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On-body Antennas and Propagation: Recent Development

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1. Introduction

There have been growing interests in body-centric wireless communications [1] due to their abundance applications, for example, in personal healthcare, smart home, personal entertainment and identification systems, space exploration and military etc. A generic concept of body-centric wireless communications may include scenarios which RF sensor nodes are placed in/on body. Antennas and propagation is the central part of body-centric wireless systems and plays an important role in the implementation of miniaturised, spectrum and power efficient RF sensor nodes and the integrity of in/on/off body communications. Of the aforementioned aspects, on-body antennas and propagation has its distinct properties due to the presence of human body. It has been found [2] that wearable antennas can suffer from reduced efficiency, radiation pattern fragmentation and variations in impedance at the feed. For on-body radio channels, main features such as shadowing effects, dynamic variation in path loss and time delay components make it different to characterise the channel behaviour. Previous studies [3, 4] demonstrated preliminary measurement results based on classic antennas such as microstrip patch, monopole, wideband bowtie etc. It is noted that the on-body radio propagation is predominantly based on space waves, creeping waves and a combination of both. In this paper, we shall present recent development in on-body antennas and propagation research, specifically, the analysis of antenna diversity for on-body communication systems; the investigation of interference between two body-centric wireless networks at 2.45GHz and 5.8GHz; the design of small antennas within ISM frequency bands for wireless wearable sensors and their on-body performance evaluation. Numerical and system modelling are essential for understanding and optimising on-body communications. Further to [4, 5], a dynamic on-body channel modelling tool has been developed to enable the description of dynamic events and ultimately characterised the on-body channel statistically.

2. Wearable Antennas and On-body Radio Propagation

For on-body environments, antennas are required to be conformal to the body and immune from frequency and polarisation detuning. Hence it is vital to understand how best to specify an antenna radiation pattern, when part of it is space and part in the lossy body; how to specify coupling into the propagation mode which may be a surface wave or free space wave or a combination of both. Such work would be based on efficient numerical simulation plus verification by measurements on real bodies or phantoms. So far, it is still unknown how close to the surface the antenna can be mounted. If it is too close, it will have low efficiency due to body loss but good coupling to the surface wave and vice versa.

We have conducted a parametric study of six different antennas for on-body applications in order to evaluate the effect of body presence on general antenna parameters, including impedance matching, radiation patterns, gain and efficiency. The unique on-body propagation channel between various antenna pairs is also investigated as it is essential for the design of wearable wireless devices. The antennas include a half-wave dipole and quarter-wave monopole aligned vertically and parallel to a standing human, implemented as a printed circuit board (PCB) trace upon FR4 substrate material; a printed circular loop implemented; an inverted L-shape antenna; a “wiggle” antenna from Cypress Semiconductor and a L shape antenna with parasitic elements [6]. All antennas are printed on an

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Antenna	Size (mm^2)	Gain (dB)	Radiation Efficiency (%)
	2.4/2.44/2.48 GHz		
Printed dipole	10x55	1.8/1.9/2.0	95/97/99
Printed monopole	80x70	3.3/3.2/3.3	100/99/100
Circular loop	60x60	2.9/2.9/3.0	97/98/99
Inverted L	50x45	3.3/3.2/3.0	100/100/99
Parasitic L-shaped	30x20	1.5/1.6/1.9	81/83/87
Wiggle antenna	25.6x23	-4.8/-5.7/-6.7	18/17/14

Table 1. Antenna types used in study and their dimensions and free space characteristics

FR4 board with ε_r = 4.6, conductivity σ = 0.002 S/m and thickness of 1.6 mm (except for the wiggle antenna, thickness of 0.7 mm is applied). All antennas demonstrate excellent free space performance across the ISM band with omni-directional patterns and excellent gain and efficiency. Table I lists the applied antenna types and their main parameters at 2.4, 2.44 and 2.48 GHz when operating in free space. As expected, the conventional antennas demonstrate excellent performance. However, when size reduction is applied (as the case for parasitic L and wiggle antennas), antenna bandwidth (impedance bandwidth and hence radiation bandwidth) and radiation efficiency decrease due to the coupling between elements and the introduction of vias. This causes the radiated power to decrease rapidly therefore affecting efficiency due to additional loading impedance.

Coupling between on-body antenna pair is investigated by examining the communication link loss and the electric field distribution along the body surface in free space environment. Table II presents the variation on path loss for various antenna types, approximate free space and on-body path losses based on the calculation using Friis' formula. The path loss is dependent on the on-body link as well as the antenna types. The worst performance is noticed for the wiggle antenna pair as predicted due to its inefficiency.

