

Progress in Body-Worn Antennas for On-Body Propagation

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Abstract—On-body propagation and on-body antennas for body-centric wireless communications are presented. The on-body communications rely on creeping waves launched and received by the antennas, respectively. Path gain and bandwidth at 2.4 GHz for different types of body-worn antennas for head-centric communications are presented. Further, an on-body channel model, to be used to find the optimal radiation pattern, is presented.

Index Terms—Wearable antennas; wireless body-area networks (WBAN); creeping waves; medical devices; IoT (Internet of Things) .

1. Introduction

Wearable antennas for on-body propagation and Internet-of-Things (IoT) have received much attention in the literature in recent years. Head models [1] and pinna model [2] have been developed to speed up the development of on-body antennas for head-centric communication in addition to a theoretical study of the electromagnetic fields at the surface of a human-body cylinder [3]. The effect of anatomical variation of the head on the ear-to-ear path gain has been studied in [4]. The morphological investigation showed that the waves creeps along different paths and constructive and destructive interference was observed, which can result in an increased package error rate *PER*. Diversity was studied in [5] and radiation pattern optimization was investigated in [1] as a way to reduce the *PER*. In this paper the recent progress in body-worn antennas for on-body propagation is summarized.

2. Antenna Types

Different on-body antenna types are shown in Fig. 1. Unbalanced antennas are shown in Fig. 1a–b and balanced in Fig. 1c–f. Behind-the-Ear (BTE) and In-the-Ear (ITE) hearing instruments (HI) are shown in Fig. 1h and Fig. 1i, respectively. In Table I the measured ear-to-ear on-body path gain, the fractional bandwidth, and polarization are given in addition to the type of HI (BTE or ITE) for the different on-body antennas.

3. Creeping waves

In Fig. 2 simulations on a specific anthropomorphic mannequin (SAM) head with ears of the electric field vectors (a) and the magnitude of Poynting vector (b) at the surface

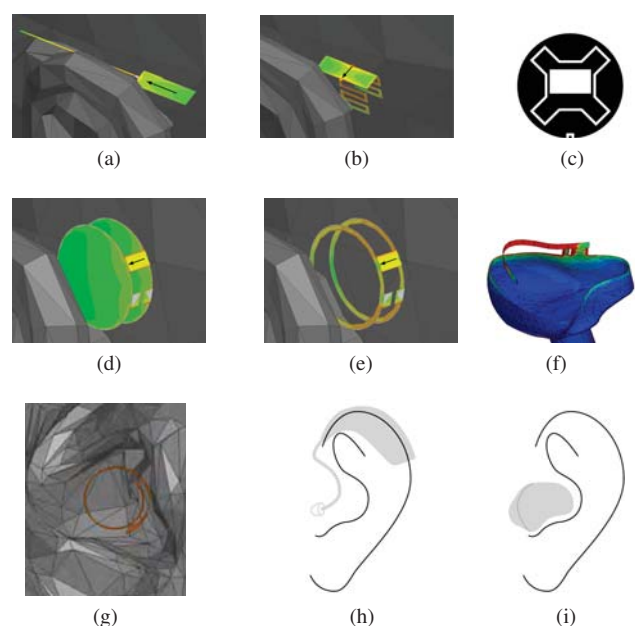


Fig. 1. On-body antenna types: a straight monopole antenna that rests on top of the ear (a) [6], a meandered monopole antenna that is fed at the center of the side of the ground plane (b) [6], and a meandered slot antenna (c) [7]; two antenna types with two parallel, circular plates (d) and one with two parallel rings (e), respectively [6]; a custom shell antenna (f) [8], and a spiral antenna (g) [9], [10]. The antennas in (a), (b), (d), (e), and (f) are shown with simulated surface current distributions. Behind-the-Ear (BTE) (h) and In-the-Ear (ITE) (i) hearing instrument (HI) types in the use position [6].

of the head are shown. It is seen that the electric field of the launched creeping wave is perpendicular to the surface of the head. From the Poynting vector plot it is seen that most of the field creeps behind the back of the head (green) and less (blue) in front of the eyes.

4. Path Gain and On-Body Antenne Gain

Ear-to-ear (E2E) path gain (PG) models are presented in [1] [17]. The on-body channel is modeled as a number of creeping waves along elliptical along the head as shown in Fig. 2c. The on-body radiation pattern is given by

$$G_{\text{on-body}}(\phi) = \int_0^{\pi} G_{\theta}(\theta, \phi) \sin(\theta) d\theta, \quad (1)$$

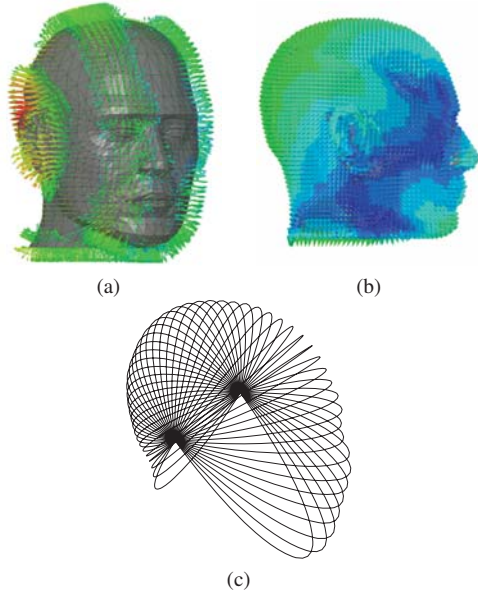


Fig. 2. Electric field vectors (a) and Poynting vector magnitude (b) that shows the interference pattern on a SAM head with ears. Head model (c) that consists of 50 elliptically-shaped paths [1], [11]–[13].

TABLE I
MEASURED EAR-TO-EAR ON-BODY PATH GAIN (PG), FRACTIONAL BANDWIDTH (BW), AND POLARIZATION AT 2.4 GHz FOR THE DIFFERENT ANTENNA TYPES SHOWN IN FIG. 1.

Type	PG (dB)	BW (%)	Polarization	Ref.
BTE	-50	9.8	normal	[14]
BTE	-59	1.1	normal	[13]
BTE	-73	8.5	tangential	[13]
BTE	-80	3.3	tangential	[9]
ITE	-63	6.1	normal	[8]
ITE	-73	2.9	normal	[10], [15]
ITE	-73	3.1	tangential	[7]
ITE	-75	2.9	normal	[16]

where $G_{\theta}(\theta, \phi) \sin(\theta)$ is the components of the far-field radiation pattern that are oriented perpendicular to the head surface. Since the electric field of the launched creeping wave is perpendicular only the θ -component has to be included.

5. Optimal Radiation Pattern

To synthesize the optimal radiation pattern a genetic algorithm is used with the on-body channel model. To obtain a robust antenna design, a Monte Carlo analysis can be added to investigate the influence of, e.g., different head shapes on the path gain [1]. Full-wave simulations as HFSS would be very time consuming, i.e., in this case hours versus seconds.

6. Conclusion

The progress in body-worn antennas for on-body head-centric propagation has been reviewed. Typical values

for the path gain (PG) is from -80 dB to -50 dB and the fractional bandwidth is from one to ten percent, respectively at 2.4 GHz.

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