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Body-Centric Wireless Communications: A Survey of Hearing-Instrument Antennas

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***Abstract*—A survey of hearing-instrument antennas used for body-centric wireless communications is presented. One challenge is to transmit a radio signal from a hearing instrument on one ear to a hearing instrument on the other ear to improve the hearing quality. Transmission through the head is not an option due to the losses at the ISM-band at 2.4 GHz. This is overcome by the use of surface waves, i.e., a wave that creeps on the top of the head. A major challenge is to construct antennas that effective launches surface waves for different types of hearing instruments.**

I. Introduction

Body-centric wireless communications have received much attention in the literature in recent years. This is due to the rise of small body-worn devices, which need to communicate wirelessly in order to offer improved functionality to the user. The Industrial, Scientific and Medical (ISM) band at 2.4 GHz is license free worldwide, and is therefore used to enable many Wireless Body Area Network (WBAN) applications. Additionally, all modern mobile phones are already equipped to communicate at 2.4 GHz by the use of the widespread Bluetooth® protocol.

Hearing Instruments (HIs) are a good example of such small body-worn devices that have become increasingly advanced in recent years. Modern top-line HIs are thus expected to be able to communicate wirelessly with mobile accessories, such as audio streamers and mobile phones. Furthermore, the binaurally fitted HIs are needed to communicate wirelessly with each other, ear-to-ear, in order to synchronize the amplification settings between the HIs. Further, it is possible to obtain audiological advantages, which, e.g. eases conversation in noisy areas. In order to conserve power, the accessory-link and the ear-to-ear link need to utilize the same radio and antenna. The challenge in using 2.4 GHz is that the head is lossy at these frequencies, with a skin depth $\delta_s \approx 21\,\text{mm}$. Therefore, the energy cannot propagate through the head. Instead the energy propagates around the head as creeping waves [1], [2].

In this presentation, the characteristics of the ear-to-ear on-body propagation will be surveyed. Additionally, some of the many examples of HI antennas found in the literature will be reviewed, e.g., [3]–[6], which are antennas that are suitable for use in small ear-worn devices.

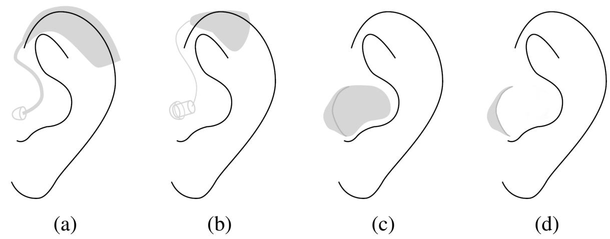

Fig. 1. The hearing instrument (HI) types in the use position for Behind-the-Ear (BTE) (a), Receiver-in-the-Ear (RIE) (b), In-the-Ear (ITE) (c), and the smaller versions of the ITE, the In-the-Canal (ITC) and Completely-in-the-Canal (CIC) (d) [1].

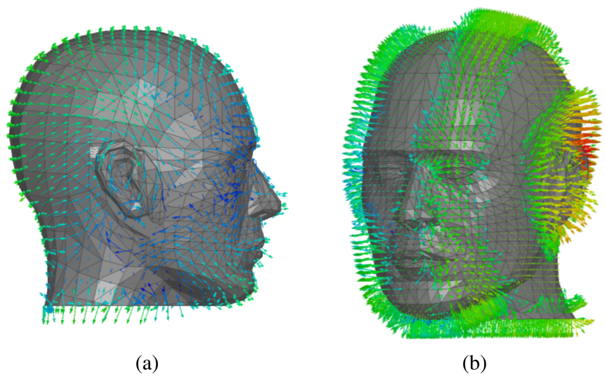

Fig. 2. Simulated Poynting vector (a) and electric field vectors (b) on the SAM head with ears [7]–[9].