Left Waist (Tx)	Right Chest (Rx1)	Right Thigh (Rx2)
Distance	34 cm	38 cm
Friis' Loss	30.85 dB	31.6 dB
On-Body Approximation	48.63 dB	49.4 dB
Dipole Antenna	51 dB	60.6 dB
Monopole Antenna	51 dB	54.8 dB
Circular Loop Antenna	55.75 dB	55.51 dB
Inverted L Antenna	55.8 dB	55.83 dB
Parasitic L Antenna	51.38 dB	54.12 dB
Wiggle Antenna	73.4 dB	77.5 dB

Table 2. Path Loss for various on-body antenna pairs

3. Antenna Design for Wireless On-body Sensors

Wearable antennas are likely integrated with RF transceivers in the design of wireless sensors. It is often required that a maximum achievable coverage range is to be delivered by the sensor with respect to the transceiver sensitivity level. The sensor antenna design is restricted by many factors including the sensor size, radio chip placement, and lumped component locations *etc*. Figure 1 shows photographs of the sensor transceiver layer and the prototype module fabricated at the Group of Healthcare Devices and Instrumentation, Philips Research. The current antenna deployed in the sensor design is a printed quarter wavelength monopole, etched on the edge of the circular PCB board. Hence the antenna is designed with the printed wire wrapping the transceiver chip and other components. The antenna is derived from a circumference monopole or an inverted L antenna [7]. The sensor antenna performance is sensitive to lumped components, pins and copper routings presence in the package. The surrounding and adjacent components are modelled as a perfect conductor block in proximity of antenna. The PCB board includes the ground plane and supply voltage copper sheets.

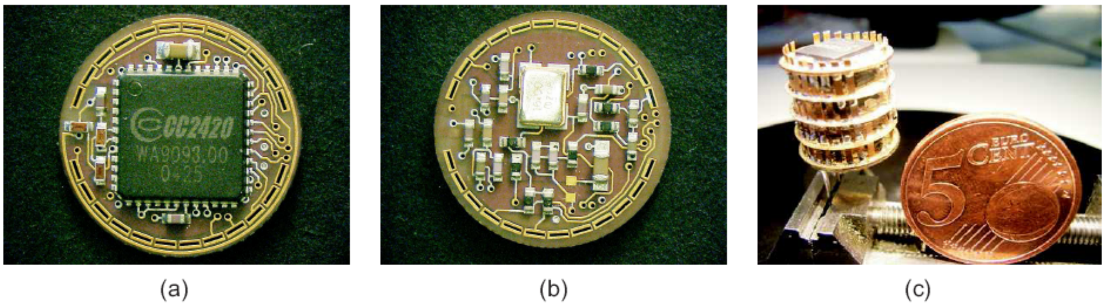

Figure 1. Photographs of (a) top view of the transceiver layer, (b) bottom view of the transceiver layer and (c) the manufactured prototype sensor

The antenna design deployed in the proposed sensor is numerically analysed using the High Frequency Structure Simulator (HFSS), Ansoft^{TM}. The antenna is modeled on FR4 substrate (ε_r=4.6 and thickness of 0.3mm). The printed antenna thickness is 35 μm and the width of the line is 150 μm. The ground and supply voltage layers added have a diameter of 5.5mm, thickness of 17.5 μm each and separation between the layers of 80 μm. The actual antenna length is 31.5mm (approximately quarter wavelength of the required frequency, 2.4GHz). The complex impedance at the RF transceiver differential output is 115+j180Ω, therefore a matching circuit is applied in order to match the output to the single-ended monopole (matching to 50Ω) [8]. Figure 2 presents the return loss of the sensor antenna when only one layer is modelled in comparison with the full sensor modelling. The one layer model includes the printed antenna, the transceiver chip and PCB board. The figure illustrates the significance of considering full structure modelling in characterising small antenna integrated with wireless sensors. The antenna may be detuned due to an increase in its electrical length caused by surrounding connectors. The calculated antenna gain is -1.2 dB with radiation efficiency of 48%. The antenna gain can be further improved to 1.6dB with efficiency of 77% by impedance matching and antenna geometrical optimization in the sensor. This illustrates the potential extended coverage area served by the sensor with simple and reliable performance enhancement techniques.

4. Antenna Diversity for On-body Communication Systems

Recent new implementations apply to more complicated activities which the body movement is involved in and they require a larger quantity of data to be transferred with higher speed. Military and sport equipment for communications between wearable instruments and sensors give an example of this [9]. The need for higher performance systems also suggests the use of multiple antenna systems in an on-body environment. Diversity is a well known technique used to reduce the fading effect due to a multi-path propagation channel, by using a multiple antenna system at the receiver. Two or more uncorrelated signals are received by the separate antennas and combined using a number of different techniques. It process results in increased signal to noise ratio (SNR) and an increase in the signal reliability, that is, the probability that the signal is greater

