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MORPHOLOGICAL INVESTIGATION OF THE DIFFERENCES ON THE EAR-TO-EAR PATH GAIN AND THE PACKET LOSS AT 2.45 GHZ

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Abstract

The effect of the anatomical variation of the head on the ear-to-ear communication at 2.45 GHz has been investigated. Several anatomical characteristics of the head, such as the dimensions and the position of the ears, have been recorded for a group of 25 test persons. Active Packet Error Rate (PER) measurements have been made by the use of digital Hearing Instruments (HI) as small wireless platforms in both indoor and outdoor environments. Two fundamentally different antenna configurations are compared. It is found that there is an effect of the distances over-the-top, around-the-front and around-the-back on the PER, due to constructive and destructive interference between surface waves that propagate along the different paths. The effect is different for the two different antenna types.

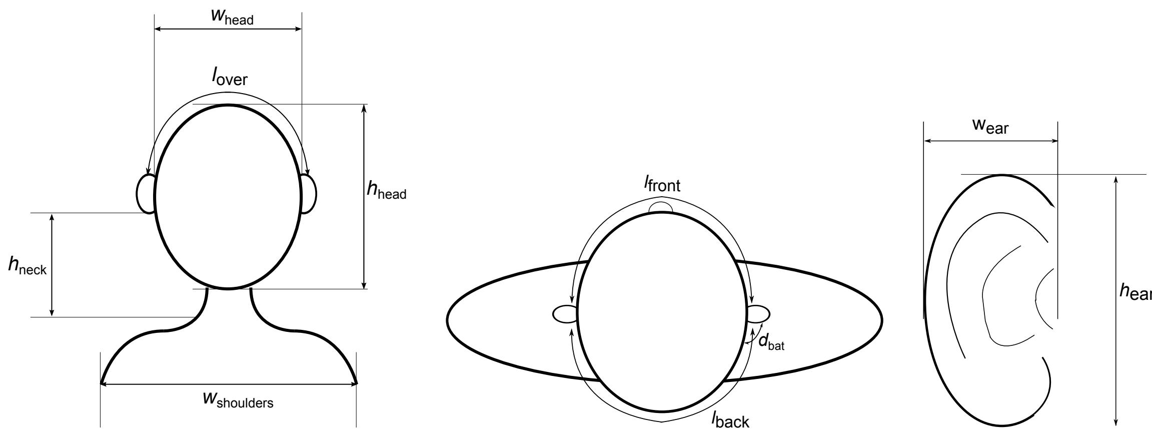
Keywords: Ear-to-ear, Ear size, Head size, Packet Error Rate (PER), WBAN.

1 Introduction

The on-body path gain ($|S_{21}|$) at 2.45 GHz has recently received much attention in the literature, e.g. [1–10]. Specifically, the ear-to-ear path gain between small digital Hearing Instruments (HI) worn behind the ears has been investigated in [6–10]. The HIs offer a challenging environment for the antennas. Since the HIs are worn in close proximity to the body, the resonance frequency of the antenna can shift due to variation of the dieelectric properties of the body. Variation of the distance between the antenna and the body may cause this effect as well [4–6]. Thus, there may be person-specific variations in the ear-to-ear on-body path gain due to varying degrees of impedance mismatch and antenna efficiency. Additionally, it has been suggested that the propagation of electromagnetic waves around the head occurs along different paths, which can interfere constructively or destructively. Thus the, ear-to-ear path gain can vary by up to 10 dB depending on the specific head dimensions [7, 8]. The previous work is based on simulations and phantom head measurements. In order to improve the design of antennas for HI applications, it is necessary to know which anatomical parameters that impact the ear-to-ear communication. Therefore there is a need for a thorough investigation of the ear-to-ear transmission channel that is based on measurements on a group of actual persons, such that person-specific variations may be captured and their causes identified. The purpose of this work is to study the influence of the anatomy of the head, such as the size and the shape, on the ear-to-ear transmission channel. The investigations are based on a group of 25 persons in both an indoor and an outdoor environment. Two different antenna types are compared, one that extends in front of the ear, and one that is confined behind the pinna of the ear. The measurements are made by the use of digital HIs as small wireless platforms and the results are presented in terms of Packet Error Rate (PER). An attempt to discover a correlation between the anatomical parameters of the head and the PER is made.

