# Antennas and Propagation for Body Centric Wireless Communications in Healthcare

***Yang Hao***

*Queen Mary College, University of London*

Queen Mary
University of London

# Outline

- Overview of Body-Centric Wireless Communications
- On-body Radio Propagation Modelling and Measurement
- On-body Antennas Design
- Demonstration and Applications of Zigbee Sensors.
- Summary and Future Challenges

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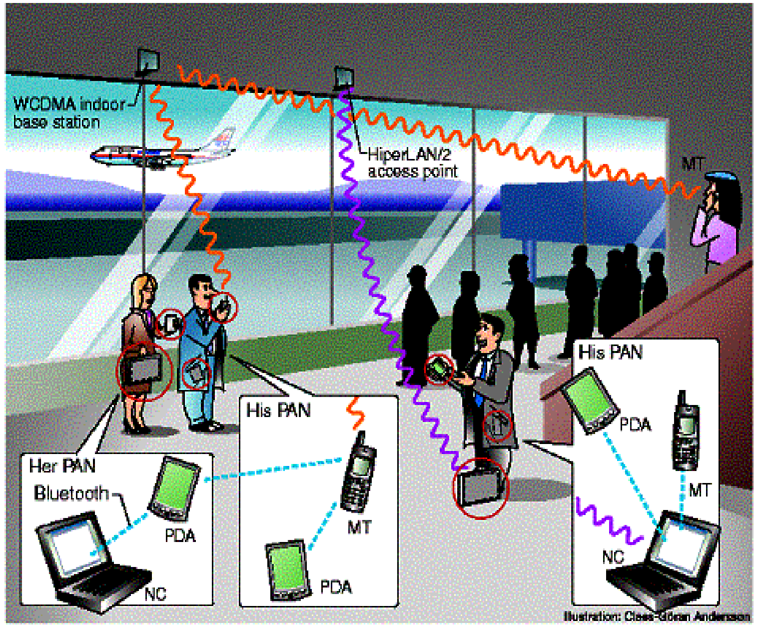
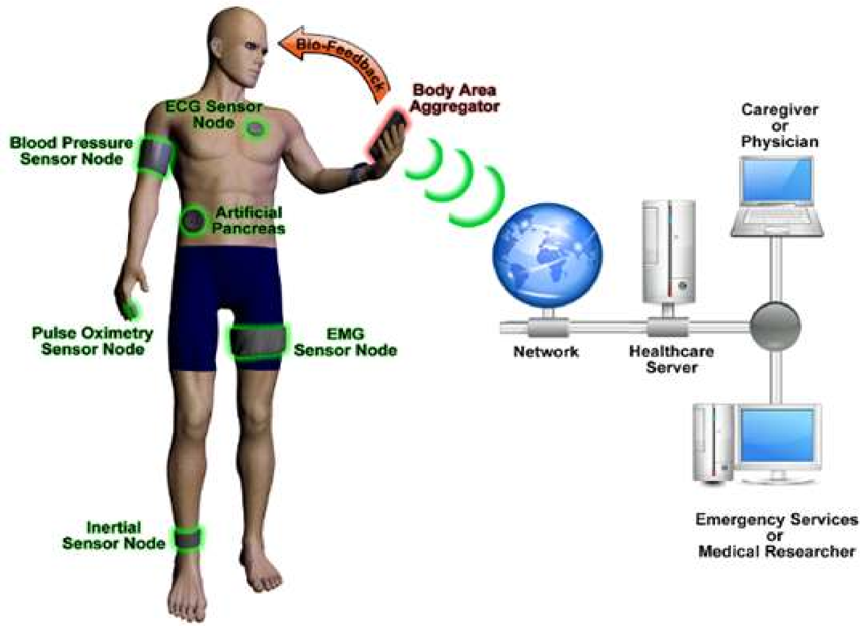
# Introduction

- Body-centric wireless communications refer to human-self and human-to-human networking with the use of wearable and implantable wireless sensors.
- It is a subject area combining wireless body-area networks (WBANs), Wireless Sensor Networks (WSNs) and Wireless Personal Area Networks (WPANs).
- Body-centric wireless communications has abundant applications in personal healthcare, smart home, personal entertainment and identification systems, space exploration and military.
- Antennas are essential part of Body-Centric Wireless Comunications and their complexity depends on the radio transceiver requirements and the surrounding environments.

# Introduction

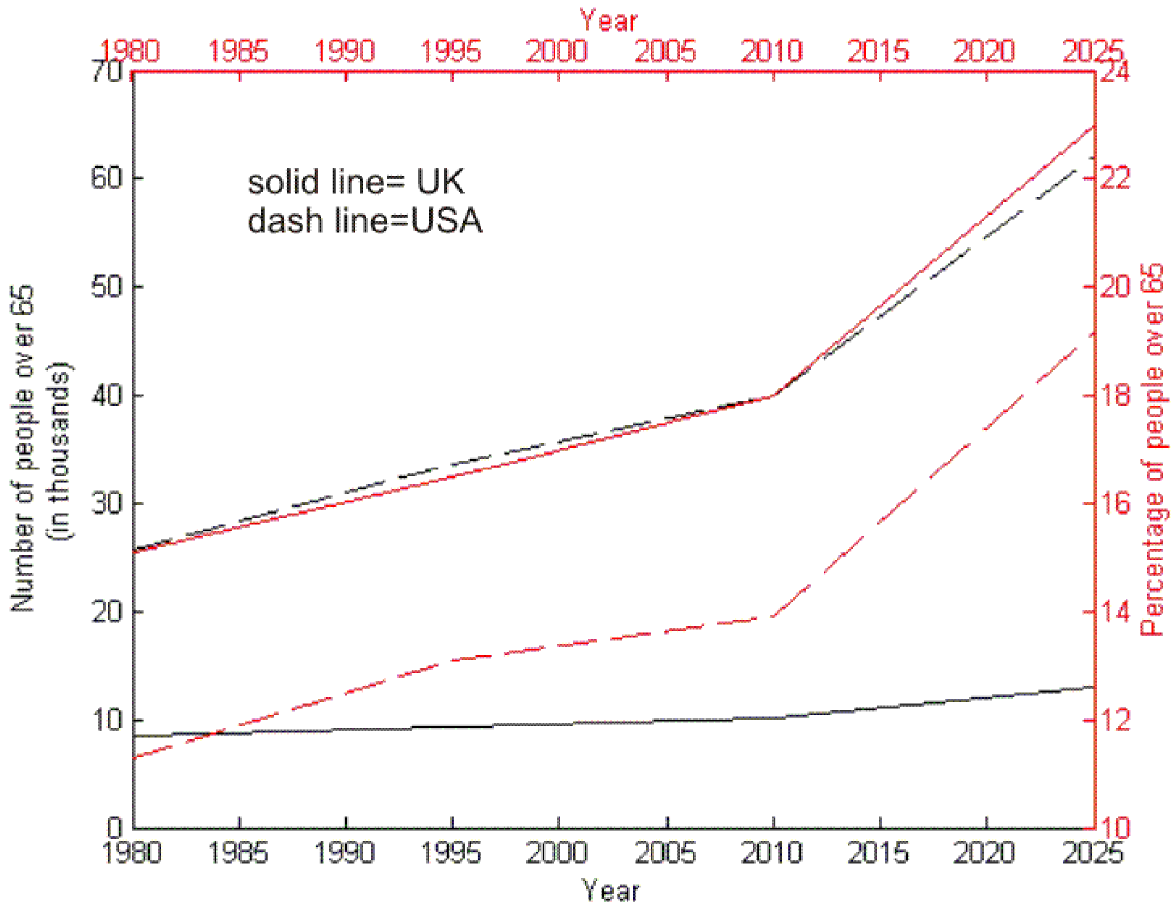
- Short personal communications
  - WBAN and WPAN networks




- Several nodes placed at various locations on the body forms a WBAN

# Introduction

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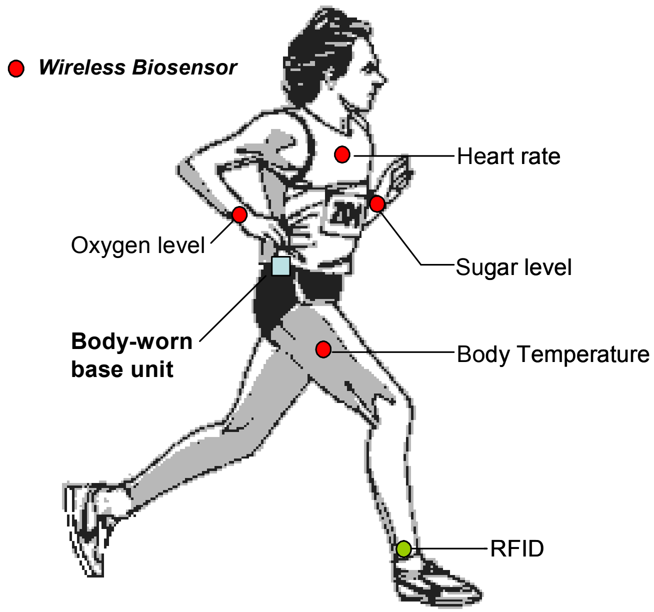
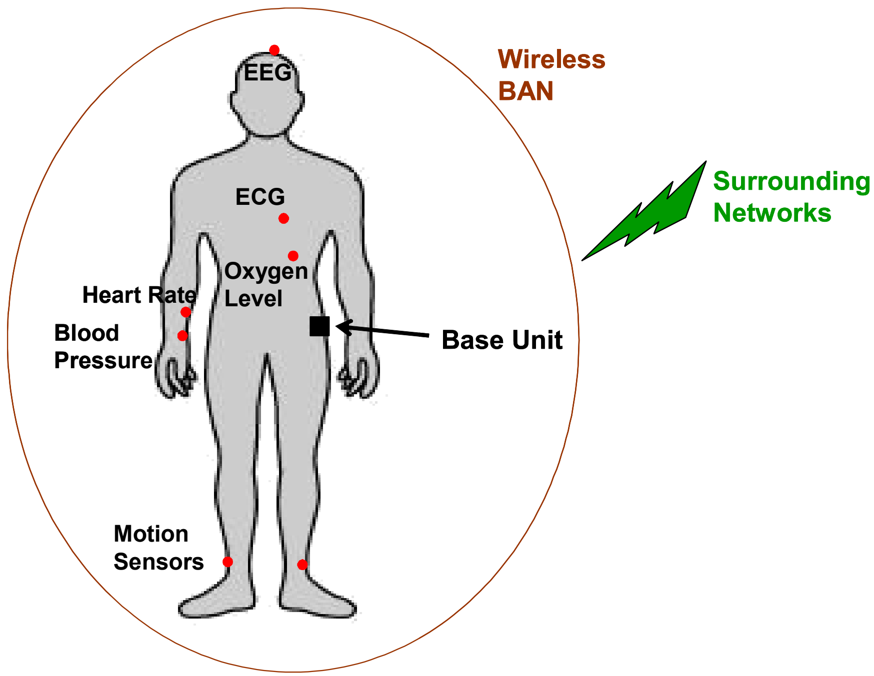
# Wireless Body Area Network in Healthcare




**Keep continuous record of patient's health at all times (including athletes performance monitoring)**

**Efficient, flexible systems with constant availability, reconfigurability and unobtrusiveness.**

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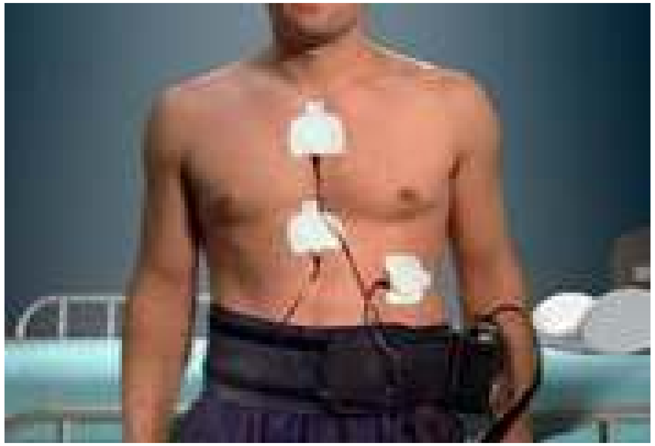
# Implantable & Wearable Sensors in Healthcare

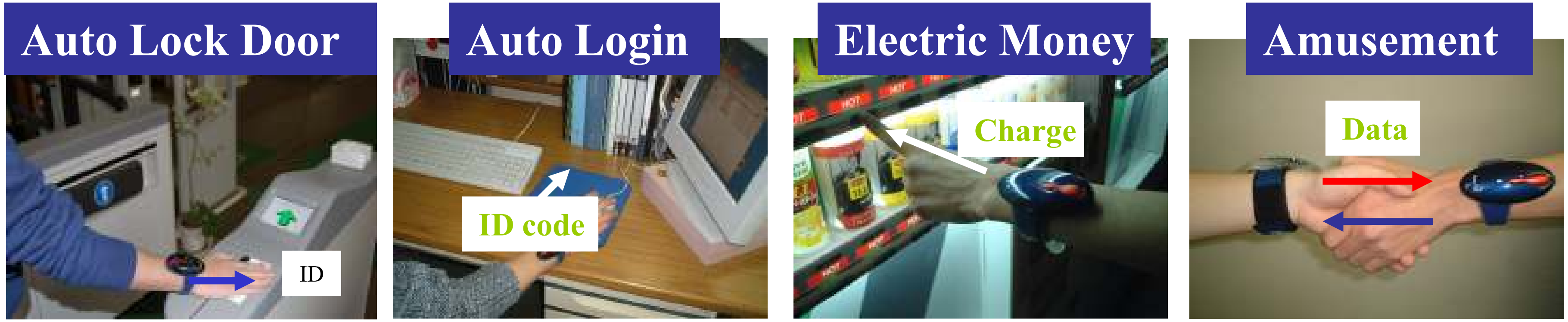
**Kenneth R. Foster and Jan Jaeger, “RFID Inside”, IEEE Spectrum, March 2007, INT**

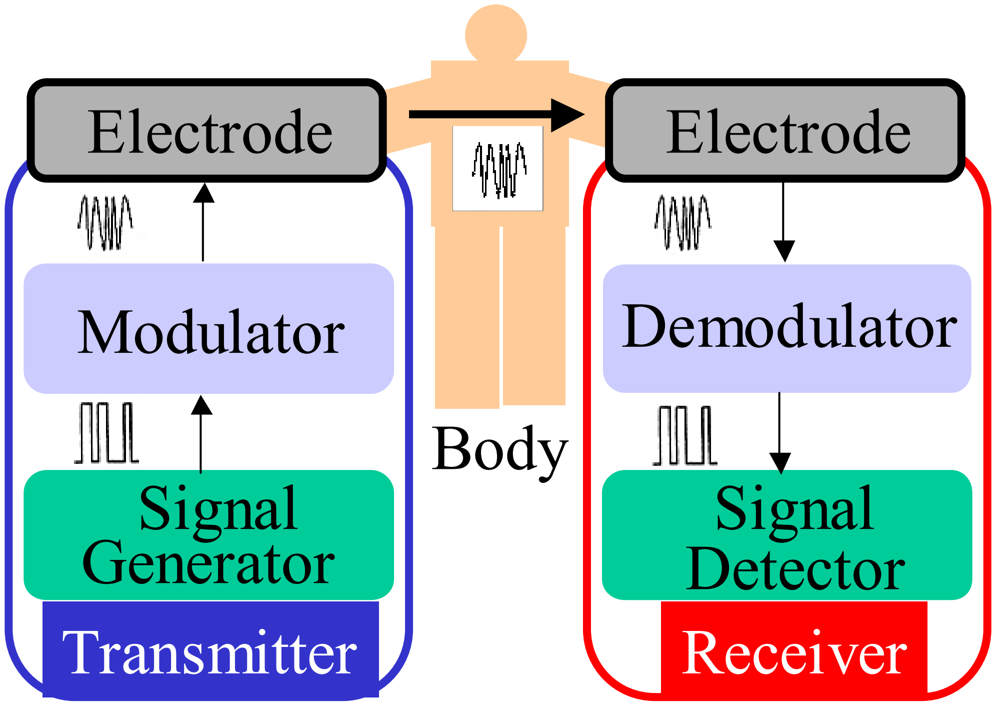


**Wireless Endoscopy**

*Source: http://www.givenimaging.com/*

# Communication systems using the human body as a transmission channel




## Applications

Security
Electric Money
Amusement
etc.


