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ANTENNAS AND PROPAGATION FOR BODY CENTRIC COMMUNICATIONS

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ABSTRACT
Body centric wireless communication is now accepted as an important part of 4th generation (and beyond) mobile communications systems, taking the form of human to human networking incorporating wearable sensors and communications. There are also a number of body centric communication systems for specialized occupations, such as paramedics and fire-fighters, military personnel and medical sensing and support.

To support these developments there is considerable ongoing research into antennas and propagation for body centric communications systems, and this paper will summarise some of it, including the characterisation of the channel on the body, the optimisation of antennas for these channels, and communications to medical implants where advanced antenna design and characterisation and modelling of the internal body channel are important research needs. In all of these areas both measurement and simulation pose very different and challenging issues to be faced by the researcher.

1 INTRODUCTION

Body centric wireless communication is now accepted as an important part of 4th generation (and beyond) mobile communications systems and will be part of the forthcoming convergence and personalization across the various domains, which include personal area networks, (PANs), and body area networks, (BANs), as noted in a forthcoming book, [1]. Advancements in the miniaturisation of wearable hardware, embedded software, digital signal processing, and biomedical engineering have made possible human to human networking incorporating wearable sensors and communications. This can be seen as a continuation of a trend spearheaded by the mobile phone, which, over the last few decades has become smaller and more convenient for personalized operation. Alongside this trend, there have been a number of body centric communication systems for specialized occupations such as paramedics and fire-fighters, as well as military personnel. Use for medical sensing and support, with either skin mounted sensors or implants, is also attracting much attention.

A parallel research activity is that of wearable computers, where the emphasis is on high levels of computational power, coupled with sensors and interface equipment. Currently these are bulky and have wired connections. The use of wireless connections in these systems is desirable although there is also a trend to the development of wired garments, and the fabric antennas noted below are part of this.

Body centric communications takes its place firmly within the sphere of personal area networks and body area networks (PANs and BANs). The content of a PAN or BAN contains a range of communications requirements. These can be classified as

- communications from off-body to an on-body device or system – ***off-body***
- communications within on-body networks and wearable systems – ***on-body***
- communications to medical implants and sensor networks – ***in-body***

All of the antenna and propagation studies for personal mobile communications come within the fist class. What is now of great interest is the second and third. Of course, in an integrated system, all may communicate with each other and the boundaries will become blurred. Thus, whilst this is not a perfect subdivision, it does serve to highlight some of the different challenges for antennas and propagation in the body centric system.

2 ON BODY SYSTEMS

2.1 Radiowave Propagation

At low frequencies, electromagnetic energy has a significant penetration depth, and the body can be used to support communications channels, [2-4]. For example at 10MHz the penetration depth is about 200mm for muscle and over 1 m for fat. At 2.45GHz the depths are 25 and 120mm respectively. The range of communication is in practice constrained to 'touch' range and hence limits its usefulness. PAN systems, in which user touch or handshake, is used for low data rate communication and has been demonstrated, [4], at 10MHz. At higher frequencies, propagation has been characterised at ISM and other bands, for example, 400, 900 and 2450MHz, [5], to produce simple analytical models for stationary bodies. The measurements were taken with dipoles oriented vertically to the body surface, and were taken over an angle of 180º around the body. The propagation mode is assumed to be a creeping wave which exhibits an exponential decay of power, [6]. The expressions are of two slope form with a breakpoint part way around the body. Beyond the breakpoint angle, the two rays are assumed to interfere, resulting in smaller decay but increased variability. The decay coefficient at 2.4 GHz corresponds approximately to 2 dB/cm, assuming that the body radius is 20 cm. Significant interference takes place beyond the breakpoint at 400 and 900 MHz, indicating the presence of multipath effects, although multipath is seen to be much smaller at 2.4 GHz.