2 Experimental setup

Two fundamentally different antenna configurations are used in the investigation. Configuration C-1 comprises a $\lambda_0/4$ monopole antenna that extends over the top of the ear, similar to Configuration C-1 in [9], where $\lambda_0 \approx 122.4$ mm is the free space wavelength at 2.45 GHz. Configuration C-2 consists of a meandered $\lambda_0/4$ monopole antenna which is fed at one side of the HI ground plane and has an identical parasitic antenna



(a) (b) (c)

Figure 1: Definition of the anatomical measurements seen in-front (a) and above (b) the head and the ear measurements (c).

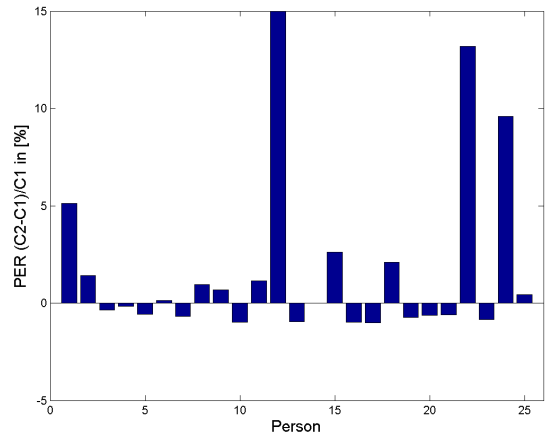
Table 2: The measured anatomical parameters of the 25 test persons. The distances are measured in millimeters (mm). Statistics are presented at the bottom of the table.

Person	Ear			Head						Shoulders	Neck
	w_{ear}	h_{ear}	d_{bat}	w_{head}	h_{head}	ℓ_{back}	ℓ_{front}	ℓ_{over}	$\ell_{perimeter}$	$w_{shoulder}$	h_{neck}
P-1	68	33	14	235	135	200	270	300	590	450	120
P-2	56	33	13	230	130	225	275	310	590	430	100
P-3	60	35	12	215	130	220	270	305	566	400	140
P-4	66	30	15	240	130	205	270	300	580	360	130
P-5	62	33	20	235	150	220	275	320	570	430	120
P-6	65	40	22	230	130	200	255	290	565	450	110
P-7	70	35	15	200	160	230	275	300	570	490	140
P-8	65	35	15	210	145	230	260	280	550	440	110
P-9	58	30	12	210	132	275	245	320	575	370	120
P-10	67	37	14	235	140	240	270	310	580	420	110
P-11	70	38	20	215	150	220	290	280	585	430	150
P-12	65	35	13	225	145	240	280	330	600	470	90
P-13	65	35	15	210	145	220	270	290	550	470	110
P-14	60	35	10	240	150	235	270	320	585	430	90
P-15	66	30	12	215	140	200	270	290	540	390	120
P-16	66	37	10	225	135	190	255	275	560	420	140
P-17	72	38	12	205	140	205	280	300	570	460	130
P-18	70	40	15	235	150	210	290	320	585	390	90
P-19	60	35	10	220	155	230	260	300	550	430	120
P-20	60	40	12	235	135	178	255	290	565	370	130
P-21	64	38	13	208	140	210	265	305	575	440	130
P-22	50	33	22	215	145	230	260	320	580	430	130
P-23	70	39	8	205	140	205	300	250	600	440	110
P-24	65	36	16	200	140	195	270	300	550	370	110
P-25	55	32	12	220	145	210	260	310	570	445	100
Min	50	30	8	200	130	178	245	540	250	360	90
1. quartile	60	33	12	210	135	205	260	565	290	420	110
Median	65	35	13	220	140	220	270	570	300	430	120
3. quartile	67	38	15	235	145	230	275	585	310	450	130
Max	72	40	22	240	160	275	300	600	330	590	150
Mean	64	35	14	221	141	217	270	572	301	433	118
Std. dev.	5	3	4	13	8	20	12	16	18	47	17

Table 1: Definition of the identified anatomical parameters. The parameters are indicated in Figure 1.