Prof. Koichi ITO

千葉大学
Chiba University

# Wearable textile system for Wireless *Body* Area Network and Wireless *Personal* Area Network

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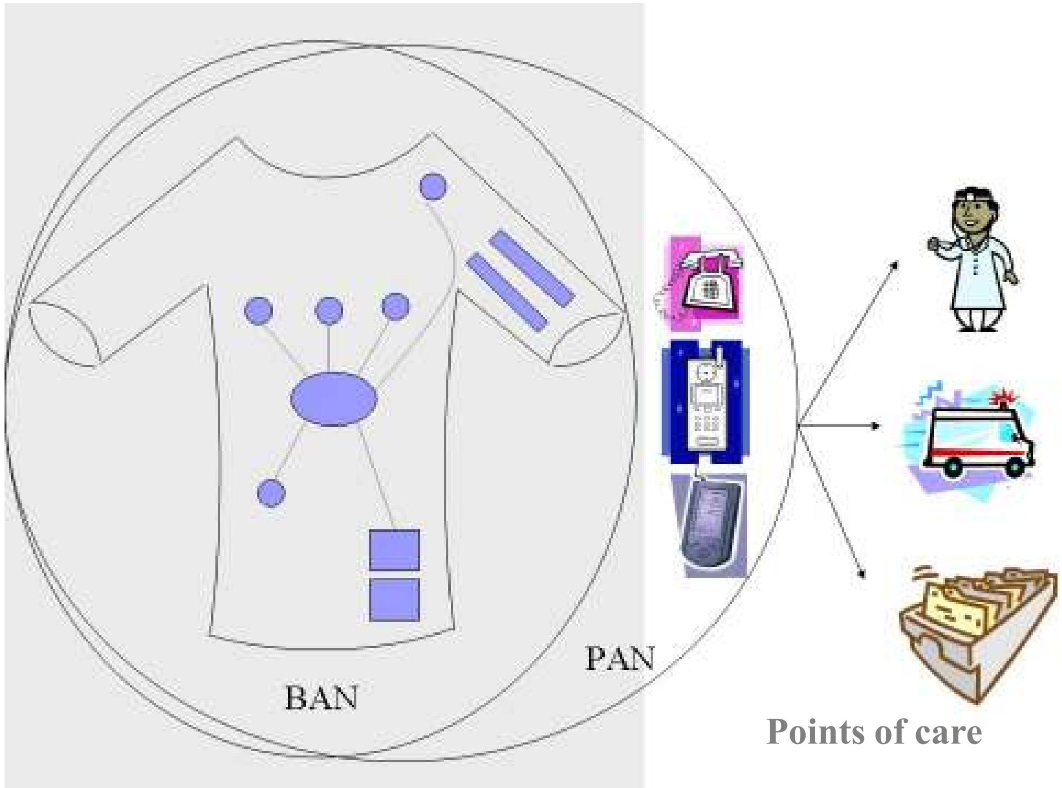
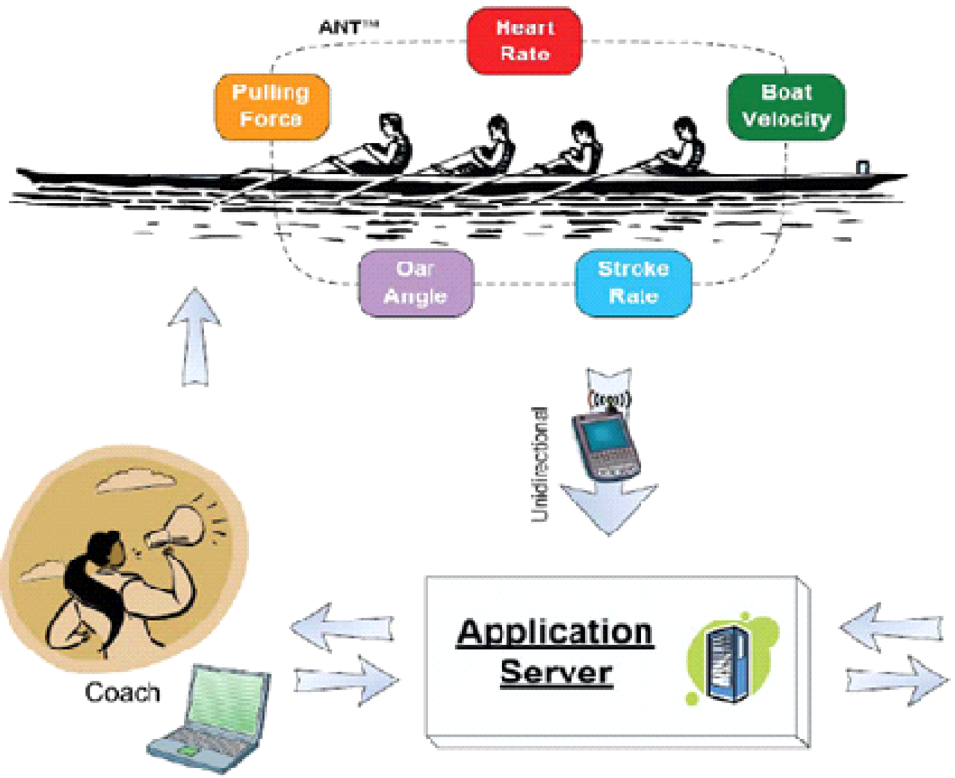
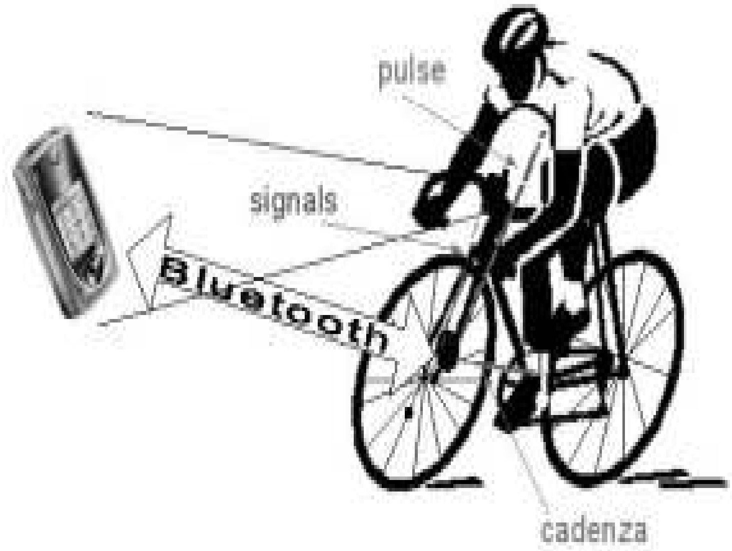



- **BAN** (Body Area Network): communication on the body, between the elements of a Wearable Textile System, i.e. sensors, processor etc.
- **PAN** (Personal Area Network): communication between the body and other devices in a short range area (about 10 m).
- Used Protocols: 802.11b, Bluetooth, Wireless USB, Zigbee, which operate in the 2.45 GHz ISM band
- Communication of data to the **Point of Care** through communications networks (GSM, GPRS, Internet etc.)

# Sports/Physiotherapy Applications

Rowing & Cycling



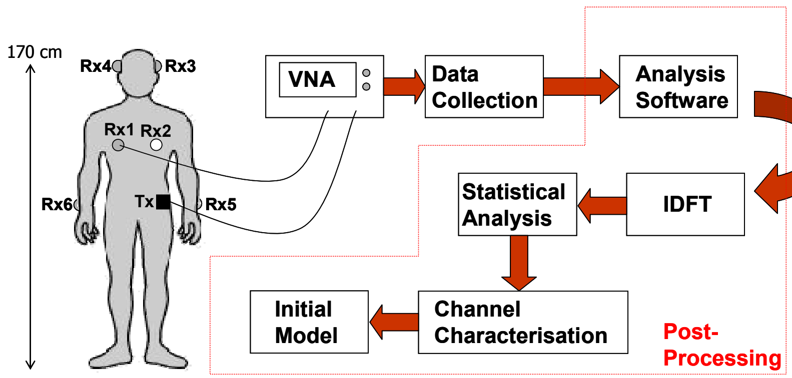



# Technologies

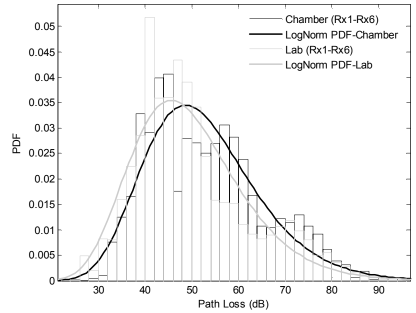
| Standard | Frequencies (MHz) | Data Rate | Max. Power | Range (m) |
|---|---|---|---|---|
| Medical implant (licensed) | 402-405 | low | low | |
| BodyLAN | 900 | 32 kb/s | 0 dBm | 2-10 |
| Bluetooth | 2400-2480 | 1 Mb/s | 0 dBm | 0.1-10 |
| ZigBee | 2400<br>915<br>868 | 250 kb/s<br>40 kb/s<br>20 kb/s | Low | 1-100 |
| UWB | 3100-10,600 | 1 Gb/s | -41 dBm/MHz | 10 |

# Research Activities for Body-Centric Wireless Communications

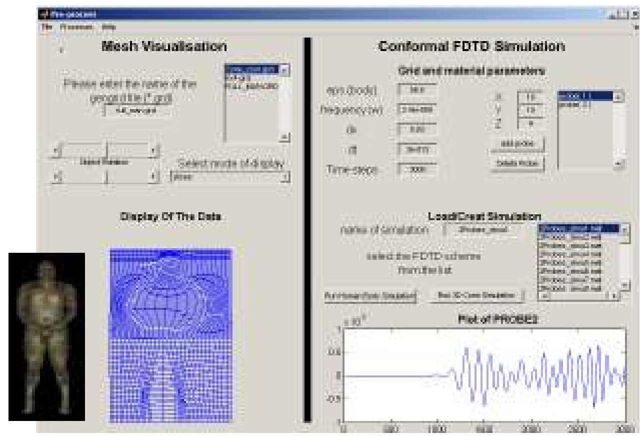
- On-Body Propagation Channels for WBAN



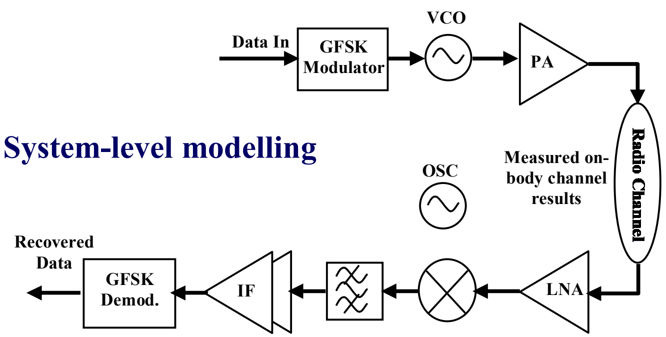

**Radio channel characterisation and modelling**




**In-house conformal FDTD**




**System-level modelling**



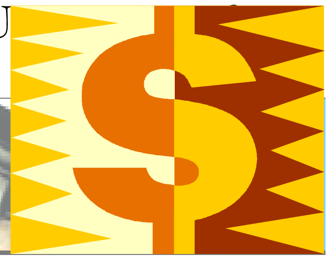


*Peter Hall and Yang Hao, **"Antennas and Propagation for Body-Centric Wireless Communications"**, 2006, Artech House.*

*Alomainy et al., "Statistical Analysis and Performance Evaluation for On-body Radio Propagation with Microstrip Patch Antennas", IEEE Transactions on Antennas and Propagation, Vol. 55, Issue 1, January 2007, pp:245 - 248.*
*Alomainy et al., "UWB On-Body Radio Propagation and System Modelling for Wireless Body-Centric Networks", IEE Proceedings Communications-Special Issue on Ultra Wideband Systems, Technologies and Applications, Vol. 153, No. 1, February 2006.*

# Current and Past Research Projects

- 2011.7 – 2016.6 "EP/I034548/1, The Quest for Ultimate Electromagnetics using Spatial Transformations (QUEST)", EPSRC, £5M jointly with Oxford, Exeter and St Andrews with QMUL £2M.
- 2011.1 – 2013.12 "PATRICIAN: New Paradigms for Body Centric Wireless Communications at MM Wavelengths", EPSRC, £400K, in total, £1.2M jointly with Birmngham and Durham.
- 2008. 6 – 2013.5 Co-Investigator for "Antennas for Healthcare and Imaging Applications", EPSRC, £1.2M.
- 2007. 11 – 2010.10 "iRFSim for BSNs: Imaging based subject-specific RF simulation environment for wearable and implantable wireless Body Sensor Networks (BSNs), a joint grant from EPSRC with Imperial College. Total Value: £700K with QMUL £350K.
- 2007. 11- 2008.10 Pankaj Vadgama, Y. Hao, "Wireless Implantable Biosensors with Advanced On-Body Data processing", joint grant with QMUL Department of Materials, NEAT, Department of Health. Total value £70K.
- 2007. 10 – 2008. 3 "Sensium Digital Plaster Antennas", Toumaz Technology, Oxford, £50K.
- 2007.4 – 2010. 3 "Wearable Antennas for Body-Centric Wireless Network", EPSRC/MoD JGS, *£350K.*
- 2006. 4 – 2007. 3, Wearable Antenna Modelling, DSTL, Total value: *£58K.*
- 2003.7 – 2006.6 EPSRC/MOD JGS: Characterisation of On-Body Communication Channels, GR/S03812/01, Value: *£150K.* Total value: 350K (shared with U
Birmingham)



# Industrial Collaborators

- Over £1M research funding from the industry for last three years
  - Philips Netherlands, Philips Shanghai
  - ONR, GE Global Research, USA
  - DSTL, UK
  - BAE Systems, Roke Manor Research Ltd, UK
  - Toumaz Technology
  - Zimiti Limited

**Microstrip antenna array suits broadband comms**

By Sara Sowah
EE Times
6 September 2001 (12:57 p.m. GMT)

PRINT THIS STORY | SEND AS EMAIL

Researchers at Queen Mary University of London have developed a low-cost microstrip antenna array for future mobile broadband communications.

The desire for mobile multimedia has prompted a flurry of design activity around millimetre wave components. Previous projects to build millimetre wave antennas have mostly been based on waveguide systems, using either dielectric lens antennas or horn antennas. Waveguide systems have the disadvantage that the circuit is bulky, unlike microstrip antennas, which are light and compact.

Current self-diplexing microstrip antennas, designed to receive and transmit simultaneously, often have poor isolation. Using a photonic band gap (PBG) structure in the design of the microstrip diplexer patch antenna array allows the antenna to isolate the receive and transmit signals from one another.

These PBG structures are built to mimic materials where dielectric permittivity varies periodically in space. One of the other properties it simulates is controlling the electromagnetic wave propagation over set frequency bands. This antenna has been designed to handle broadband systems up to 60GHz.

The PGB technique has been used in optoelectronics for the fabrication of lasers and in surface wave suppression for antennas. The technique has been further developed and tailored for this application.

The antennas are cheap to make because they can be fabricated in just one process. They can be produced using either an etching or a micro machining process.

Dr Yang Hao, from the department of electronic engineering at Queen Mary University of London, believes that, along with broadband multimedia communications and mobile Internet applications, the antenna could also be used to develop a low-cost basestation for an intelligent transport system, allowing a traffic control network to communicate with drivers.

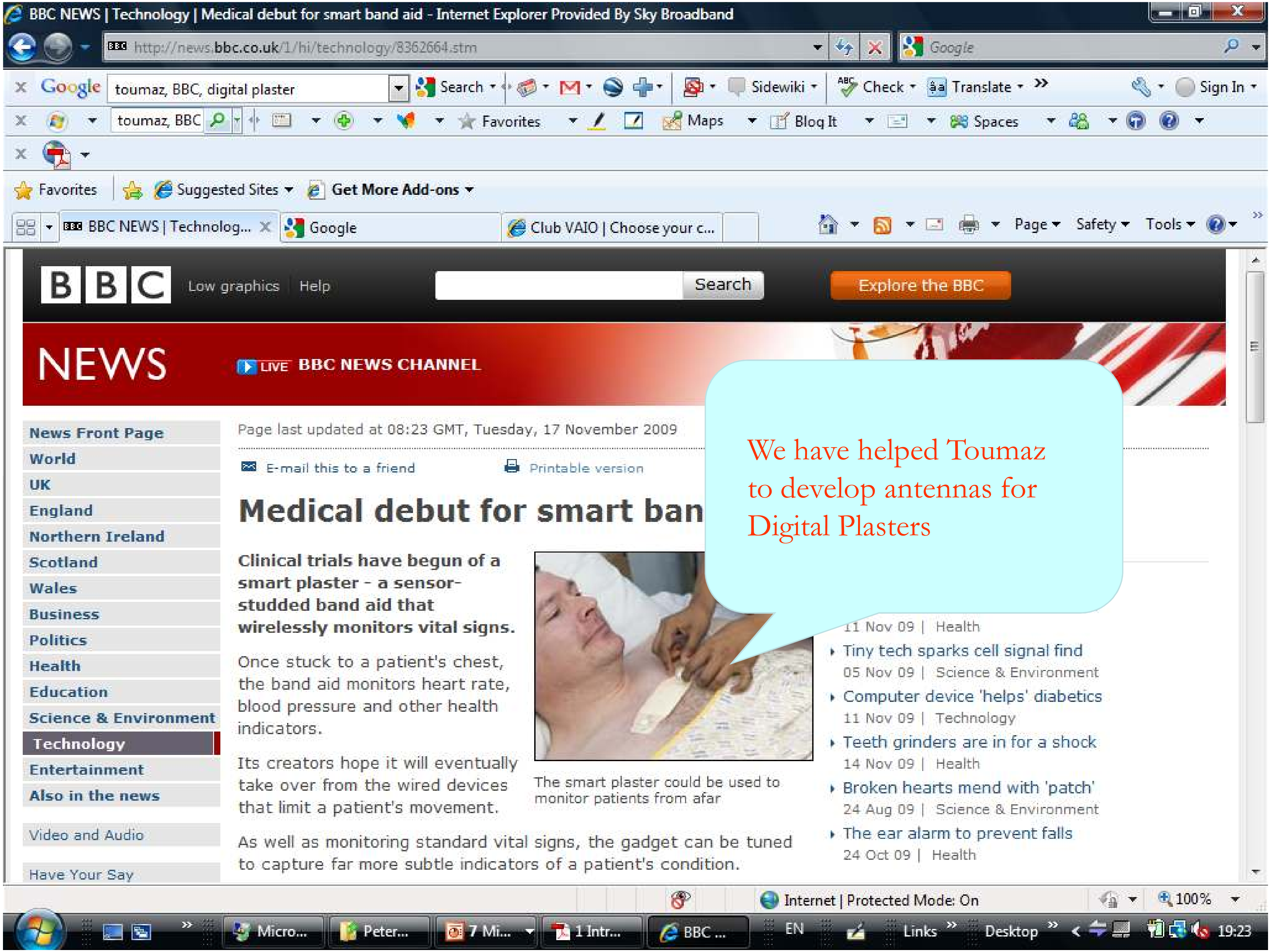
"There are lots of possible applications for this technology," said Dr Hao.