Measurements of channel loss, for many body postures and antenna positions, have recently been made at 2.45GHz, [7, 8]. Fig 1 shows the results collated to allow separation into classes of on-body propagation path gain - distance variation. Two types of path gain variation with the distance can be roughly distinguished based on the propagation scenario, namely, variation in the illuminated region and in the shadow region. The data points for the propagation scenarios in which a line of sight (LOS) was present, (receiver in the illuminated region), are shown in Fig. 4 by '+' signs. The path gain of the antennas in free space in the ground plane direction relative to each other, given by the Friis formula, is also shown for comparison as a solid line. Fig. 4 shows that most of the LOS data points follow the free space curve but are generally below it with the mean difference between the measured and theoretical values of 5.1 dB. Thus, the path gain in the illuminated region at 2.45 GHz is given by the formula:

$$G_P[\text{dB}] = -5.33 - 20\log_{10} d[\text{cm}] \qquad (1)$$

The standard deviation of the difference between the measured LOS values and those given by this formula is 4.2 dB. This deviation can be attributed to the mutual orientation of the antennas, which are not normally co-polarized and in the boresight direction of each other. Occasionally this leads to very large (up to 25 dB) discrepancies between the data and the free space curve. The complexity of determining the relative orientation of the antennas along the on-body propagation path renders it impractical to attempt a more accurate theoretical prediction model, as the radiation pattern contribution and polarization mismatch could not be measured sufficiently accurately.

The data points represented by circles in Fig. 4 correspond to the scenarios when there was no LOS between the antennas, and the dominant propagation path corresponded to a creeping wave propagating around the body. Generally speaking, the distance variation of such a wave is fairly complex and depends on a number of parameters. For example, the distance variation is different on the free space sections of the propagation path and on the sections conformal to the body. However, because the human body has a complex geometry, which is highly variable between individuals, tracing propagation paths around it is difficult and often inaccurate. Nevertheless, the non-LOS data points do appear to follow a trend shown as a straight line in Fig. 4. This trend corresponds to an exponential attenuation according to the following linear regression formula:

$$G_P[\text{dB}] = -0.36d[\text{cm}] - 35 \qquad (2)$$

where d is the antenna separation distance represented in centimeters and G_P is the path gain in dB. The actual data points are spread around this line with a standard deviation of 5.6 dB.

A number of propagation scenarios could not be clearly identified as either LOS or non-LOS because the receiving antenna was very close to the shadow boundary. Therefore, with a slight change of body posture it could become either obstructed (completely or partially) or unobstructed by a body part such as the trunk or an arm. These transition data points are shown in Fig. 4 as x marks. Some of them seem to follow the same trend as the LOS data while others are clustered together with the non-LOS data points.

