the earmuff.