# Catwalk goes techno

Published on 21 October 2008

## By Sian Harris

We have helped Toumaz to develop antennas for Digital Plasters



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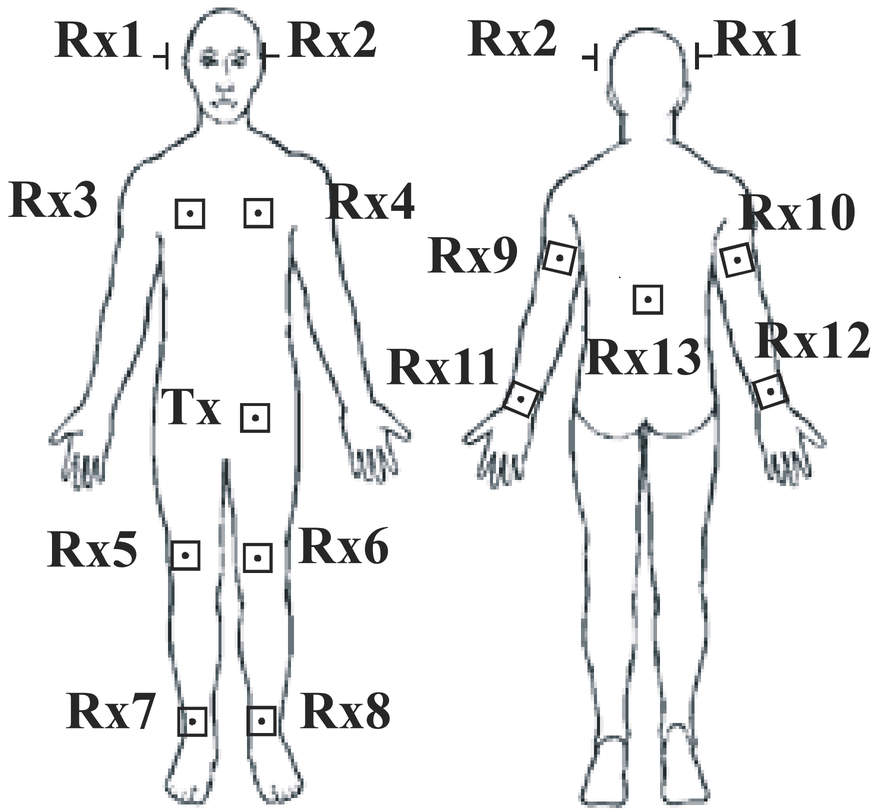
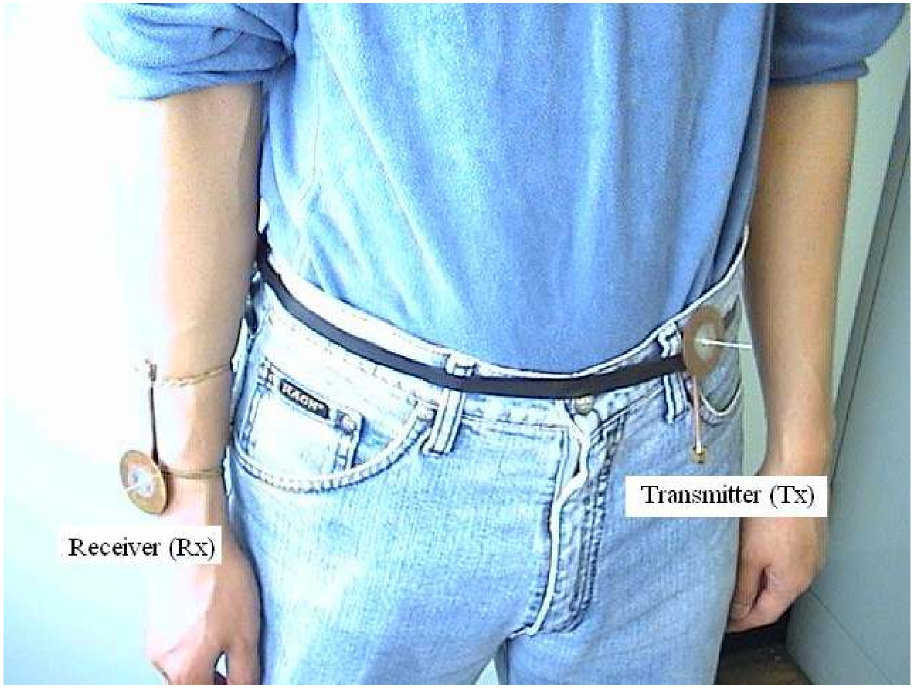
# Narrowband Measurements

- Vector network analyser measurements inside anechoic chamber
- Frequency: 2.45 GHz
- 2 quarter-wavelength monopoles, patches etc.
- Single Tx position and multiple Rx positions
- A number of static postures + arbitrary movements



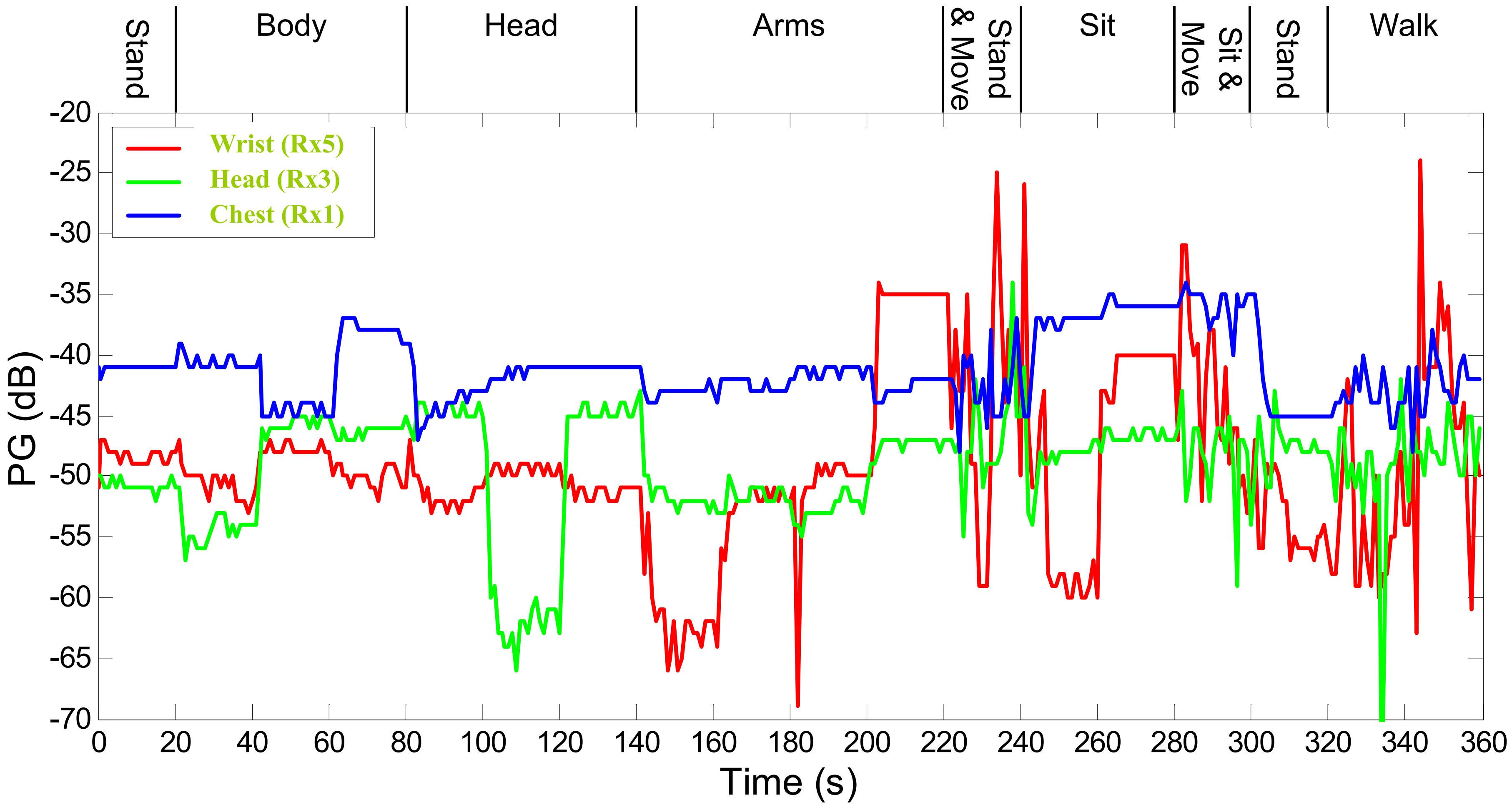
# Measurements Setup

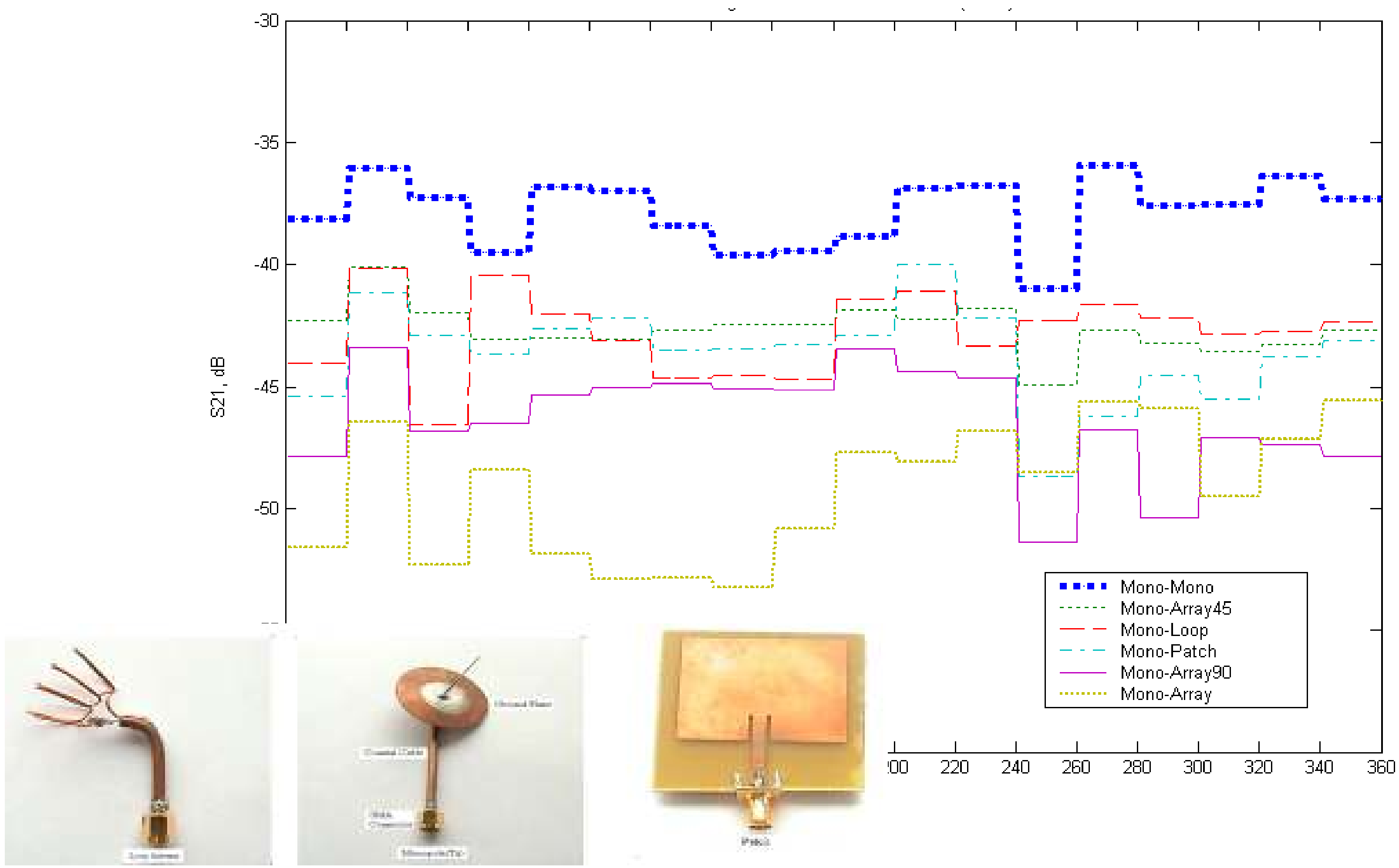
# Body Positions

| N | Start Time | Category | Position | N | Start Time | Category | Position |
|---|---|---|---|---|---|---|---|
| 1 | 0 | Standing | Upright still | 10 | 180 | Arms Movement | Forward |
| 2 | 20 | Trunk Movement | Left turn | 11 | 200 | | Forearms forward |
| 3 | 40 | | Right turn | 12 | 220 | Standing & Moving | |
| 4 | 60 | | Leaning forward | 13 | 240 | Sitting | Arms down the sides |
| 5 | 80 | Head Movement | Leaning forward | 14 | 260 | | Hands in the lap |
| 6 | 100 | | Left turn | 15 | 280 | Sitting & Moving | |
| 7 | 120 | | Right turn | 16 | 300 | Standing | Upright still |
| 8 | 140 | Arms Movement | Sideways | 17 | 320 | Walking | Arms close to body |
| 9 | 160 | | Upwards | 18 | 340 | | |

# Chamber Measurement Results



# Different Antenna Types

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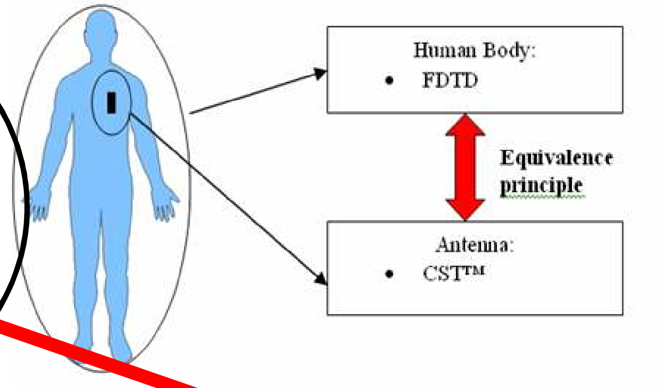
# FDTD Modelling of On-body Antennas

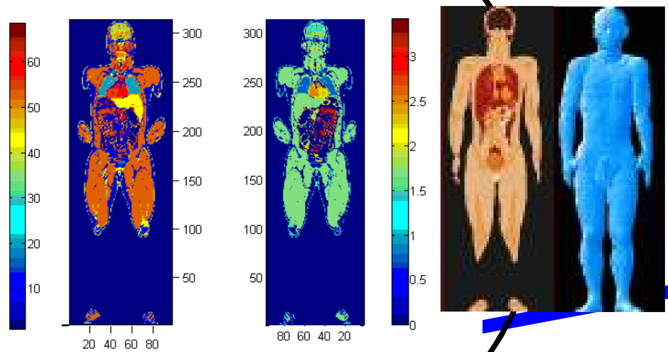
**CST Microwave Studio :**

**<u>e,h on the box</u>**

$$\begin{cases} \bar{m} = \hat{n} \times \bar{h} \\ \bar{j} = \bar{e} \times \hat{n} \end{cases}$$




**Hugo Body Model**



ε σ

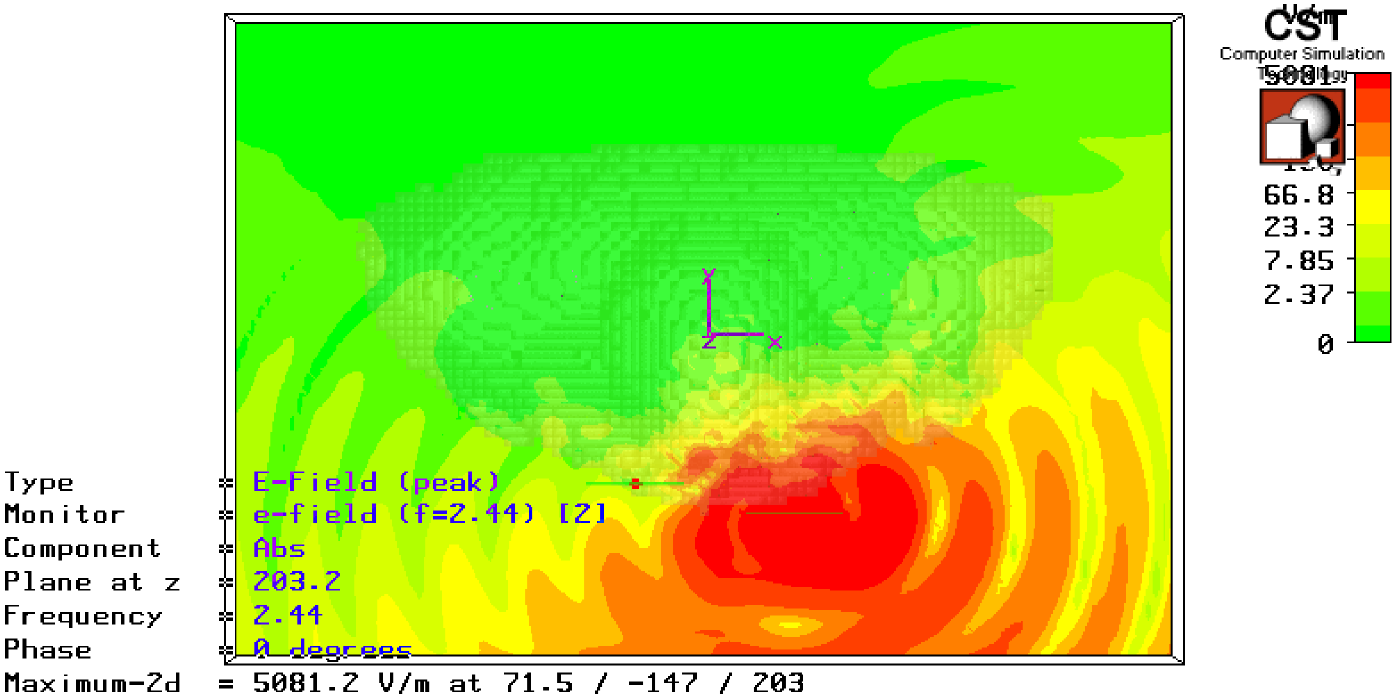
$$\begin{cases} \nabla \times \bar{e} = -\mu \dfrac{d\bar{h}}{dt} - \bar{m} \\ \nabla \times \bar{h} = \varepsilon \dfrac{d\bar{e}}{dt} + \sigma \bar{e} + \bar{j} \end{cases}$$