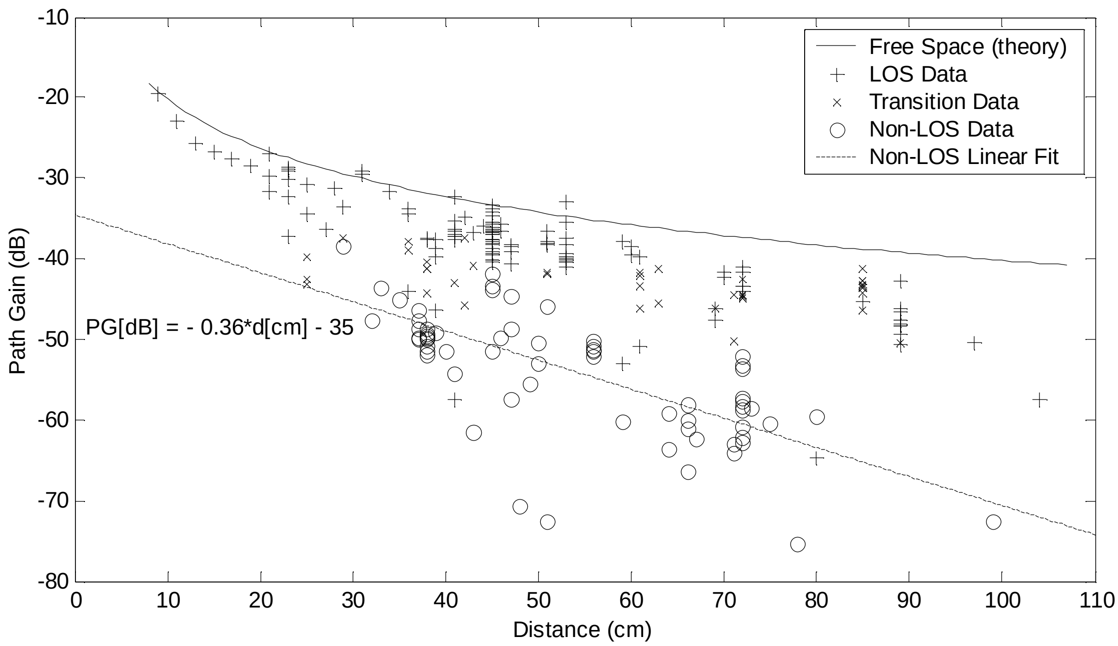

Fig. 1. Classes of on-body propagation path gain distance variation

(Frequency =2.45GHz, path gain measured with quarter wavelength monopoles)

Recent results at the University of Birmingham show that there is a significant multipath on the body at 2.45 GHz, in an anechoic environment. Fig 2 shows the simulated signal received by an antenna on the back from an antenna on the front, transmitting a wideband pulse. The arrival of signals at three different times can be seen. An associated experiment, in which an array was rotated in front of the body about an axis normal to the body surface showed that strong signals were arriving from a number of different directions, including the shoulders, the waist and from between the legs. Measurement of the physical length of these paths and subsequent estimation of the path delays showed encouraging agreement with the timings noted in Figure 2. A diversity

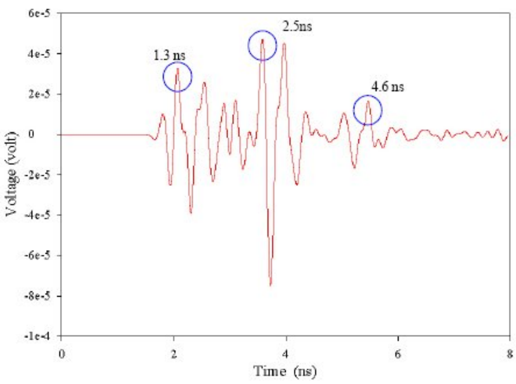

Fig 2 Signal received at antenna on back of body from antenna on front transmitting wideband pulse (Simulation with XFDTD using 'Norman' voxel phantom)

gain of up to 6 dB has been achieved with a pattern diversity antenna at 2.45GHz, [9]. Measurement of the diversity gain of pairs of monopole antennas as diversity receivers, is now under way in collaboration with the University of Pisa. Initial results show that diversity significant gain can achieved, of the order of that noted above.

Ultra wideband signals will have some significance in on body communications and there is much work underway to characterize the path loss and dispersion properties, [10,11, 12]. On-body propagation channel measured was performed using a cpw-fed UWB antenna [10]. For this measurement, a matrix of measurement points is used for reliable and efficient channel characterisation and modelling with minimum distance between Tx and Rx of 10cm. Different antenna positions and various angular orientations are applied with reference to the transmit antenna on the right waist. When comparing impulse performance of the antenna placed on the body at different angular position, a minimum fidelity of 60% can be obtained. The probability density function of measured path loss data for all body postures and all antenna orientations fitted well to a normal Gaussian distribution with a high scaling (σ =14.5) value. This variation is due to body geometry changes, including angular positions, which verifies the rapidly changing on-body environment. To provide on-body channel models applicable to system designs from

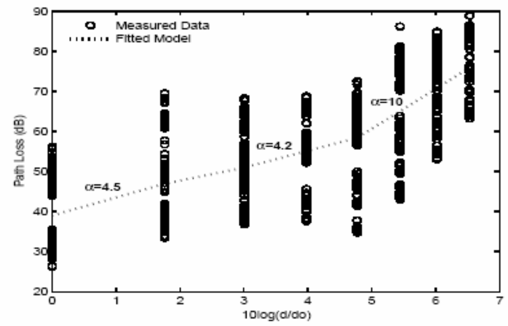

Fig 3. Measured and modelled on-body path loss with CPW-fed UWB antenna, multi-slope fitting

large-scale analysis, the measured path loss data is fitted using linear power law. However, to efficiently model the path loss a multi-slope approach is required with specified breaking points at which the received power decays is different speeds. Figures 3 and 4 show the measured and modelled multi-slope on-body path loss and excess time delay respectively. The high value of the path loss exponent in the first region is due to the smaller distances between Tx and Rx. Then the communication in the following region is assumed to be far field. Finally, at distances where the Rx is on