Parameter	Definition
w_{ear}	Width of the ear
h_{ear}	Height of the ear
d_{bat}	Distance between the pinna and the head
w_{head}	Width of the head
h_{head}	Height of the head
ℓ_{back}	Distance around-the-back of the head
ℓ_{front}	Distance around-the-front of the head
ℓ_{over}	Distance over-the-top of the head
$\ell_{\text{perimeter}}$	Perimeter around the head
w_{shoulder}	Width of the shoulders
h_{neck}	Height of the neck

element on the opposite side, similar to Configuration C-2 in [10]. The two antenna configurations are expected to have different on-body radiation patterns. Therefore the results may depend on different anatomical parameters as the electromagnetic waves that travel along the surface of the head may take different paths in the two configurations. A host of anatomical parameters of the head that may vary from person to person have been identified. The anatomical parameters are indicated in Figure 1 and described in Table 1, and they are listed for each of the 25 persons in Table 2. The ear-to-ear PER measurements are made in both an indoor and an outdoor environment. In the indoor environment the person was sitting at a table, and in the outdoor environment the person was walking along a predefined route.



(a)

Figure 2: The PER relationship between C-1 and C-2 calculated by $(\mathrm{C2}-\mathrm{C1})/\mathrm{C1}$**.**

3 Results and Discussion

The PER relationship between the two configurations for each of the 25 persons is presented in the barplot in Figure 2, for the outdoor enviroment. Thus, the measurement should be unaffected by reflections and interfering radio signals in the ISM-band. The relationship between C-1 and C-2 are calculated by $(\mathrm{C2}-\mathrm{C1})/\mathrm{C1}$. Where a smiliar relationship between the two configurations will be found when the result goes to zero. It is clear that the PER is highly dependent on the person and also the antenna configuration. The sample correlation coefficient between each of the measured anatomical parameters and the PER has been listed for the two antenna configurations and both environments in Table 3. It is observed that there is no clear linear correlation between any of the anatomical parameters and the PER. The highest correlation is found for the distance along the perimeter of the head, $\ell_{\text{perimeter}}$, and for the width of the head, w_{head}, however these two parameters are most likely dependent on each other. Some correlation is also observed with the height of the neck, h_{neck}, but only for C-2 where the antenna is located behind the pinna of the ear. A combination of several anatomical parameters may be the key to understanding the person-specific PER as it was suggested in [7, 8]. In the previous work the simulations and the phantom head measurements indicated that the ear-to-ear transmission may be dominated by two or more paths around the head. Minima in path gain occur when the dominant path lengths differ by odd multiples of $\lambda_0/2$, while maxima occur when the dominant path lengths differ by even multiples of $\lambda_0/2$. The colored plots in Figure 3 show the PER as a function of the distance over-the-top, ℓ_{over}, on the first axis, and the distance around-the-back, ℓ_{back}, on the second axis. Both distances are normalized to λ_0. The black crosses indicate the combination of the two distances for each of the 25 persons, where the PER has been measured. The PER has been interpolated in between the measured values in order to form the plots. The color scale ranges from blue, low PER to red, high PER. From Figure 3a and 3b it is seen that there is no unambiguous connection between the PER and the distances around-the-back and over-the-top for C-1. However, an interesting trend can be observed for C-2 in Figure 3c and 3d. It appears that the PER is low when the distances around-the-back and over-the-top differ by approximately $\lambda_0/2$. This is exactly opposite of the predictions in [7, 8] and it requires further investigation. A possible explanation may be that since the phase centre of the antennas is not known, the distances around-the-back and over-the-top may systematically be measured from the wrong position on the head. If for example the distance over-the-top is underestimated by $\lambda_0/8 \approx 15\,\text{mm}$ on both sides of the head, and the distance around-the-back is overestimated by the same amount the picture is changed completely to fit [7, 8]. Thus, if the position of the phase

Table 3: The correlation factor of the anatomical data

Subject	Ear			Head						Shoulders	Neck
	w_{ear}	h_{ear}	d_{bat}	w_{head}	h_{head}	ℓ_{back}	ℓ_{front}	ℓ_{over}	$\ell_{\text{perimeter}}$	$w_{\text{shoulders}}$	h_{neck}
C-1 indoor	–0.01	0.08	–0.01	0.31	0.14	0.04	0.13	–0.14	0.32	0.05	–0.15
C-1 outdoor	–0.06	0.21	0.01	0.42	–0.22	-0.10	–0.07	–0.28	0.10	–0.16	0.09
C-2 indoor	–0.34	–0.26	–0.04	0.27	–0.12	0.25	0.20	–0.28	0.55	–0.27	–0.38
C-2 outdoor	–0.01	0.03	0.17	0.38	–0.11	0.21	0.12	–0.10	0.42	0.16	–0.52