**Maxwell Equations**

**A. Sani, Y. Zhao, A. Alomainy, Y. Hao and C. G. Parini, "An Efficient FDTD Algorithm Based on Equivalence Principle for Analyzing On-Body Antenna Performance", IEEE Transactions on Antennas and Propagation, April 2009, vol. 57, issue 4, pp. 1006-1014.**

# Wearable Sensor Field Distribution

**Printed Monopole on the left side of the waist**



# Homogeneous vs Inhomogeneous Phantoms

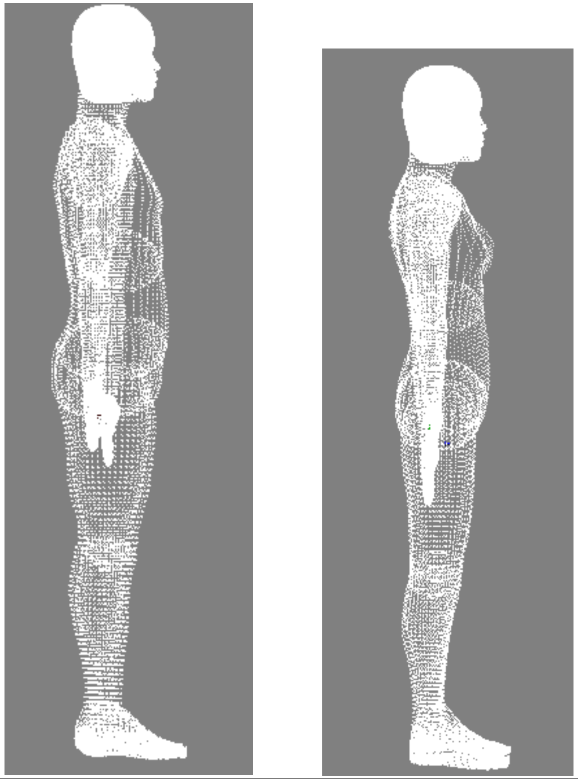
**Since the skin depth is small, a homogeneous phantom made of muscle tissue is suitable for modeling on-body communications at 2.4 GHz.**


| RX | Muscle | 2/3 Muscle |
|---|---|---|
| 1 | +1.0 | +1.6 |
| 2 | -2.4 | -1.7 |
| 3 | +2.9 | +1.6 |
| 4 | +2.9 | +2.5 |
| 5 | -2.9 | -3.4 |
| 6 | -2.7 | -2.8 |
| 7 | +1.6 | +2.0 |
| 8 | -2.0 | -2.6 |
| 9 | +2.4 | +2.4 |
| 10 | -2.8 | -1.4 |

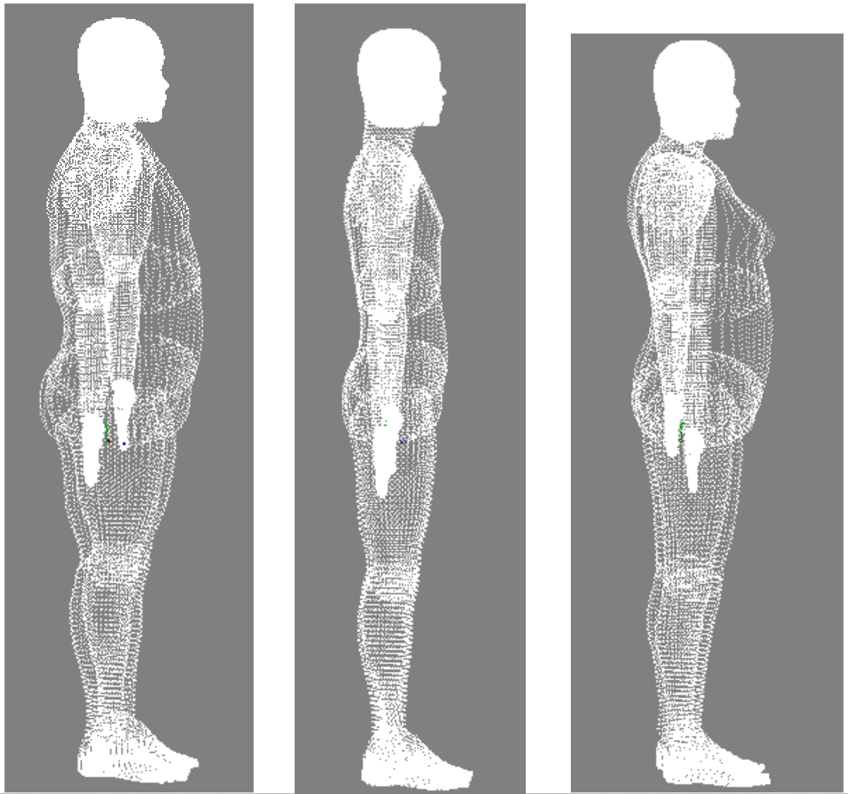
**Difference in terms of received power (in dB) between homogeneous and inhomogeneous phantoms.**

# Homogeneous Phantoms: Mesh Generator

Male or Female

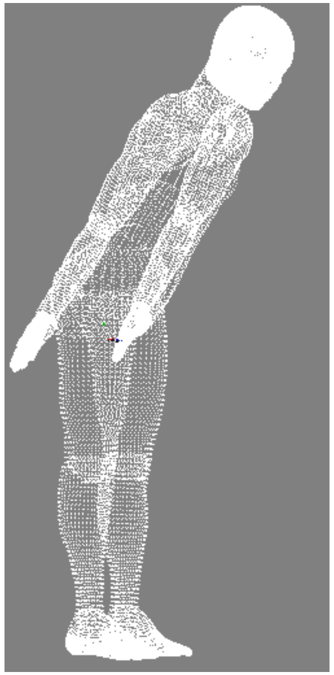


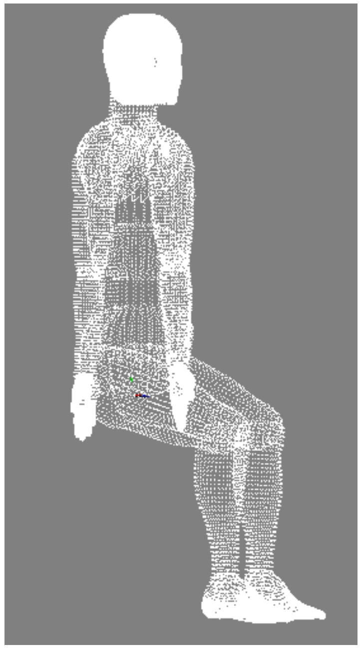
Different body size



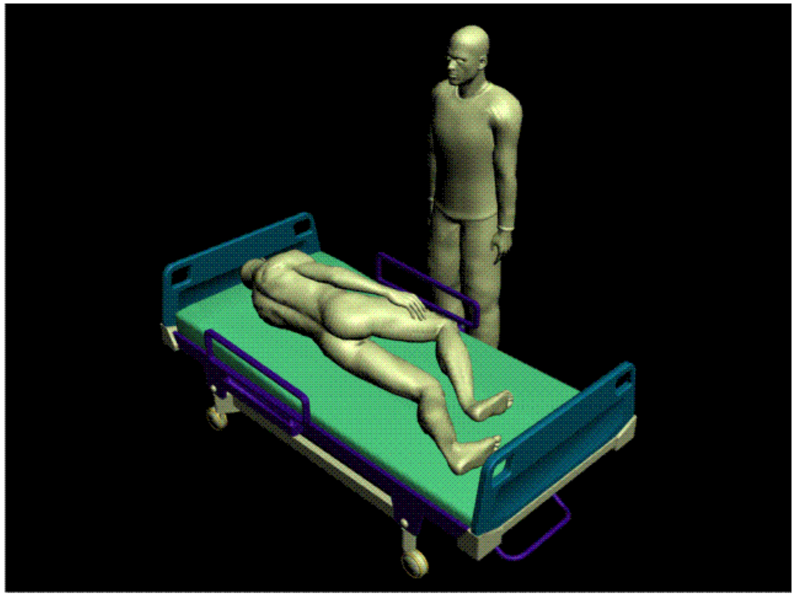
# Homogeneous Phantoms: Mesh Generator

Different postures

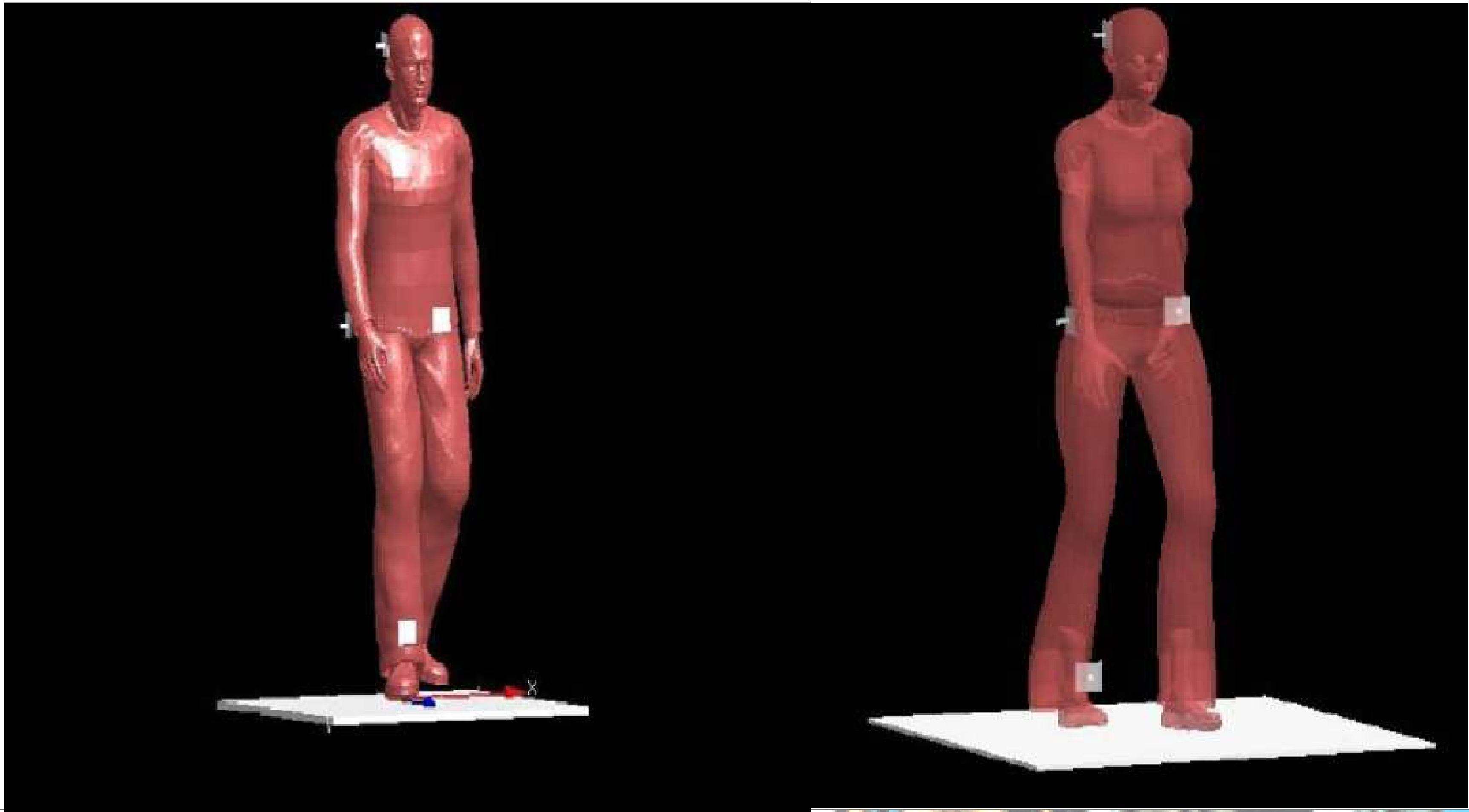




Complex scenarios

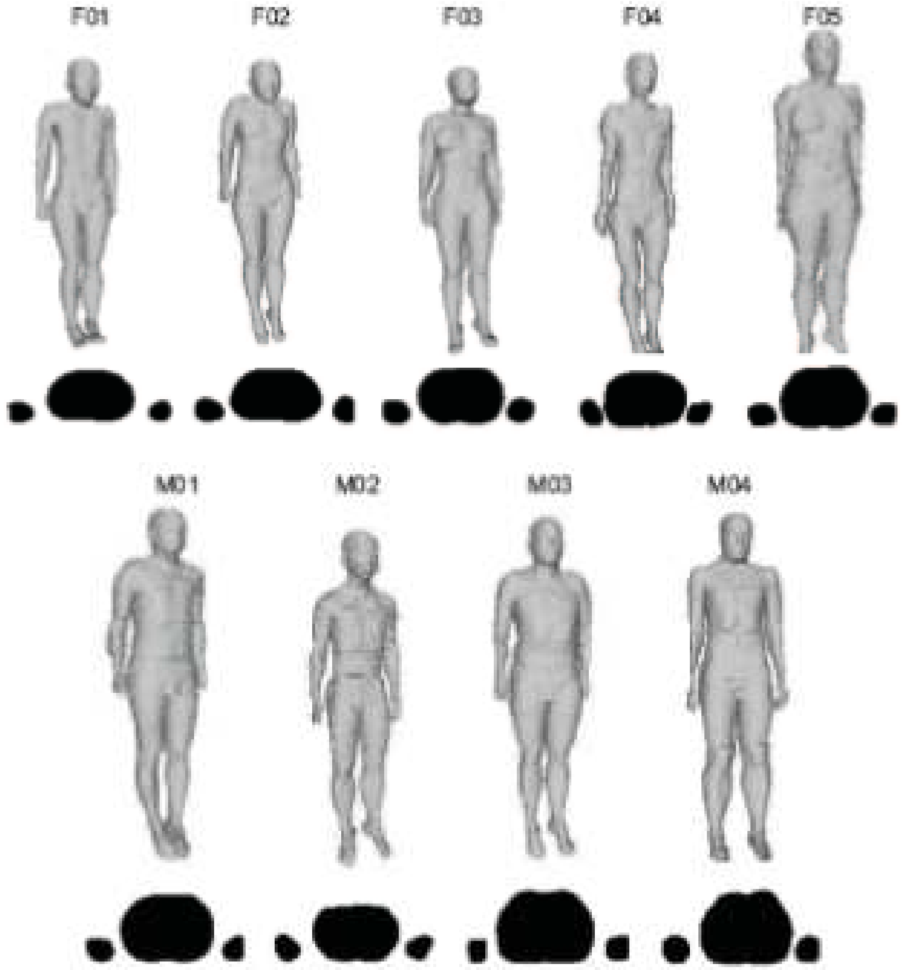


# Dynamic Human Phantom: James and Jessica



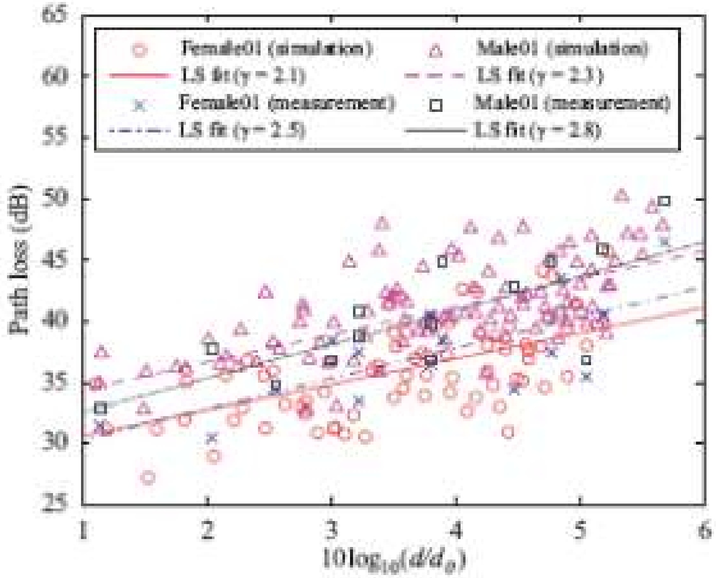
# Imperial/QMUL Digital Body Phantoms

| | F01 | F02 | F03 | F04 | F05 | M01 | M02 | M03 | M04 |
|---|---|---|---|---|---|---|---|---|---|
| Height (m) | 1.60 | 1.66 | 1.55 | 1.65 | 1.80 | 1.76 | 1.67 | 1.78 | 1.80 |
| Weight (kg) | 50 | 55 | 52 | 52 | 75 | 73 | 56 | 87 | 85 |
| BMI | 19.5 | 20.0 | 21.6 | 19.1 | 23.1 | 23.6 | 20.1 | 27.5 | 26.2 |
| Waist (cm) | 67.0 | 72.7 | 68.8 | 66.2 | 81.9 | 82.6 | 67.1 | 91.0 | 84.2 |
| Chest (cm) | 79.4 | 85.6 | 96.9 | 80.7 | 107.9 | 91.3 | 82.1 | 101.1 | 98.4 |



# Subject-specific On-body Radio Channel

- Propagation along the torso $PL_{dB}(d) = PL_{dB}(d_0) + 10\gamma \log_{10}(d/d_0) + X_\sigma$




PATH LOSS EXPONENT AND STANDARD DEVIATION OF THE SHADOWING FACTOR FOR THE NINE SUBJECTS (F – FEMALE, M – MALE).

| | F01 | F02 | F03 | F04 | F05 | M01 | M02 | M03 | M04 |
|---|---|---|---|---|---|---|---|---|---|
| $\gamma$ | 2.3 | 2.4 | 2.3 | 2.7 | 2.9 | 2.5 | 2.6 | 3.1 | 3.0 |
| $\sigma$ | 4.0 | 3.9 | 3.8 | 6.0 | 4.1 | 3.9 | 4.5 | 4.8 | 3.8 |