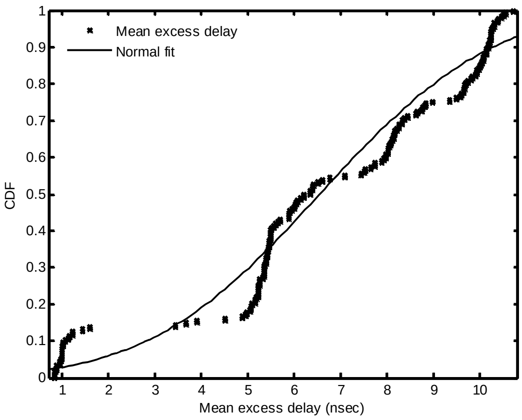

Fig 4. Measured and modelled on-body mean excess delay with CPW-fed UWB antenna (Threshold used for detecting mutlipath components is -25dB below the strongest path level for time window of around 30 nanoseconds)

the side and the back of the body, it is mainly non-line of sight link and thus surface or creeping waves, caused by the body shadowing.

2.2 Wearable Antennas

One of the dominant research topics in antennas for body centric communications is wearable, fabric based antennas. Early interest lead to the development of an RF helmet antenna [13,14] and an RF vest antenna [15,16], operating over a wide frequency band. Since then, the research on wearable antennas has received significant research interest, [17,18]. The wearable antenna has come to be defined as an antenna which is designed and meant to be a part of clothing [19], although it is clear that antennas will be worn on the body in equipment placed in pockets or attached to the body directly, such as Bluetooth headsets or medical sensors discussed in section 3. Of course wearable antennas may be used for links to antennas off the body, such as mobile communications base stations, or satellites, for links to other wearable antennas on the body, or communicating to medical implants.

There are several, significant challenges in the design of wearable, fabric based antennas, that relate mainly to the use of fabrics. They are prone to bending, flexing and wrinkling, and the antennas must remain operational under these circumstances. Fabrics generally have a low dielectric constant which helps in getting wide bandwidth from the antenna. Either conducting films or conducting fibres may be used. In the latter case, fibre conductivity and the weave patterns may be important. Fig 5 shows a wearable patch antenna constructed from copper foil and fleece fabric, [20]. The fleece, serving as the dielectric in this patch antenna was 3.5mm thick and the ground plane was 110 x 130 mm. For this thickness of material the bandwidths were slightly lower than the GSM 1900 and WLAN allocations, indicating the need for thicker fleece material

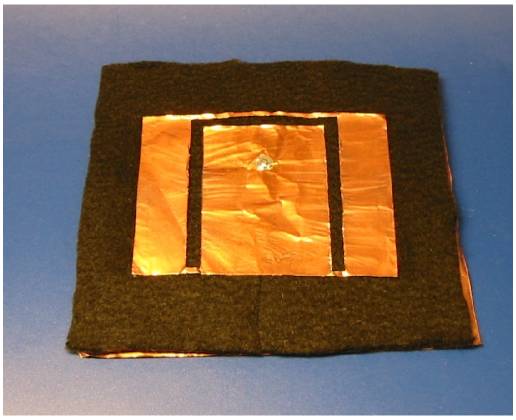

Fig 5 Dual band fleece fabric wearable antenna for 1.9 and 2.4GHz

The performance of various conventional, non fabric, antennas, including monopole, patch and PIFA, operating in on body communications links, has been examined. In such paths it is important to have a pattern and polarisation that support propagation close to the body. However, in any given situation, the path loss is dependent on the antenna type and the posture of the body, which determines the antennas spacings and mutual orientation. In most positions on the body and for most postures, the monopole, oriented with the ground plane parallel to the body surface, gives the least path loss. However choice of antenna will also depend on the size available in the equipment being used for the application in mind.