II. Hearing-Instrument Types

The HIs can be classified in four main types, see Fig. 1. The Behind-The-Ear (BTE) and the Receiver-In-the-Ear (RIE) HIs sit behind the ear, as shown in Fig. 1a and Fig. 1b, respectively. The In-The-Ear (ITE) and In-The-Canal (ITC) types are custom–made to fit the individual ear canals, and are shown in Fig. 1c and Fig. 1d, respectively. Common to all four types is that they are generally made as small as possible, in an effort to conceal the devices.

III. Creeping waves

To improve hearing radio signals are transmitted from the antenna in the hearing instrument on one ear to the antenna in the hearing instrument on the other ear. Transmission of the signal through the head is not an option due to the very high losses at the ISM-band at 2.4 GHz. This is overcome by the

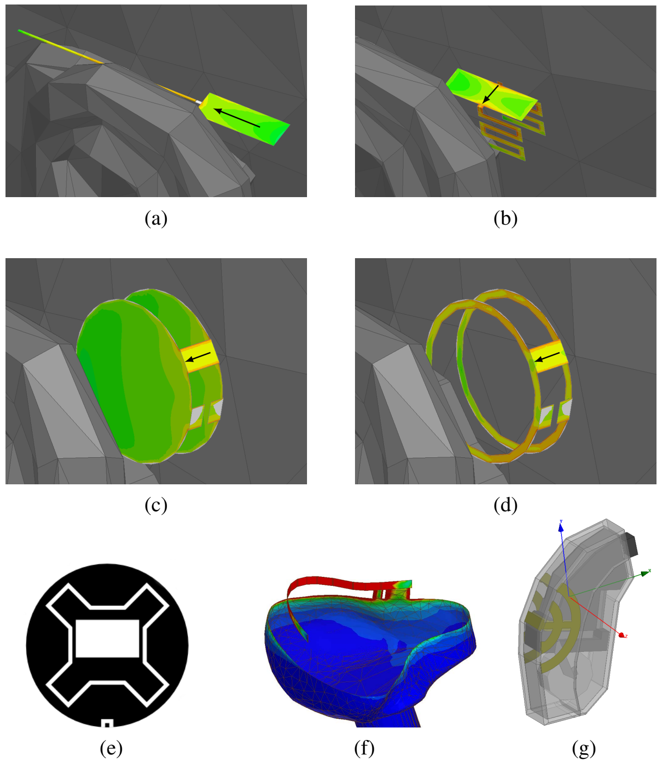

Fig. 3. Hearing-Instrument antenna types shown with simulated surface current distributions. A straight monopole antenna that rests on top of the ear (a), a meandered monopole antenna that is fed at the center of the side of the ground plane (b), antenna with two parallel circular plates (c) and rings (d) [1], [11], a meandered slot antenna (e) [12], a custom shell antenna (f) [13], and an electric coupled antenna [6].

use of creeping waves that propagates on the surface of the head. To do this the challenge is to construct antennas that effectively launches creeping waves, e.g., the electric field is perpendicular to the surface. Optimal antenna are developed for each type of hearing instrument. Typical measured propagation losses are in the range 50–80 dB depending on the type of hearing instrument. Simulations of the creeping waves at the surface of the head on a specific anthropomorphic mannequin (SAM) head of the electric field vectors and Poynting vector are shown in Fig. 2.

IV. Hearing-Instrument Antennas

To obtain a low path loss, i.e., high on-body path gain ($|S_{21}|$) the on-body antenna is oriented such that the electric field is perpendicular to the surface of the head. This will ensure an efficient launch of a creeping wave [1]. Further, the antenna should radiate along the surface of the body. Many hearing-instrument antennas have been presented in the literature, e.g., [6], [7], [10]–[13]. However, to be useful, e.g., in HIs, the antenna must be physically small in order to fit the devices—but not necessarily electrically small at 2.4 GHz. Typical measured fractional bandwidths are in the range 1–10%. Examples of hearing-instrument antennas for body-centric wireless communications are shown in Fig. 3.

V. Conclusion

The main types (BTE, RIE, ITE, and CIC) of hearing instruments have been introduced. The different hearing-instrument antenna types used for body-centric wireless communications at the 2.4 GHz ISM band are presented. The ear-to-ear propagation communication relies on creeping waves on the surface of the head.

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