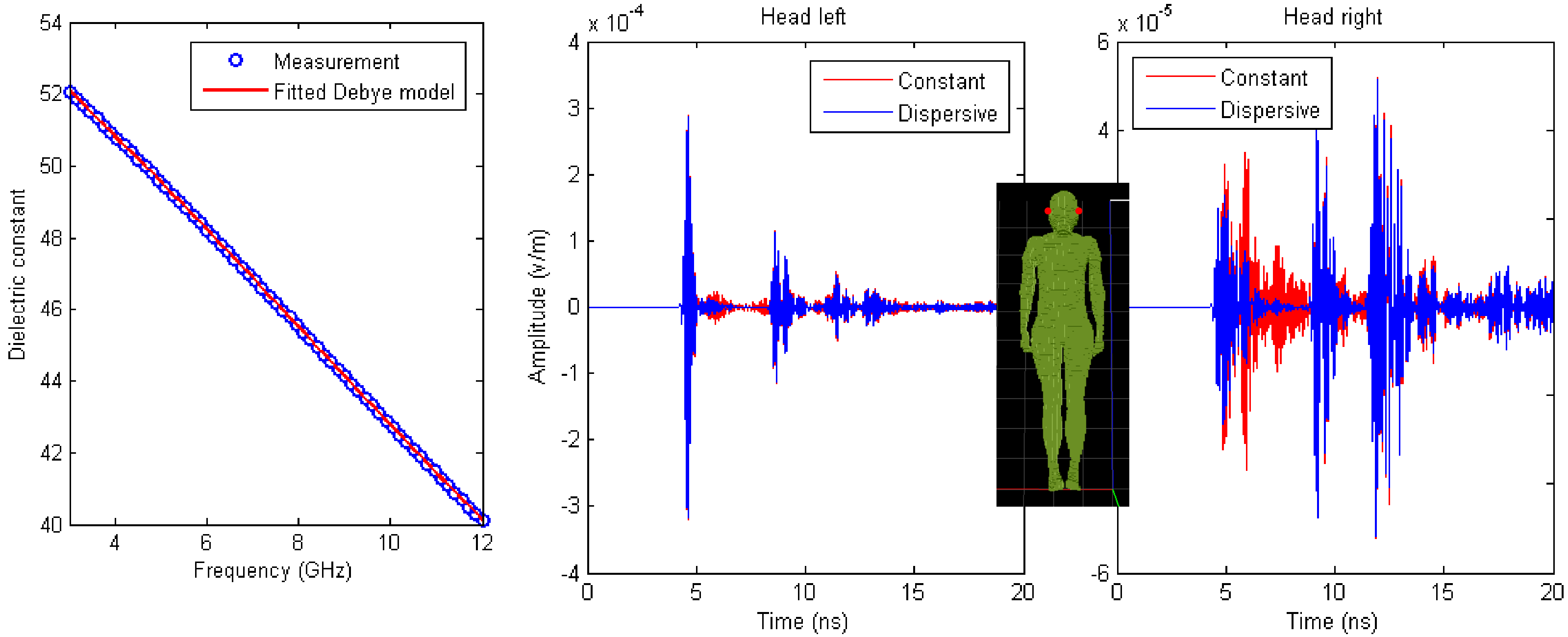
**The transmitter is on the left side of the waist.**

**•Good agreement between simulated and measured data.**

**•Subject with a bigger cuarvature radius at the trunk (F05, M03, M04) presents higher path loss exponent.→ the on-body channel is subject specific.**

# Subject-specific On-body UWB Radio Channel

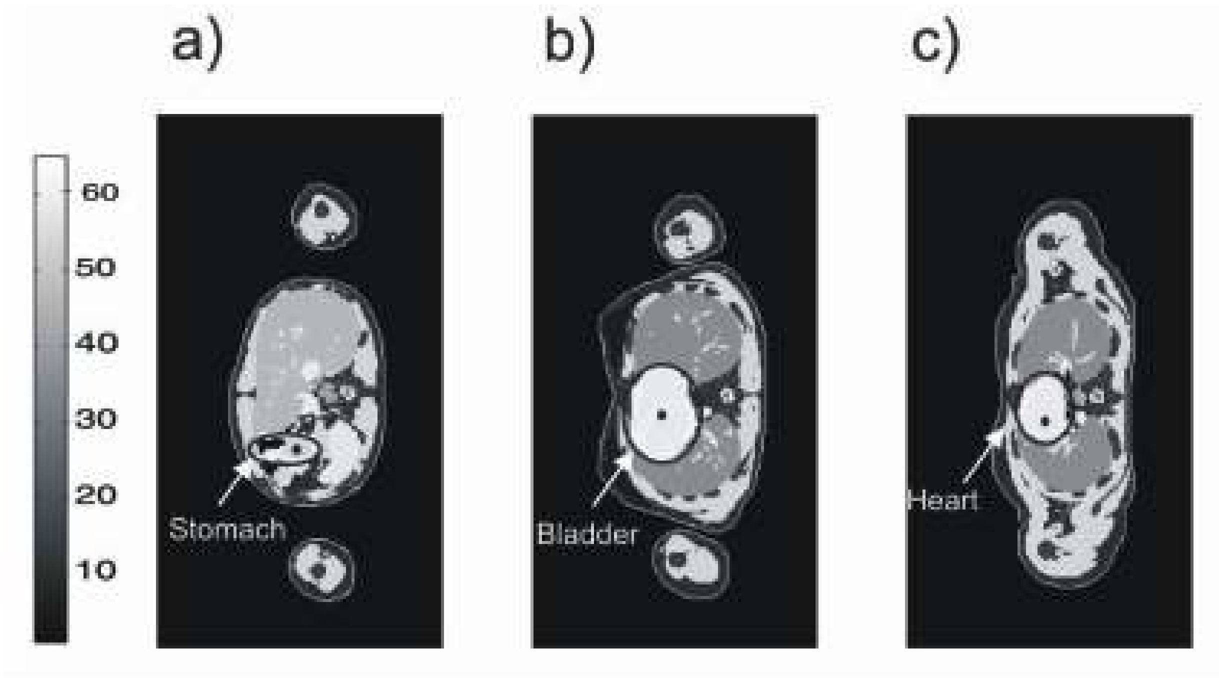
- Dispersive FDTD modeling.

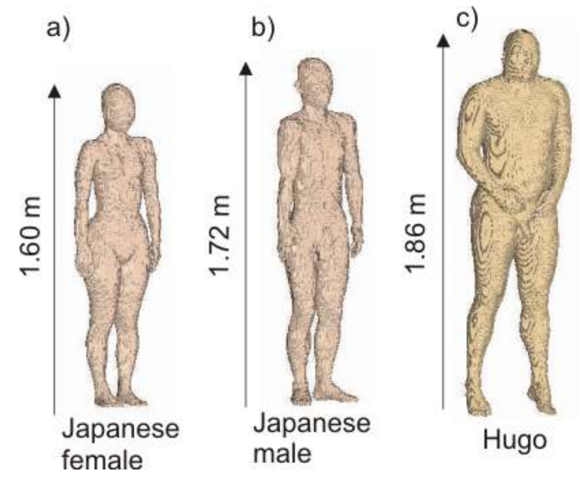



**3-pole Debye model**

$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\Delta\varepsilon_1}{1 + j\omega\tau_1} + \frac{\Delta\varepsilon_2}{1 + j\omega\tau_2} + \frac{\Delta\varepsilon_3}{1 + j\omega\tau_3} + \frac{\sigma}{j\omega\varepsilon_0}$$

# Subject-Specific In-body Simulations




**Parameters of the organs' content**

| | 402MHz | | 868MHz | |
|---|---|---|---|---|
| **Organ** | **σ(S/m)** | $\varepsilon_r$ | **σ(S/m)** | $\varepsilon_r$ |
| **Stomach** | **0.81** | **57.96** | **0.96** | **56.03** |
| **Bladder** | **1.35** | **64.16** | **1.52** | **61.46** |
| **Heart** | **1.35** | **64.16** | **1.52** | **61.46** |

**Andrea Sani, Akram Alomainy, Yang Hao, "Numerical Characterization and Link Budget Evaluation of Wireless Implants Considering Different Digital Human Phantoms", IEEE Transactions on Microwave Theory and Techniques, Biomedical Special Issue 2009**

# Body Losses

It is considered only the power dissipated while the wave propagates inside the tissues.

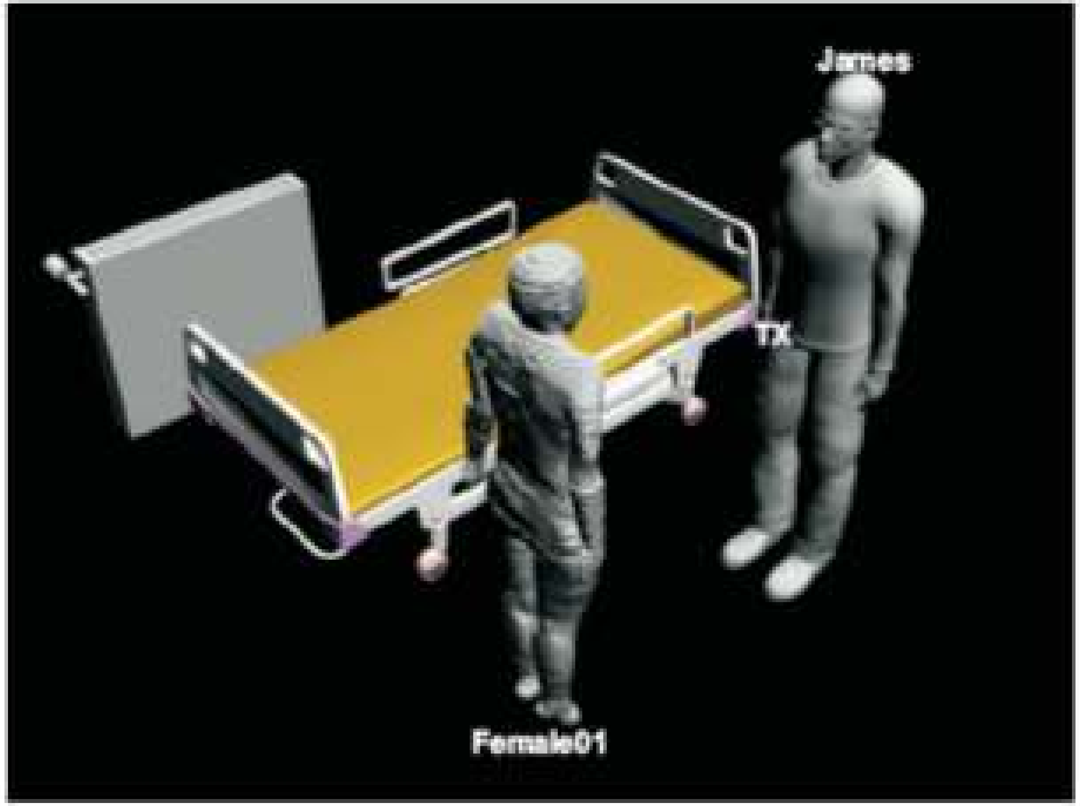
$$\eta_{dB} = 10\log\left(\frac{P_{body}}{P_{free}}\right)$$

It is considered an insulation of 4mm between the source and the body tissues.

| 402MHz | Stomach (Empty) | Stomach (Full) | Bladder | Heart |
|---|---|---|---|---|
| Asian Female | -10.8 | -13.4 | -17.8 | -18.4 |
| Asian male | -11.4 | -15.3 | -18.2 | -19.8 |
| Hugo | -11.8 | -16.8 | -22.5 | -24.2 |
| **868MHz** | **Stomach (Empty)** | **Stomach (Full)** | **Bladder** | **Heart** |
| Asian Female | -14.4 | -17.8 | -19.2 | -27.0 |
| Asian male | -15.1 | -19.5 | -23.5 | -27.2 |
| Hugo | -15.8 | -21.4 | -27.0 | -33.0 |

**The in-body radio channel is very much subject-specific**

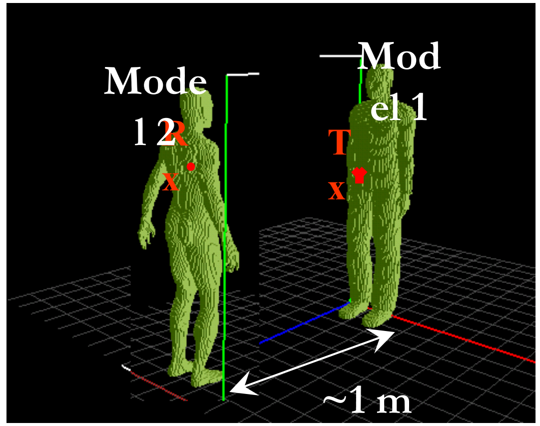
# Subject-specific Inter-body Radio Channels

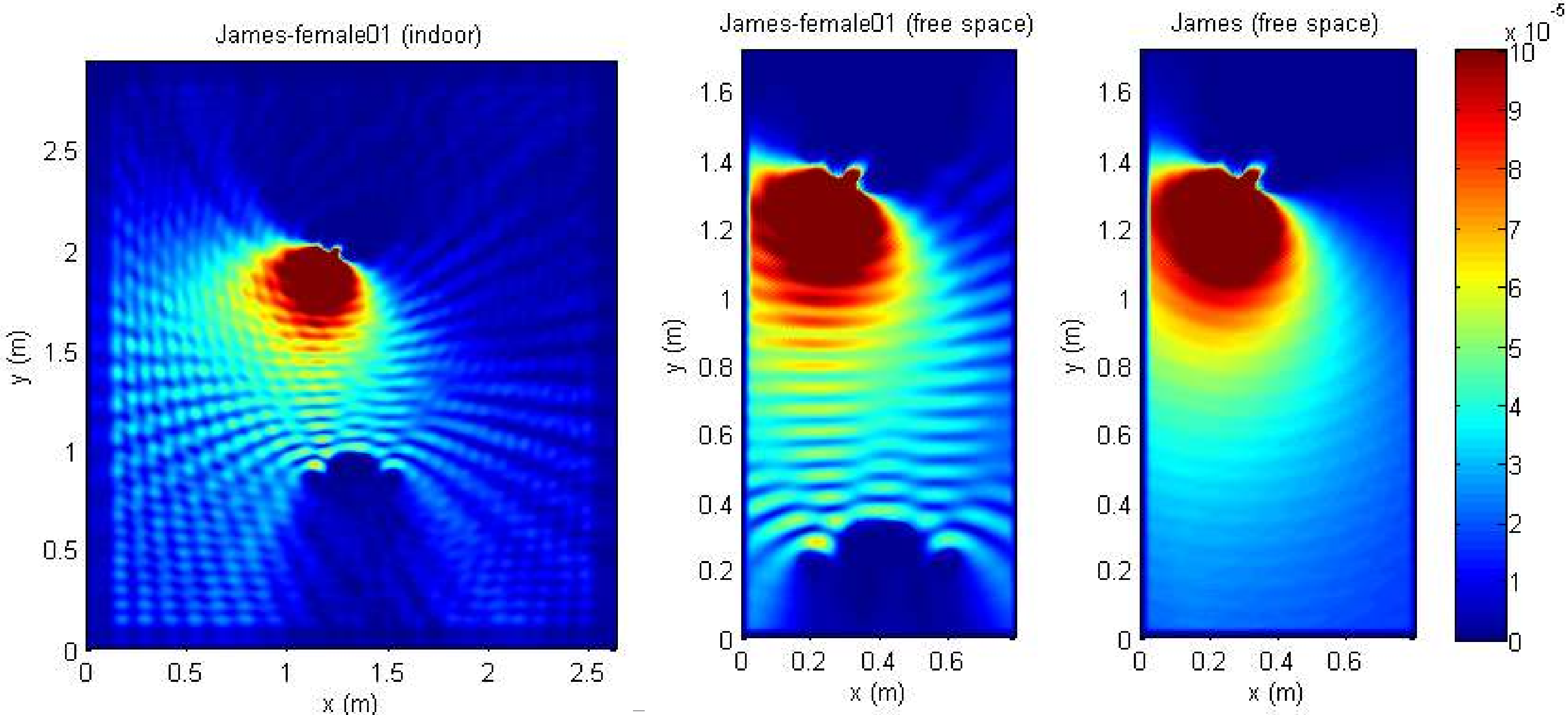



Size of domain:
2.94 × 2.64 × 2.74 $m^3$
Frequency: 2.4 GHz
Scenarios:
– Indoor (with walls, floor and furniture), models 1 & 2
Model 1: James-standing
Model 2:
F01,F02,F03,F04,F05
M01,M02,M03,M04.
Antenna:
Tx – Planar inverted-L, modelled through EP in FDTD
Each simulation lasts 11 hrs.