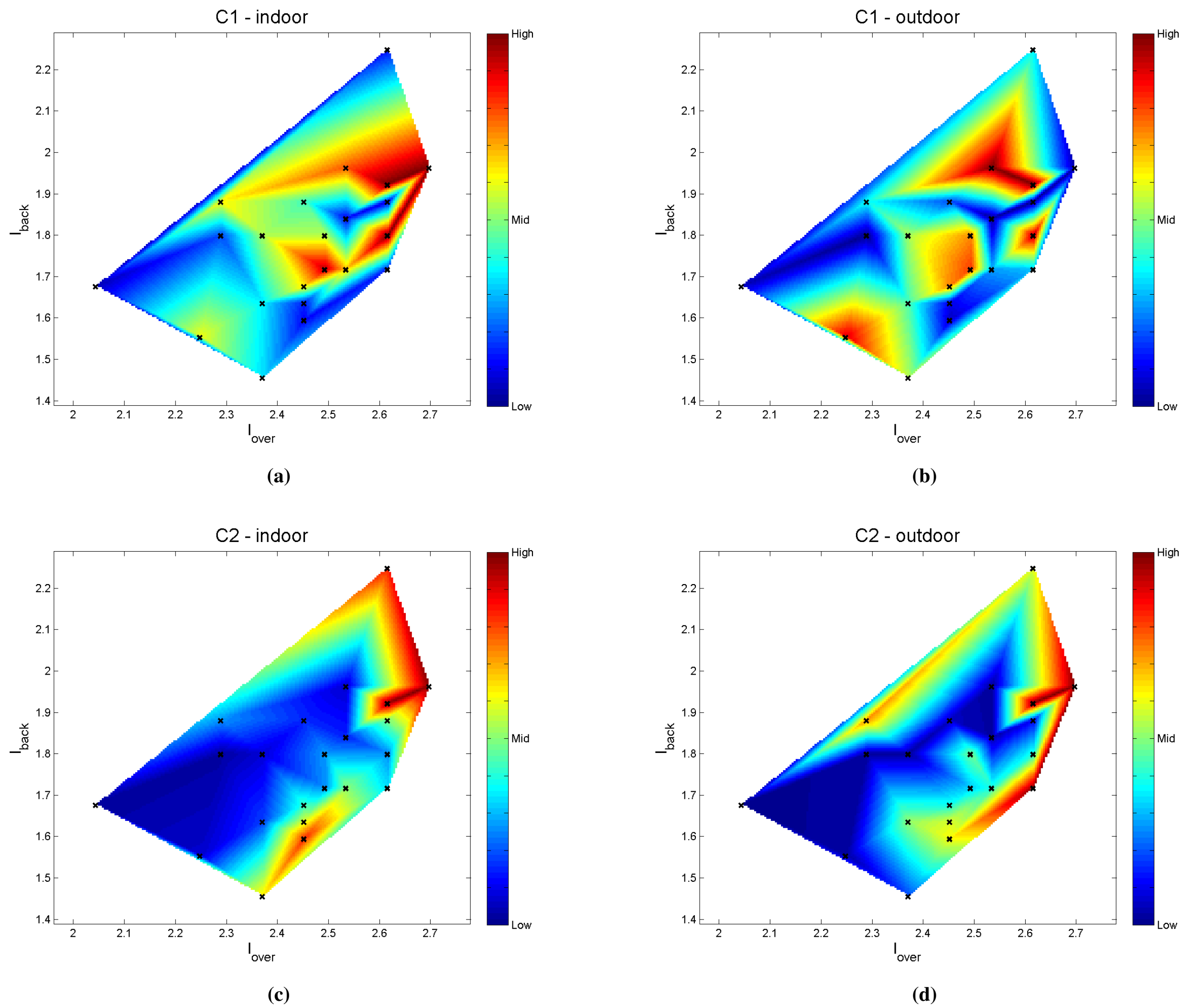


Figure 3: The PER as a function of the distance over-the-top and the distance around-the-back. The plots show configuration C-1 indoor (a) and outdoor (b) as well as configuration C-2 indoor (c) and outdoor (d).