3 TELEMEDICINE SYSTEMS

Antennas and propagation for telemedicine systems can be considered in two parts, those for systems outside the body and those that communicate with internal implanted sensors and devices.

A good introduction and overview of wireless telemedicine can be found in [21]. While the antennas and propagation aspects of telemedicine technology have similarities with other body-centric applications, transmitted power levels are generally much lower and antenna efficiencies reduced because of battery and packaging constraints. Figure 6 illustrates the concept of a fully-connected patient-centric wearable telemedicine system, highlighting both existing and emerging technologies. In this approach a network of low power wearable devices (sensors or actuators, surface worn or implanted) is established using short range UHF radio. However, these devices may not have sufficient data processing, energy or memory resources to fully realise their function and so a more substantial 'controller' or 'basestation' device may also be part of the wearable network.

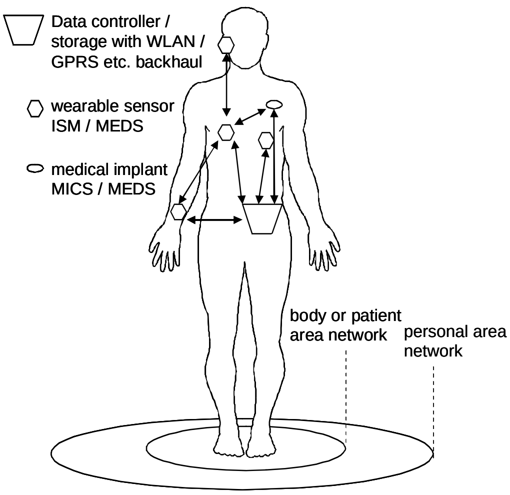

Fig 6 Wearable telemedicine system
WLAN – wireless local area network
GPRS – General Packet Radio Service
ISM – Industrial, Scientific and Medical
MEDS – Medical Data Service
MICS – Medical Implant Communications Service

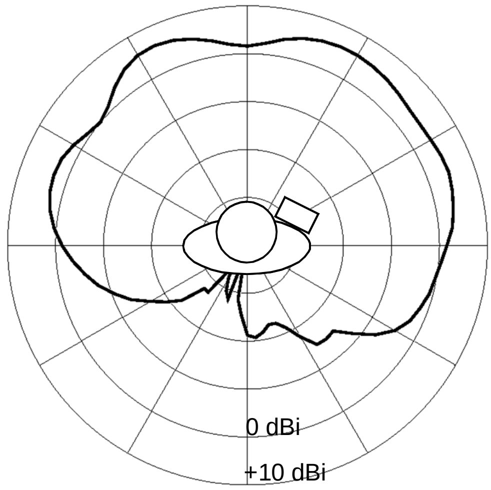

Figure 7 Azimuthal radiation pattern for hip-worn 5.2 GHz telemedicine unit.

In terms of antennas at frequencies below 1 GHz a small loop is a reasonable choice for compact body mounted telemedicine equipment. At higher frequencies monopoles, PIFAs and dipoles have been used, and in these cases the body will have a significant effect. Figure 7 shows an FDTD simulation of the azimuthal radiation pattern of a hip worn telemedicine unit operating at 5.2 GHz, [22]. The model included an anatomically realistic human body phantom, a conducting box (representing the patient unit) and a thin-wire dipole antenna. The overall FDTD grid was 499 x 93 x 154 with cubic 3.6 mm voxels. The body phantom was for a 1.75 m tall adult male and incorporated 21 tissue types. The sleeve-dipole antenna used in measurements was modelled as a centre-fed 25.2 mm (0.36 mm radius) thin-wire element and was positioned with a minimum antenna-body spacing of 14.4 mm. The high degree of separation ($> 2\lambda$) reduced the overall body losses, with a corresponding FDTD-computed radiation efficiency of 83.3 % at 5.2 GHz. The computed pattern was strongly directional, with a peak gain of +6.0 dBi and a through-body null of –37.9 dBi in the azimuthal plane