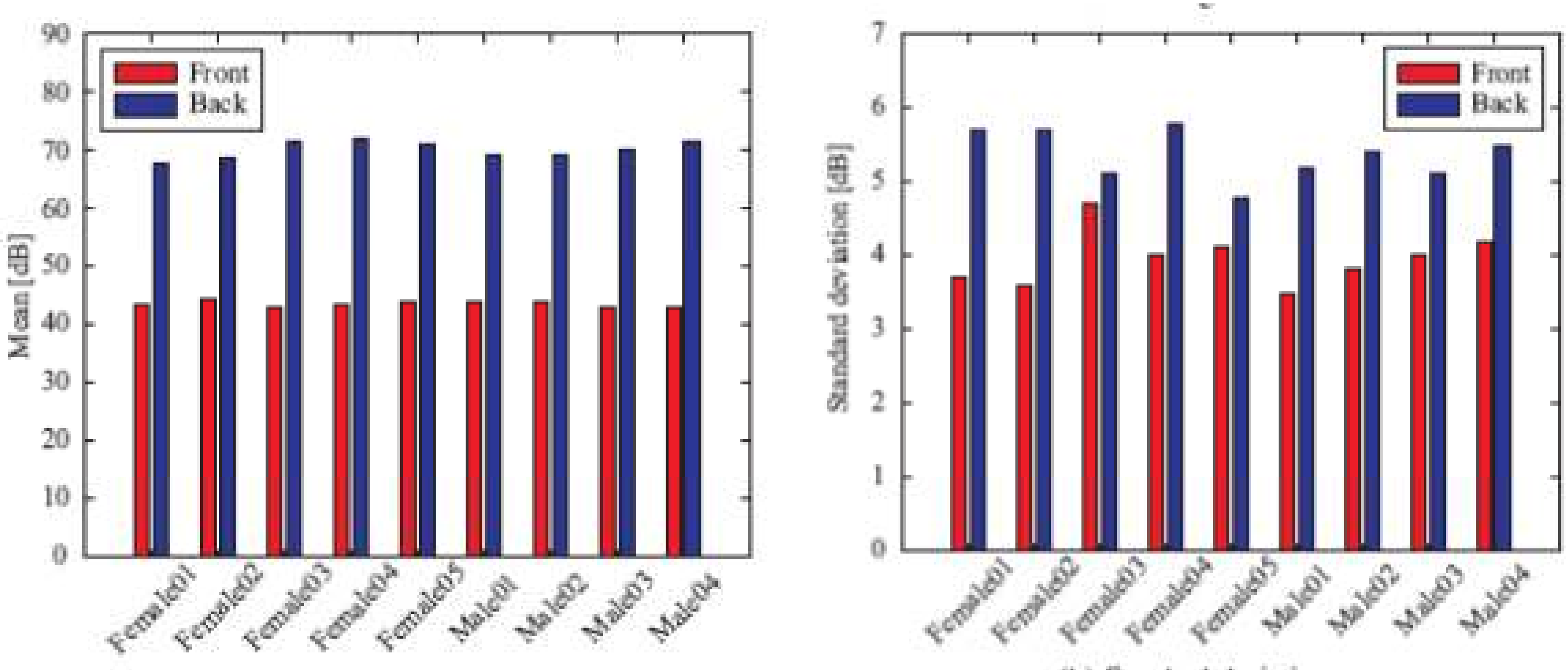
A. Sani , Y. Zhao, A. Alomainy, Y. Hao, and C.G. Parini. "An Efficient FDTD Algorithm Based on Equivalence Principle for Analyzing On-Body Antenna Performance" IEEE Transactions on Antenna and Propagation, April 2009.

# Subject-specific Inter-body Radio Channels



# Subject-specific Inter-body Radio Channel




(a) Average value

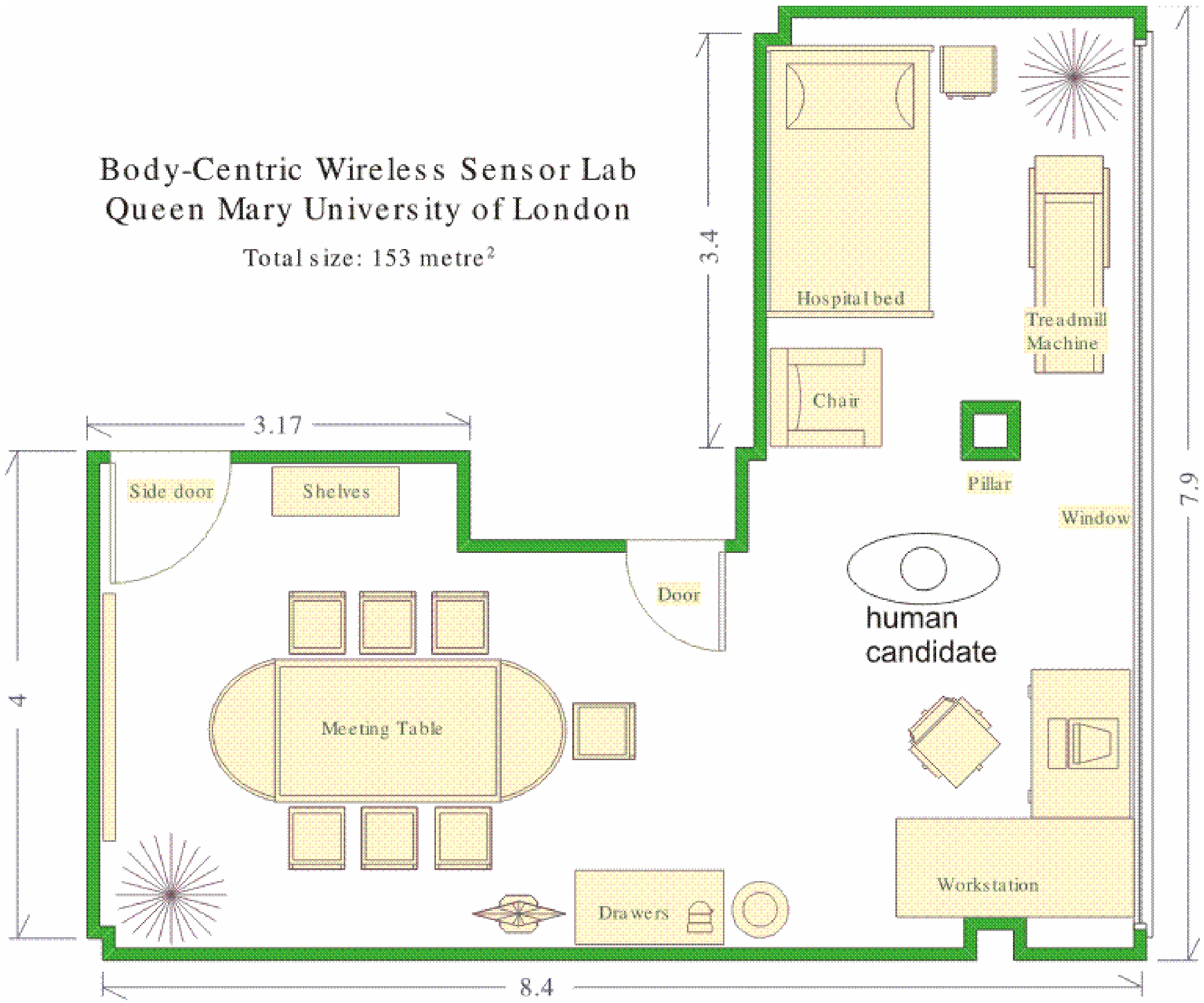
(b) Standard deviation

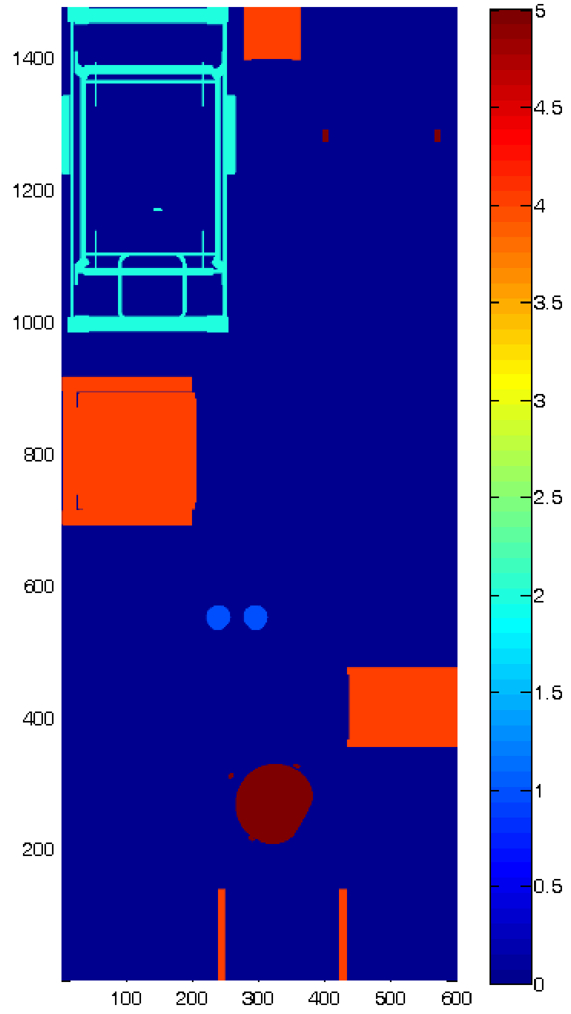
**The wave reaches the receiver through free space propagation (LOS), or reflections from surrounding scatterers (NLOS)**

↓

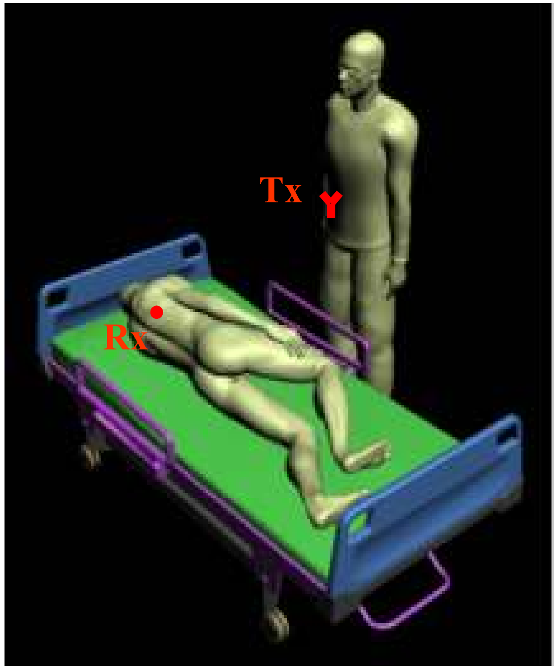
**The inter-body radio channel is not much subject-specific**

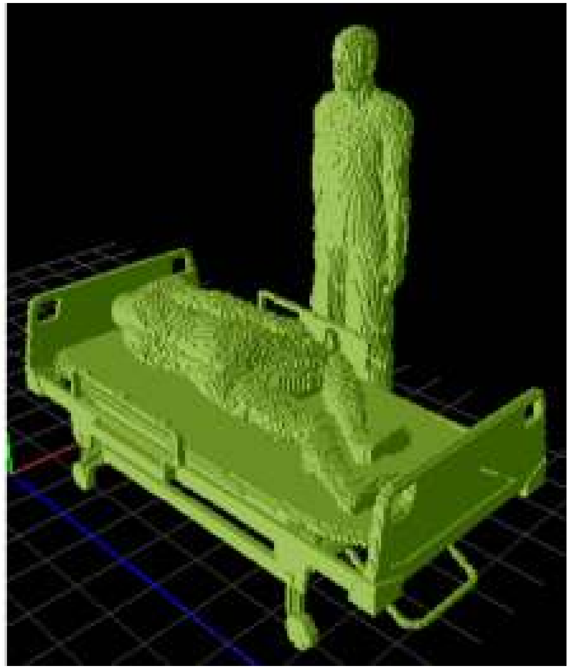
# Modelling Indoor Radio Propagation



# Modelling Inter-body Radio Propagation



| Average path loss [dB] | | |
|---|---|---|
| | Front | Back |
| Simul. | 46.2 | 54.8 |
| Meas. | 47.5 | 56.2 |

**Simulations and measurements were performed at 2.4 GHz**

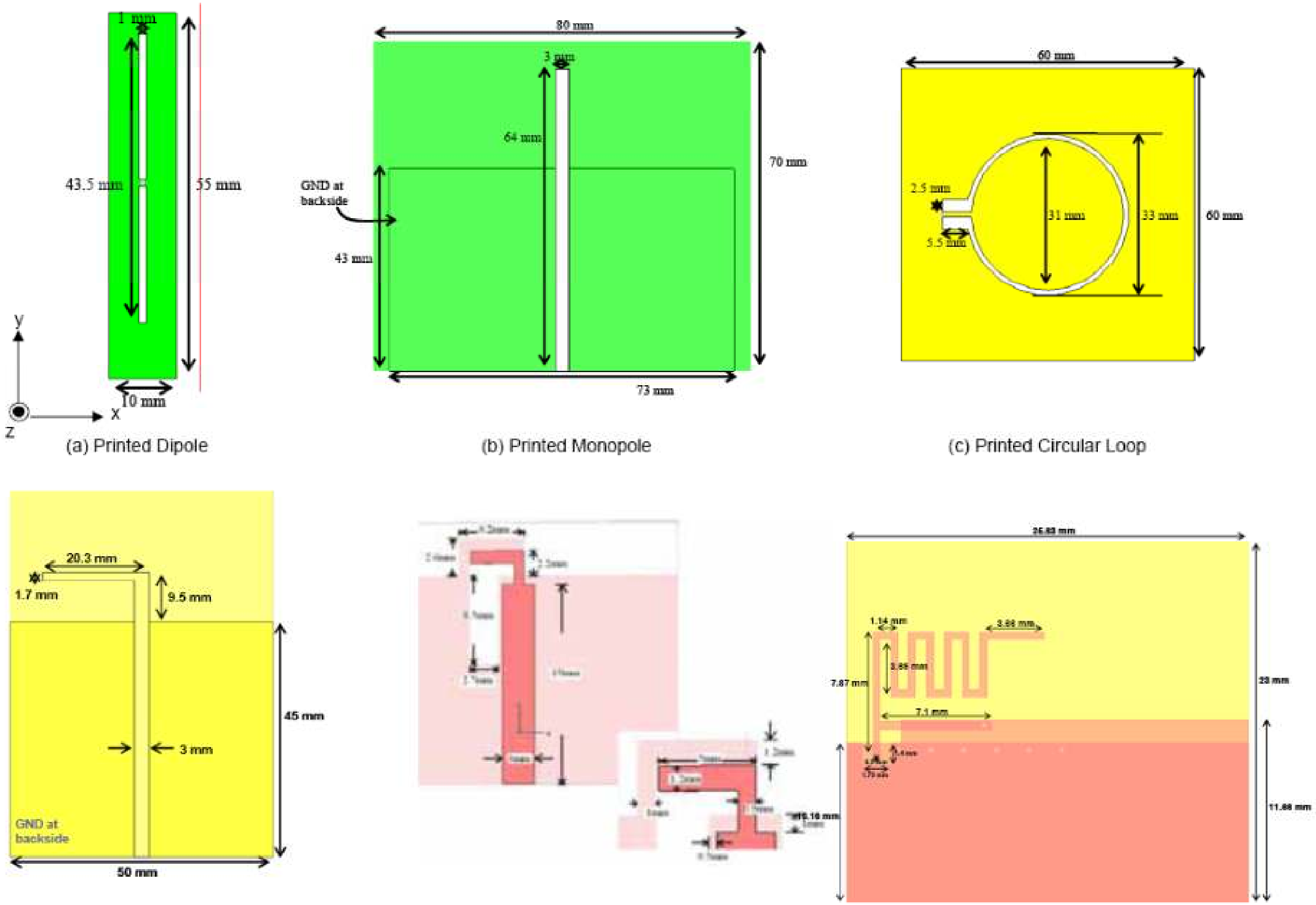
| | Human muscle | Bed cushion | Bed frame | Walls/floor |
|---|---|---|---|---|
| Dielectric constant | 52.79 | 1.3 | 1.0 | 2.4 |
| Conductivity | 1.7 | 0.01 | $10^6$ | 0.15 |

Queen Mary
University of London

# Outline

- Overview of Body-Centric Wireless Communications
- On-body Radio Propagation Modelling and Measurement
- On-body Antennas Design
- Demonstration and Applications of Zigbee Sensors.
- Summary and Future Challenges

# Different Antenna Types in On-body Channel Modelling




(a) Printed Dipole (b) Printed Monopole (c) Printed Circular Loop

(d) Inverted L (e) Parasitic L (f) Wiggle Antenna

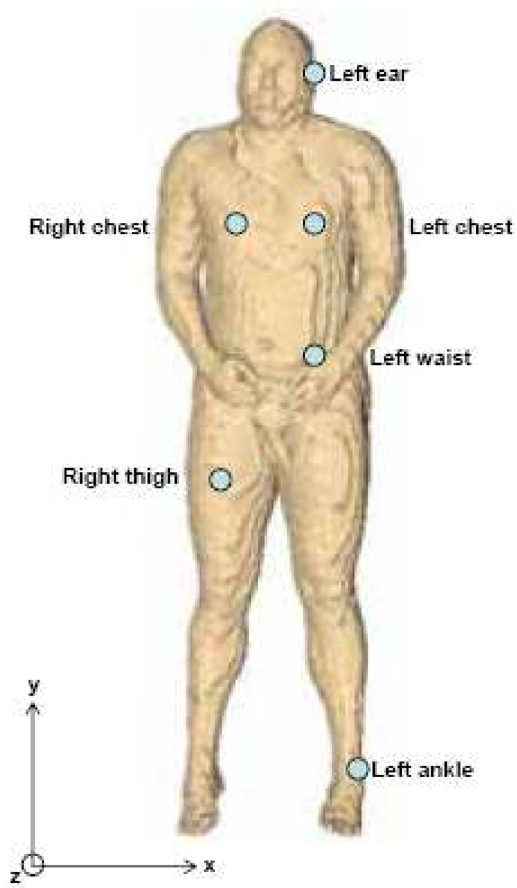
# Wearable Antenna Performance in Free Space