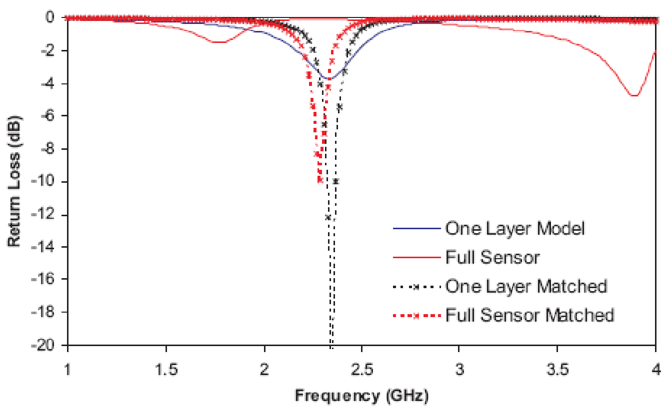

Figure 2. Comparison of sensor antenna return loss for one layer and fullsensor models. Comparison between original antenna matching and modified matching circuits.

than a certain threshold. At present, diversity is widely applied in receiving at base stations for mobile cellular systems and recent studies have been conducted on portable devices. In both previous applications, the base station antenna system, whether or not in a diversity configuration, is always fixed and the mobile unit moves in the propagation environment. In this case, the multi-path effect is mostly determined by the environment that closely surrounds the receiving terminal. On the contrary, in an on-body propagation system, the performance is mostly determined by the body activity, as both the transmitting and the receiving systems are placed on the same moving environment.

In this paper a preliminary study on the feasibility of a diversity scheme in an on-body environment has been carried out. Considerations on the systems and its applications have been discussed and commented. Measurements have been conducted in an anechoic chamber and a monopole antenna has been used as a transmitter and two monopoles on a common ground plane as a receiver. Collected samples have been used to calculate the diversity gain, for the most relevant combination techniques and for several positions of the receiving antennas on the body. Results in Table 3 show improvement in the signal reliability that prove the applicability of a diversity scheme to on-body communication systems.

Diversity Gain	RX placement Ankle	RX placement right-head	RX placement right chest	RX placement Centre back
SC	2.57	4.61	2.17	5.86
EGC	3.69	5.53	3.16	6.65
MRC	4.28	6	3.89	7.12

Table 3 Diversity Gain for some placements of the receiving antennas for standing postures (Selection Combining (SC). Equal Gain Combining (EGC), Maximum Ratio Combining (MRC))

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References

[1] Peter S. Hall and Yang Hao, “Antennas and Propagation for Body-Centric Wireless Communications”, ISBN 1-58053-493-7, 314 pages. Copyright 2006, Artech House Publisher.
[2] Alomainy, A.; Hao, Y.; Owadally, A.; Parini, C. G.; Nechayev, Y.; Constantinou, C. C.; Hall, P. S.; “Statistical Analysis and Performance Evaluation for On-Body Radio Propagation With Microstrip Patch Antennas”, IEEE Transactions on Antennas and Propagation, Vol. 55, No. 1, Jan. 2007 Page(s):245 – 248.
[3] P. S. Hall, Y. Hao, Y. I. Nechayev, A. Alomainy, C. C. Constantinou, C. G. Parini, M. R. Kamarudin, T. Z. Salim, D. T. M. Hee, R. Dubrovka, A. S. Owadally, and W. Song, "Antennas and propagation for on-body communication systems," to appear on IEEE Antennas and Propagation Magazine, April 2007.
[4] Yan Zhao, Yang Hao, Akram Alomainy, and Clive Parini, ‘UWB On-Body Radio Channel Modelling Using Ray Theory and Sub-band FDTD Method’, Microwave Theory and Techniques, IEEE Transactions on, Volume 54, Issue 4, Part 2, April 2006 Page(s):1827 - 1835
[5] Alomainy, Y. Hao, X. Hu, C. G. Parini and P. S. Hall, “UWB On-Body Radio Propagation and System Modelling for Wireless Body-Centric Networks”, Communications, IEE Proceedings-, Volume 153, Issue 1, 2 Feb. 2006 Page(s):107 - 114 .
[6] Kam Man Shum, Chi Hou Chan and Kwai Man Luk, “Design of Small Antennas for Joypad Applications”, 2006 IEEE International Workshop on Antenna Technology, NY, March 6-8, 2006.
[7] Jen-Yea Jan, Liang-Chih Tseng, Wen-Shyang Chen, Yuan-Tung Cheng, ”Printed monopole antennas stacked with a shorted parasitic wire for Bluetooth and WLAN applications”, IEEE 2004, Antennas and Propagation Society International Symposium, Vol. 3, June 2004 pp: 2607 - 2610.
[8] Chipcon CC2420 transceiver chip, 2.4 GHz IEEE 802.15.4/ZigBee-ready RF Transceiver, URL: http://www.chipcon.com
[9] http://www.apple.com/ipod/nike