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Pacemakers and implantable RFID use the inductive link with a carrier frequencies between 9kHz to 315KHz with a data rate of up to 512kb/s. Use of the Medical Implant Communication System (MICS), [23], at 402 to 405 MHz, allows bands of 300kHz to be achieved. Examination of the electric and magnetic components of the field, when a plane wave meets the body, show that there is a node of the electric field and the anti-node of the magnetic field at the surface of the body. Inside the body there is a dominating propagating wave which is attenuated due to the conductivity of the muscle tissue. The magnetic field is strong at the surface the body which implies that a magnetic antenna would be beneficial for subcutaneous implants. RF telemetry reception from implanted sensors has been demonstrated by several researchers [24, 25].

For deeper implants various antenna types have been examined, such as the long wire antenna, [26], the patch or PIFA, [27] and the coil [25], although it has been shown that in the body environment a magnetic based antenna will still have significantly better efficiency than an electric one, and that increasing the insulation diameter around the antenna will also increase its efficiency.

4 THE FUTURE

For on- or in-body environments, antennas are required to be conformal and immune from frequency and polarisation detuning. It is also likely that the associated electronics and sensors will be conformal in shape. Whilst many antennas in wearable equipment will be of conventional miniaturised form, some will be made using textiles, particularly for specialist occupations such as firefighters and paramedics, and also where fashion dictates form and design. Antennas for medical implants are particularly challenging due to a very variable environment and the need for low frequency operation using small antennas. Conventionally, in antenna design, physical dimensions, directivity, efficiency and so on, are constrained by the wavelength of the radiation involved. These constraints are very relevant to body centric antenna applications.

The use of medical implants will increase as the number and capability of nano and micro sensors and devices increases. Communications between implants may then be used to form networks, which improve the system functionality. It could be said that system design will be unique to the implant function required, but for future design and production efficiency through commonality, more systematic studies of antennas and propagation for implant are required.

Although there has been significant progress in simulation tools, there is still a need for improvement particularly in run time for full body simulators.

REFERENCES

1. Hall, P S and Hao, Y, (eds), ‘Antennas and Propagation for Body Centric Wireless Communications’, (Artech House, Boston/London, 2006)
2. T. G. Zimmerman, "Personal Area Networks: Near-Field Intra-Body Communication," IBM Systems Journal, vol.35, no.3&4, pp.609-617, 1996.
3. T. G. Zimmerman, J. R. Smith, J. A. Paradiso, D. Allport and N. Gershenfeld, “Applying Electric Field Sensing to Human-Computer Interfaces,” Proc. of CHI’95, pp.280-287, May 1995.
4. K. Fujii, K. Ito and S. Tajima, "A study on the receiving signal level in relation with the location of electrodes for wearable devices using human body as a transmission channel," Proc 2003 IEEE Int Symp on Ants and Prop pp.1071-1074, Columbus, OH, USA, June 2003.

5 Ryckaert, J, De Doncker, P, Meys, R, de Le Hoye, A and Donnay, S, “Channel model for wireless communication around human body”, Electronics Letts, 29th April 2004, Vol. 40, No. 9, pp 543-544

6 McNamara, D.A., et al.: ‘Introduction to the uniform geometrical theory of diffraction’ (Artech House, Boston, 1990)

7 Nechayev, Y I, Hall, P S, Constantinou, C C, Hao, Y, Alomainy, A, Dubrovka, R and Parini, C, “On-body path gain variations with changing body posture and antenna position”, IEEE AP-S International Symposium, Washington, USA, July 2005, pp731-734

8 Hao, Y, Alomainy, A, Zhao, Y and Parini, C, Nechayev, Y I, Hall, P S, Constantinou, C C “Antennas and Propagation for Body Centric Wireless Communications”, International Wireless Summit 05, Aalborg, Denmark, September 2005

9 Kamarudin, M R and Hall, P S, “Diversity measurement of antennas in the on-body environment’, EuCAP 2006, Nice, 6-10 November 2006-07-18

10 Alomainy, A.; Hao, Y.; Parini, C.G.; Hall, P.S.; “Comparison between two different antennas for UWB on-body propagation measurements”, Antennas and Wireless Propagation Letters Volume 4, 2005 Page(s):31 – 34.