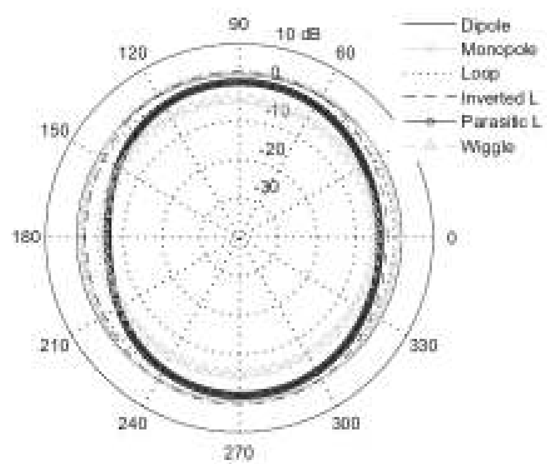
TABLE I

ANTENNA TYPES APPLIED IN NUMERICAL ANALYSIS, THEIR RELATED DIMENSIONS AND FREE SPACE ANTENNA PARAMETERS

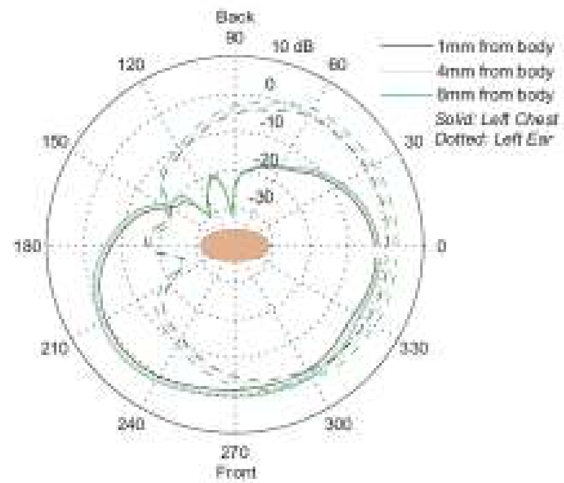
| Antenna | Size ($mm^2$) | Gain (dB) | Radiation Efficiency (%) |
|---|---|---|---|
| | 2.4/2.44/2.48 GHz | | |
| Printed dipole | 10x55 | 1.8/1.9/2.0 | 95/97/99 |
| Printed monopole | 80x70 | 3.3/3.2/3.3 | 100/99/100 |
| Circular loop | 60x60 | 2.9/2.9/3.0 | 97/98/99 |
| Inverted L | 50x45 | 3.3/3.2/3.0 | 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 |

# Wearable Antenna On-body Performance



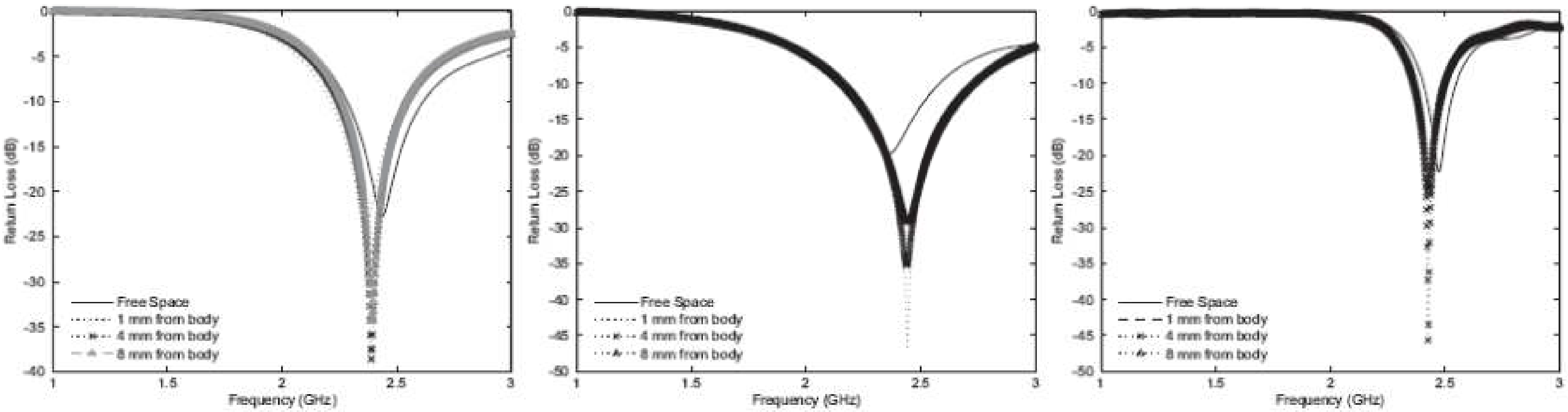




Radiation patterns of the applied antennas in free space at 2.44 GHz in the azimuth plane (xz)




Radiation patterns of the printed dipole antenna placed on left side of the chest and the left ear at 2.44 GHz in the azimuth plane (xz).

# Frequency Detuning




(a) Printed Dipole (b) Printed Monopole (c) Parasitic L

Return loss of the proposed antennas when placed on the left side of the chest at various distances from the body (1, 4 and 8 mm).

# Wearable Antenna On-body Performance

| | | 1mm/4mm/8mm | | | | |
|---|---|---|---|---|---|---|
| Antenna | Parameter/Position | Right Chest | Left Chest | Left Ear | Left Waist | Right Thigh |
| Printed Dipole | Gain (dB) | 2.6/3.1/3.6 | 0.9/1.6/2.4 | 1.0/2.1/3.2 | -/2.2/- | -/2.9/- |
| | Efficiency (%) | 39/47/48 | 28/33/38 | 27/33/43 | -/26/- | -/44/- |
| Printed Monopole | Gain (dB) | 4.0/4.5/5.0 | 3.5/4.0/4.5 | 2.5/3.5/4.4 | -/5.2/- | -/4.5/- |
| | Efficiency (%) | 49/53/59 | 45/51/58 | 32/39/49 | -/56/- | -/48/- |
| Circular Loop | Gain (dB) | 2.0/2.6/3.0 | 1.4/-/3.0 | 1.7/2.3/3.3 | -/5.3/- | -/3.7/- |
| | Efficiency (%) | 30/34/38 | 25/-/35 | 26/30/36 | -/49/- | -/39/- |
| Inverted L | Gain (dB) | 3.2/3.4/3.8 | 3.4/3.5/3.9 | 0.8/2.4/3.4 | -/4.0/- | -/4.3/- |
| | Efficiency (%) | 44/46/50 | 35/39/45 | 23/32/41 | -/43/- | -/50/- |
| Parasitic L | Gain (dB) | 1.9/2.1/2.5 | 0.5/0.8/1.4 | 1/1.5/- | -/3.5/- | -/2.2/- |
| | Efficiency (%) | 29/31/35 | 26/29/32 | 20/23/- | -/39/- | -/32/- |
| Wiggle Antenna | Gain (dB) | -4.2/-/- | - | - | - | - |
| | Efficiency (%) | 2/-/- | - | - | - | - |

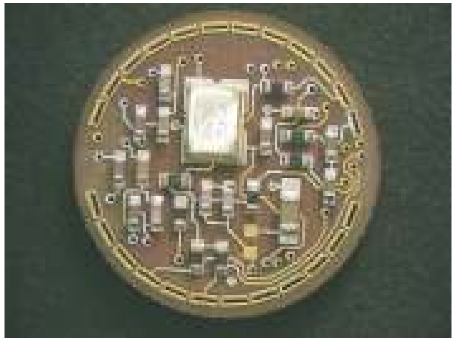
# Sensor Antenna Design Challenges

- Antenna to be compact and easily integrated.
- Immuned from de-tuning and performance degradation due to surrounding components and when placed on the body.
- Achieve maximum radiated power to enlarge coverage area specifically for communication between body mounted devices and base units/access points.
- Overcome shadowing proplems caused by the human body and the dynamic environment

# Sensor Transceiver Module

Top Layer - Transceiver

Bottom Layer - Transceiver

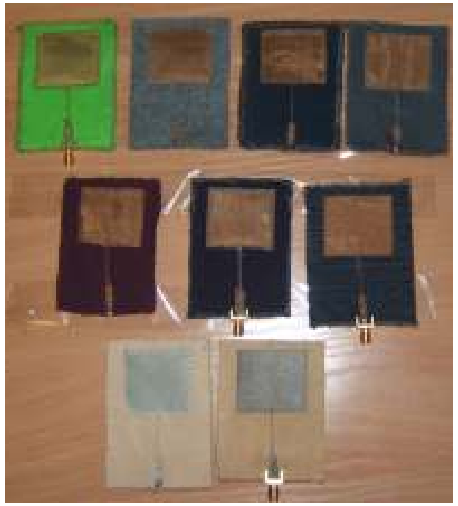


**Antenna printed around the circumference of the sensor transceiver board**

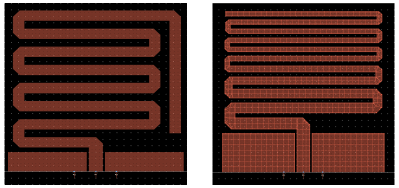
Sensor Prototype

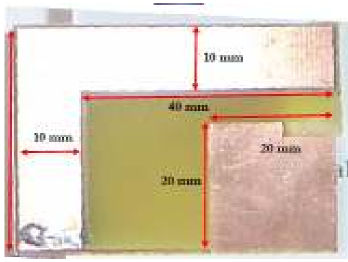
**Akram Alomainy, Yang Hao and Frank Pasveer, *Chapter 6: Antennas for Wearable Devices*, in "Antennas for Portable Devices", Wiley & Sons, Inc., 2007**

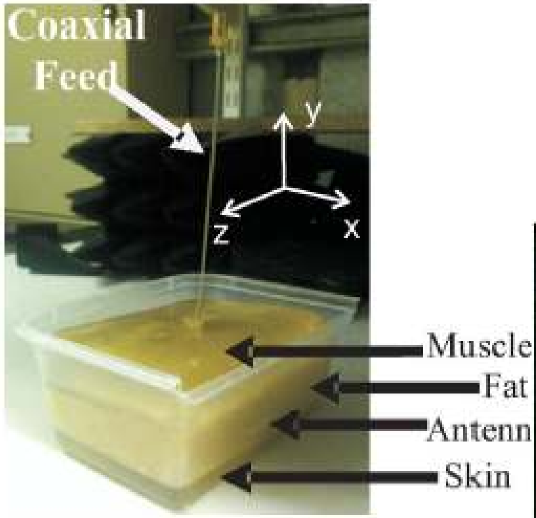
# Various Sensor Antennas Developed at QMUL

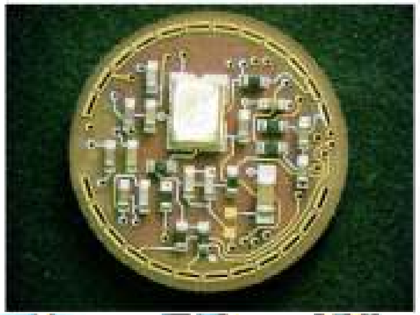






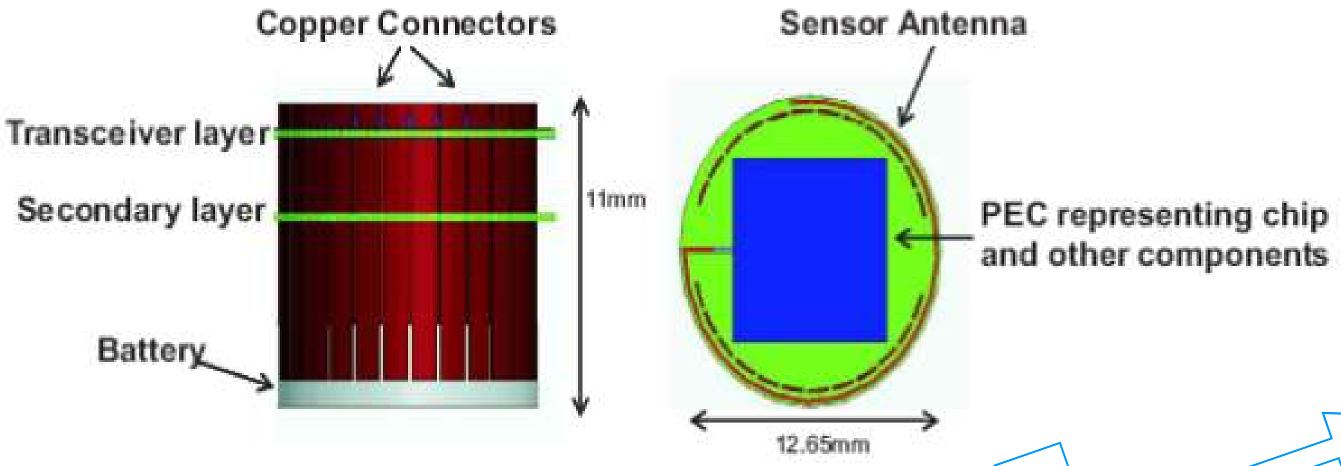








# Applied Sensor Models

- The performance of the sensor antenna is investigated using full wave EM numerical modelling techniques.



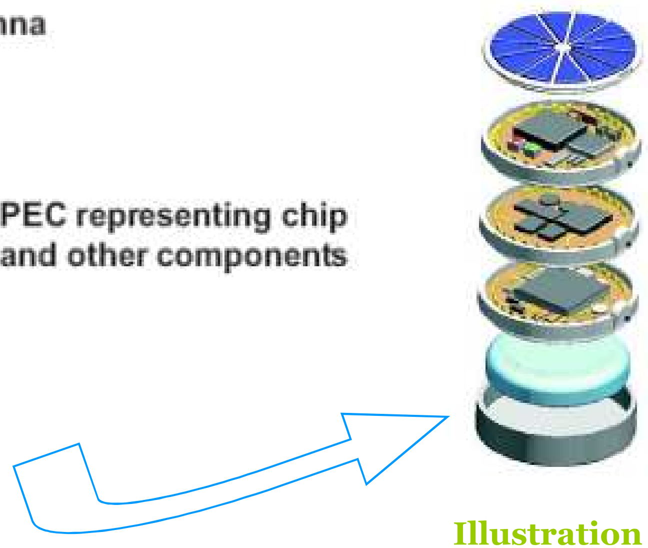
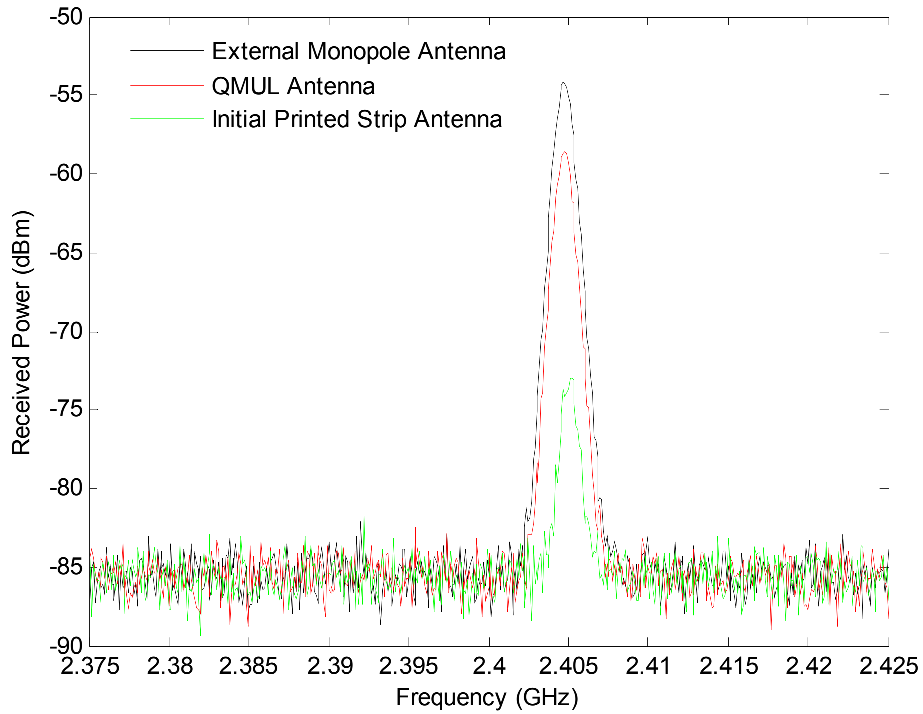



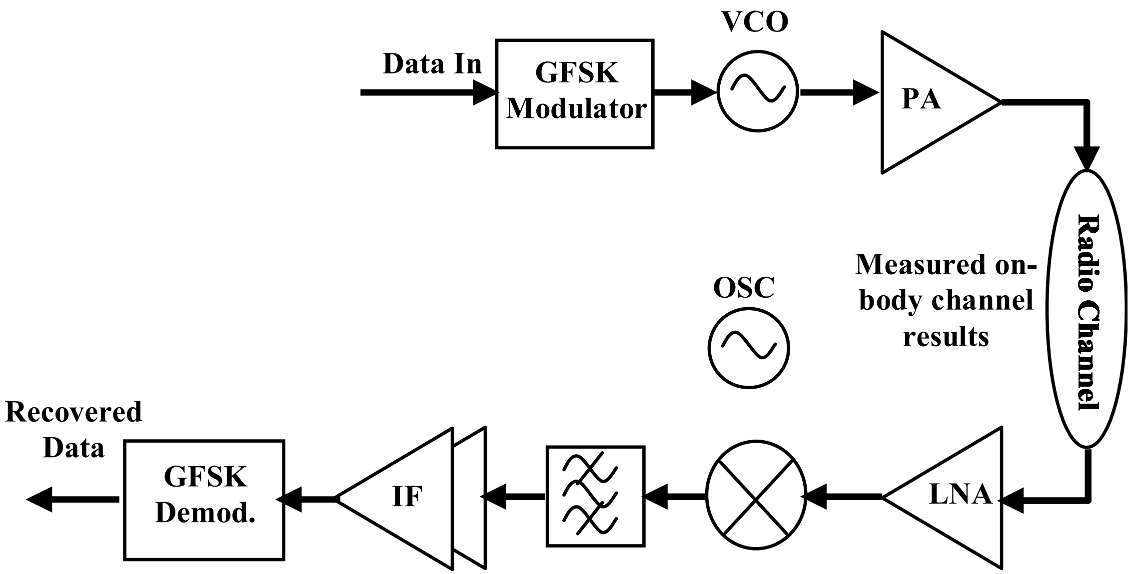
Illustration of production sensor

# Improved Antenna Performance

- Measurement performed with Microstrip Patch at 2.4 GHz working as the receiver. Output power of 0dBm. Three cases are applied for transmitter:
- Transceiver module with external monopole antenna.
- Transceiver module with modified QMUL antenna.
- Initial quarter-wavelength printed strip antenna.