center of the antenna had been estimated at a position around $\sqrt{2} \cdot 15\,\text{mm} \approx 20\,\text{mm}$ away from the one that was systematically used the results would have been completely different. For now it can be concluded that for configuration C-2 the PER is low when the distances around-the-back and over-the-top differ by some amount. The PER as a function of the distance over-the-top and the distance around-the-front is plotted in Figure 4. Is is seen that for C-1 in Figure 4a and 4b there is again no clear dependence of the PER on the two parameters. However there is an identifiable cluster of people

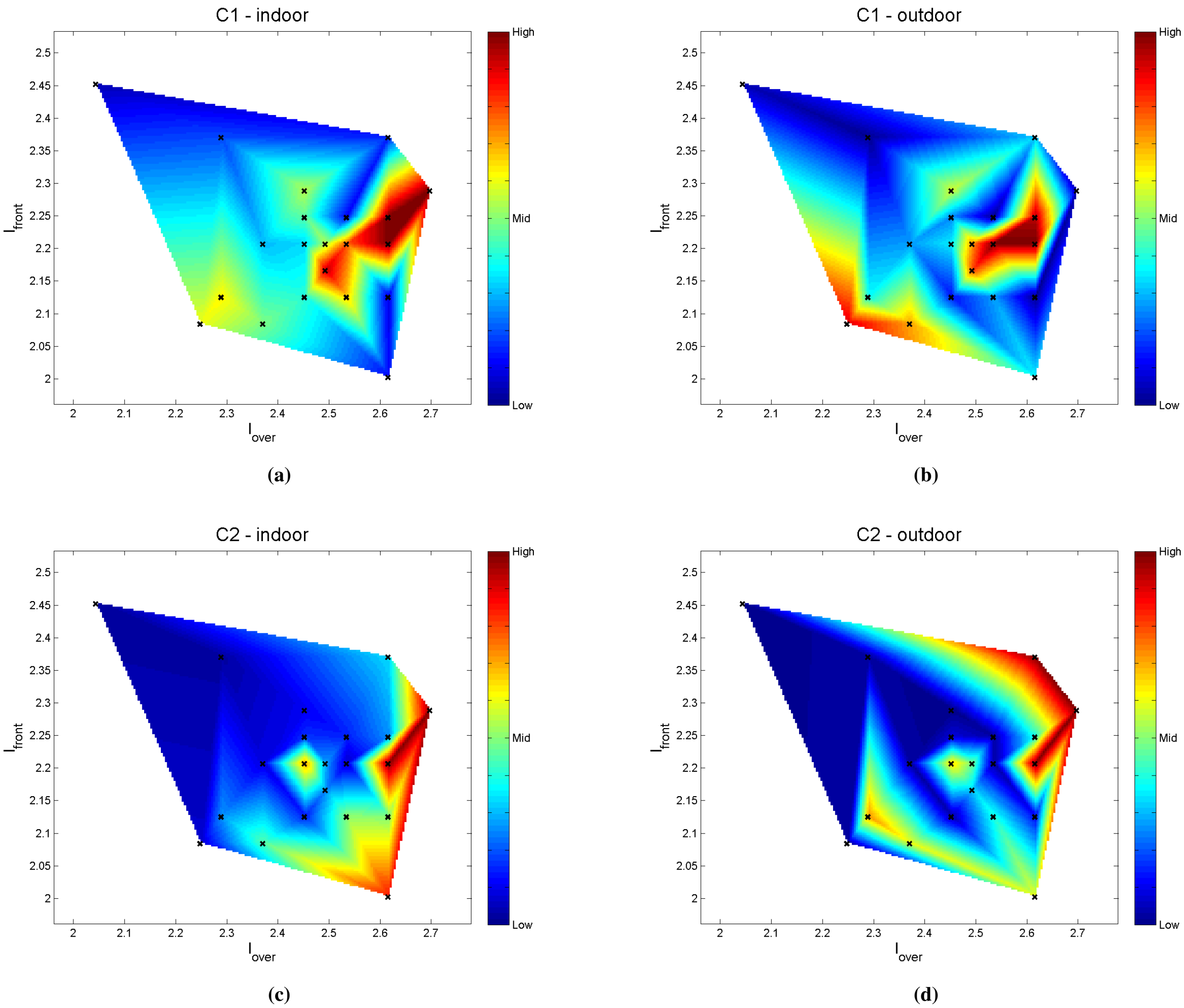


Figure 4: The PER as a function of the distance over-the-top and the distance around-the-front. The plots show configuration C-1 indoor (a) and outdoor (b) as well as configuration C-2 indoor (c) and outdoor (d).