11 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”, IEE proceedings on communications, special issue on UWB, 2006.

12 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
13 J. Lebaric, A.-T. Tan, Ultra-Wideband RF Helmet Antenna, IEEE MILCOM 2000, Vol. 2, 2000, pp. 591 – 594.
14 J. Lebaric, A.-T. Tan, Ultra-Wideband Conformal Helmet Antenna, IEEE Asia Pacific Microwave Conference, 2000, pp. 1477 – 1481.
15 R. Abramo, R. Adams, F. V. Canez, H. Price, P. Haglind, Fabrication and Testing of the COMVIN Vest Antenna, IEEE MILCOM 2000, Vol. 2, 2000, pp. 595 – 598.
16 J. E. Lebaric, R. W. Adler, M. E. Limbert, Ultra-Wideband, Zero Visual Signature RF Vest Antenna for Man-Portable Radios, IEEE MILCOM 2001, Vol. 2, 2001, pp. 1291 – 1294.
17 Salonen, P., Hurme, H., A Novel Fabric WLAN Antenna for Wearable Applications, 2003 IEEE Antennas and Propagation Society International Symposium, Columbus, Ohio, USA, vol. 2, 2003, pp. 700 – 703.
18 M. Tanaka, J.-H. Jang, Wearable Microstrip Antenna, 2003 IEEE Antennas and Propagation Society International Symposium, Columbus, Ohio, USA, vol. 2, 2003, pp. 704 – 707.
19 L. Sydänheimo, M. Keskilammi, M. Kivikoski, "A Small Planar Inverted-F Antenna for Wearable Applications", The Third International Symposium on Wearable Computers, 1999, pp. 95 – 100.
20 P. Salonen, Rahmat-Sami, Y, "Dual band wearable antenna", 200 IEEE Antennas and Propagation Society International Symposium, Monterey, California, USA, June 20-25 2004.
21 C.S. Pattichis, E. Kyriacou, S. Voskarides, M.S. Pattichis, R. Istepanian and C.N. Schizas, "Wireless telemedicine systems: an overview," *IEEE Antennas & Propagation Mag.*, Vol. 44, 2, pp. 143–153, April 2002.
22 K.I. Ziri-Castro, W.G. Scanlon and N.E. Evans, "Indoor radio channel characterisation and modelling for a 5.2-GHz bodyworn receiver," *IEEE Antennas and Wireless Propagation Letters*, Vol. 3, 11, pp. 219–222, 2004.
23 ETSI EN 301 839-1 Electromagnetic compatibility and Radio spectrum Matters (ERM);Radio equipment in the frequency range 402 MHz to 405 MHz for Ultra Low Power Active Medical Implants and Accessories;Part 1: Technical characteristics, including electromagnetic compatibility requirements, and test methods., European Telecommunications Standards Institute, 2002.
24 J.A. Von Arx and K. Najafi, "On-Chip Coils with Integrated Cores for Remote Inductive Powering of Integrated Microsystems," 1997 Inter. Conf. Solid-State Sensors and Actuators, TRANSDUCERS '97, Chicago, IL, pp. 999–1002, June 16–19, 1997.
25 R.N. Simons, D.G. Hall, and F.A. Miranda, "RF Telemetry Systems for an Implantable Bio-MEMS Sensor," 2004 IEEE MTT-S Inter. Microwave Symposium Dig., Vol. 3, pp. 1433-1436, Fort Worth, Texas, June 6-11, 2004.
26 C. A. Caceres, Ed., Biomedical Telemetry. Academic Press, 1965.
27 J. Kim and Y. Rhamat-Samii, "Implanted antennas inside a human body: Simulations, designs and characterizations," IEEE Transactions on Microwave Theory and Technoques, vol. 52, no. 8, pp. 1934—1943, Aug. 2004.