on the right hand side of the plots with similar anatomical parameters that experience a high PER. For antenna configuration C-2, the PER is largely independent on the distance around-the-front as seen in Figure 4c and 4d. It is therefore concluded that for C-2 the electromagnetic waves primarily travel around-the-back and over-the-top of the head. In contrast the wave propagation may be more complicated for configuration C-1, and the dependence of the anatomical parameters can not be understood completely based on the presented results.

4 Conclusion

The ear-to-ear PER measurement results were presented for two different antenna configurations in both indoor and outdoor environments. Eleven anatomical parameters of the head were identified and determined for a group of 25 persons. The initial results showed no strong correlation between any of the individual anatomical parameters and the measured PER. Further studies revealed that for the antenna configuration that is confined behind the pinna of the ear, there is a tendency that the PER is low when the distances around-the-back and over-the-top differ by the same length. This indicates that constructive interference occurs between waves that travel around-the back and over-the-top of the head. However, the dependence of the PER on the anatomical parameters seems more complicated for the antenna configuration where the antenna extends in front of the ear. This antenna configuration can also transmit around-the-front of the head, thus the interference pattern on the opposite side of the head becomes more complex.

References

[1] P. S. Hall, Y. Hao, Y. Nechayev, A. Alomainy, C. C. Constantinou, C. Parini, M. R. Kamarudin, T. Z. Salim, D. T. M. Heel, R. Dubrovka, A. S. Owadall, W. Song, A. Serra, P. Nepa, M. Gaio, and M. Bozzetti, "Antennas and Propagation for On-Body Communication Systems," *IEEE Antennas and Propagation Magazine*, vol. 49, no. 3, pp. 41–57, 2007.

[2] K.-L. Wong and C.-I. Lin, "Characteristics of a 2.4-GHz Compact Shorted Patch Antenna in Close Proximity to a Lossy Medium," *Microwave and Optical Technology Letters*, pp. 480–483, Jun. 2005.

[3] T. Alves, B. Poussot, and J.-M. Laheurte, "Analytical Propagation Modeling of BAN Channels Based on the Creeping-Wave Theory," *IEEE Transactions on Antennas and Propagation*, pp. 1269–1274, Apr. 2011.

[4] A. Alomainy, Y. Hao, and D. M. Davenport, "Parametric Study of Wearable Antennas with Varying Distances from the Body and Different On-Body Positions," *IET Seminar on Antennas and Propagation for Body-Centric Wireless Communications*, pp. 84–89, 2007.

[5] R. Chandra and A. J. Johansson, "An Elliptical Analytic Link Loss Model for Wireless Propagation Around the Human Torso," *6th European Conference on Antennas and Propagation (EuCAP)*, pp. 3121–3124, 2012.

[6] ——, "Influence on the Ear-to-Ear Link Loss from Heterogeneous Head Phantom Variations," *5th European Conference on Antennas and Propagation (EUCAP)*, pp. 1612–1615, 2011.

[7] S. H. Kvist, J. Thaysen, and K. B. Jakobsen, "The Effect of the Head Size on the Ear-to-Ear Radio-Propagation Channel for Body-Centric Wireless Networks," *Loughborough Antennas and Propagation Conference*, pp. 345–348, 2010.

[8] ——, "Investigation of the Ear-To-Ear Radio Propagation Channel," *5th European Conference on Antennas and Propagation (EUCAP)*, pp. 3640–3644, 2011.

[9] ——, "Polarization of Unbalanced Antennas for Ear-to-Ear On-Body Communications at 2.45 GHz." *Loughborough Antennas and Propagation Conference*, 2011.

[10] ——, "Improvement of the Ear-to-Ear Path Gain At 2 . 45 GHz Using Parasitic Antenna Element," *6th European Conference on Antennas and Propagation (EUCAP)*, vol. 2, pp. 944–947, 2011.