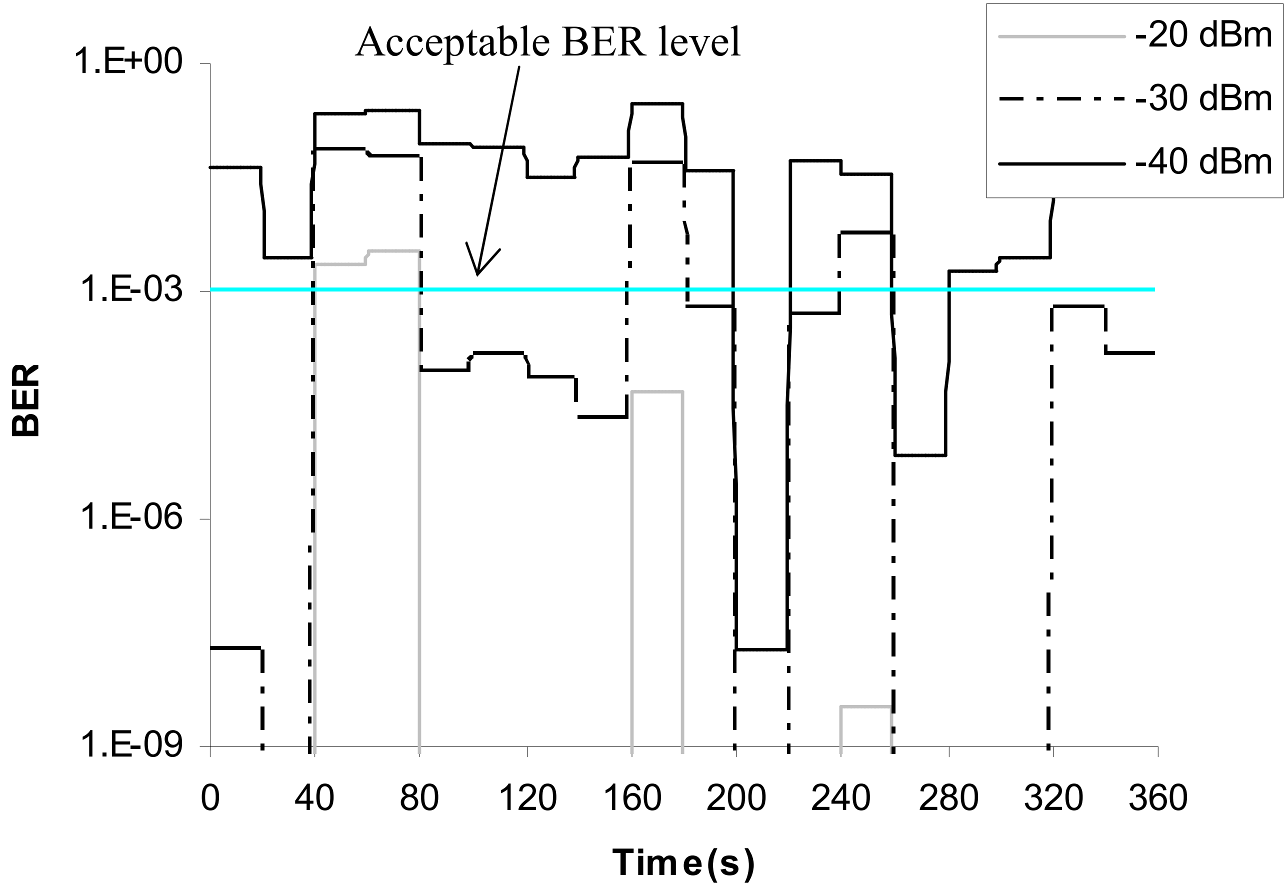
# Transceiver System Modelling




- Measured channel data (in lab) used for system performance evaluation include direct paths, multipath components and channel noise and their variation due to body postures and movements.

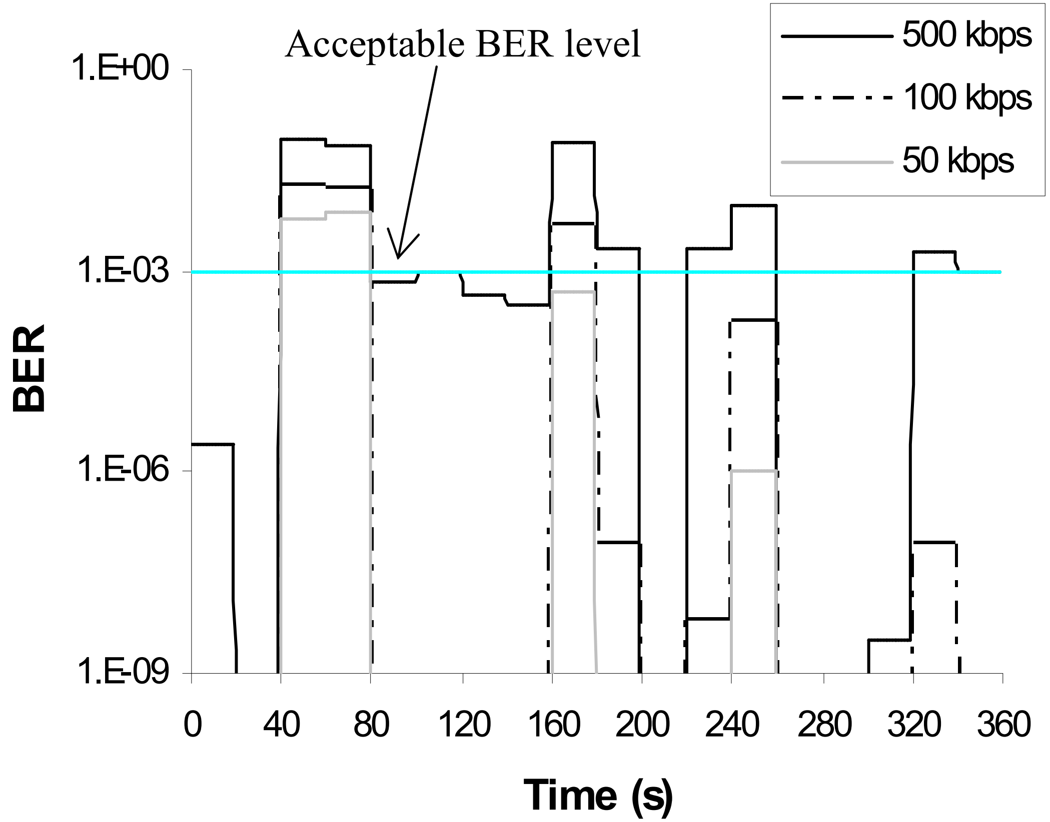
Alomainy, A.; Hao, Y.; Owadally, A.; Parini, C. G.; Nechayev, Y.; Constantinou, C. C.; Hall, P. S.; "Statistical Analysis and Performance Evaluation for On-Body Radio Propagation With Microstrip Patch Antennas", IEEE Transactions on Antennas and Propagation, Volume 55, Issue 1, Jan. 2007 Page(s):245 – 248.

# BER performance VS Transmitted Power



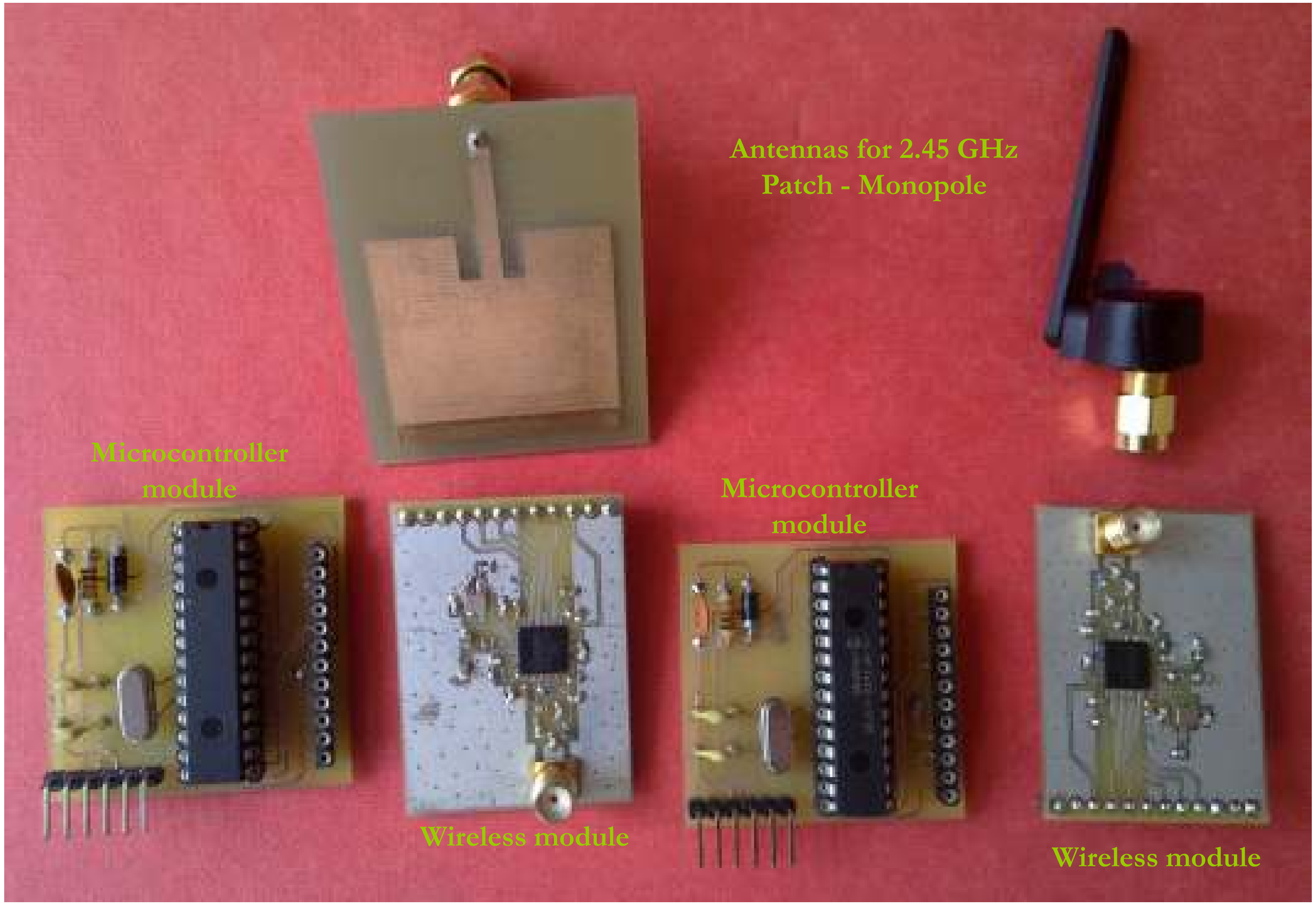

Trunk-to-Left Hand Rx5 scenarios

# BER performance VS Data Rate

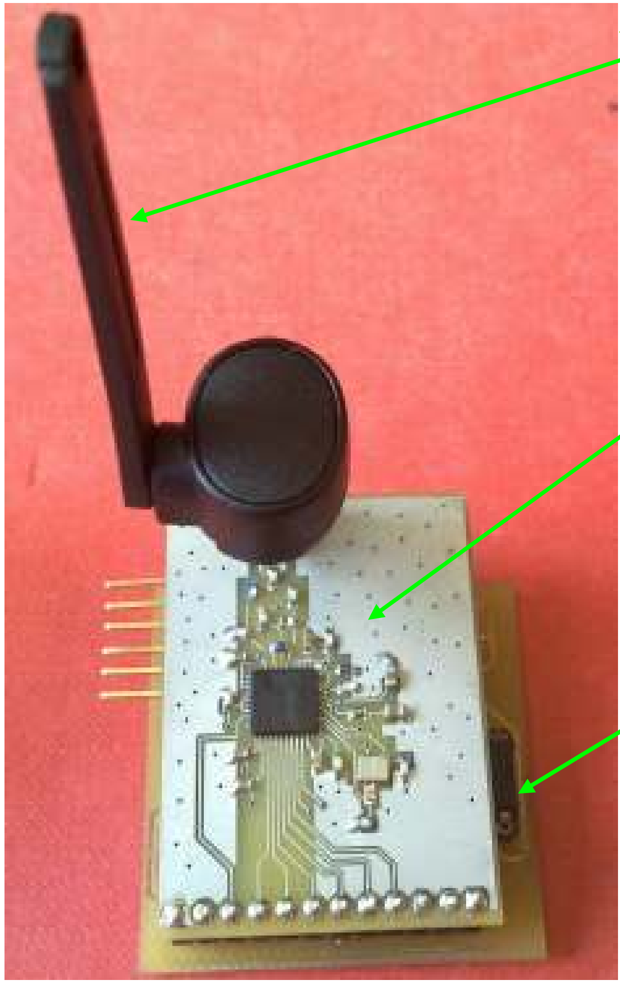



Trunk-to-Left Hand Rx5 scenarios

# Design of Wireless Modules at 2.45 [GHz]



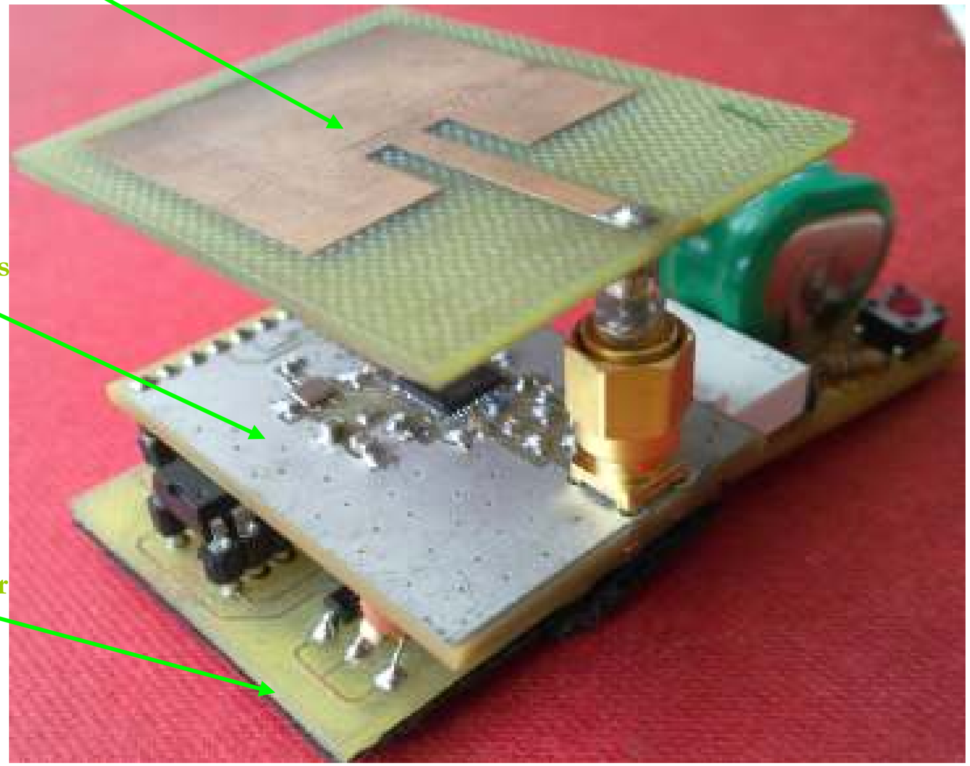
# Assembled Wireless Modules



Antennas for 2.45 GHz
Monopole - Patch

2.45 GHz Wireless
modules

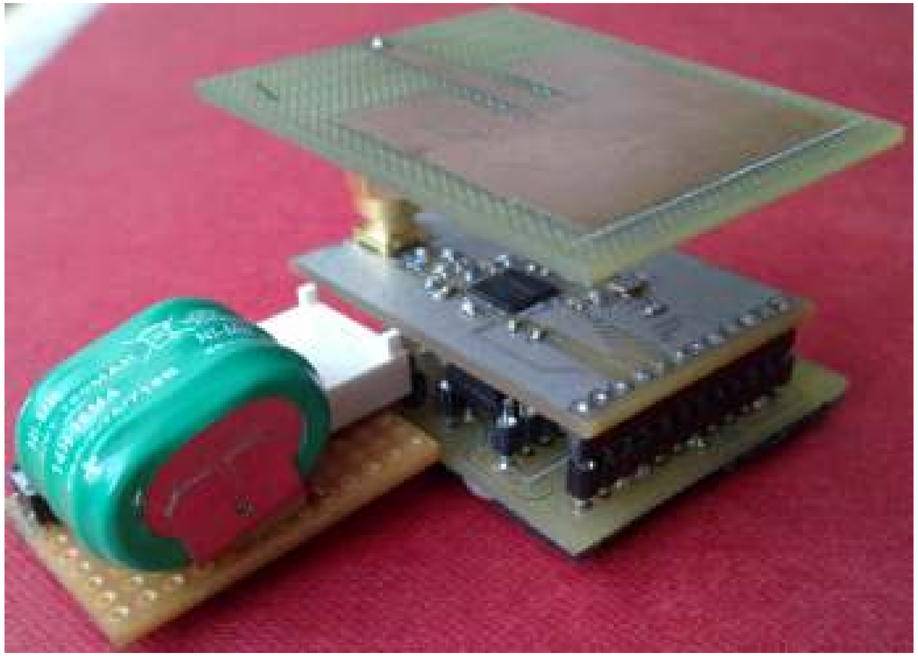
Microcontroller
modules



# Texas Instruments Transceiver CC2420

- True single-chip 2.4 GHz IEEE 802.15.4 compliant RF transceiver with baseband modem and MAC support
- DSSS baseband modem with 2 MChips/s and 250 kbps effective data rate.
- Suitable for both RFD and FFD operation
- Low current consumption (RX: 19.7 mA, TX: 17.4 mA)
- Programmable output power
- Low supply voltage (2.1 – 3.6 V) with integrated voltage regulator

# Embedded Radio System



- Measures average received power ("S21" parameters).
- Limited Tx. Power (Defined by battery life and transceiver).
- Measurement of signal's phase is not possible.
- Number of samples over time are defined by the clock speed of the transceiver and also by the microcontroller speed cycle.

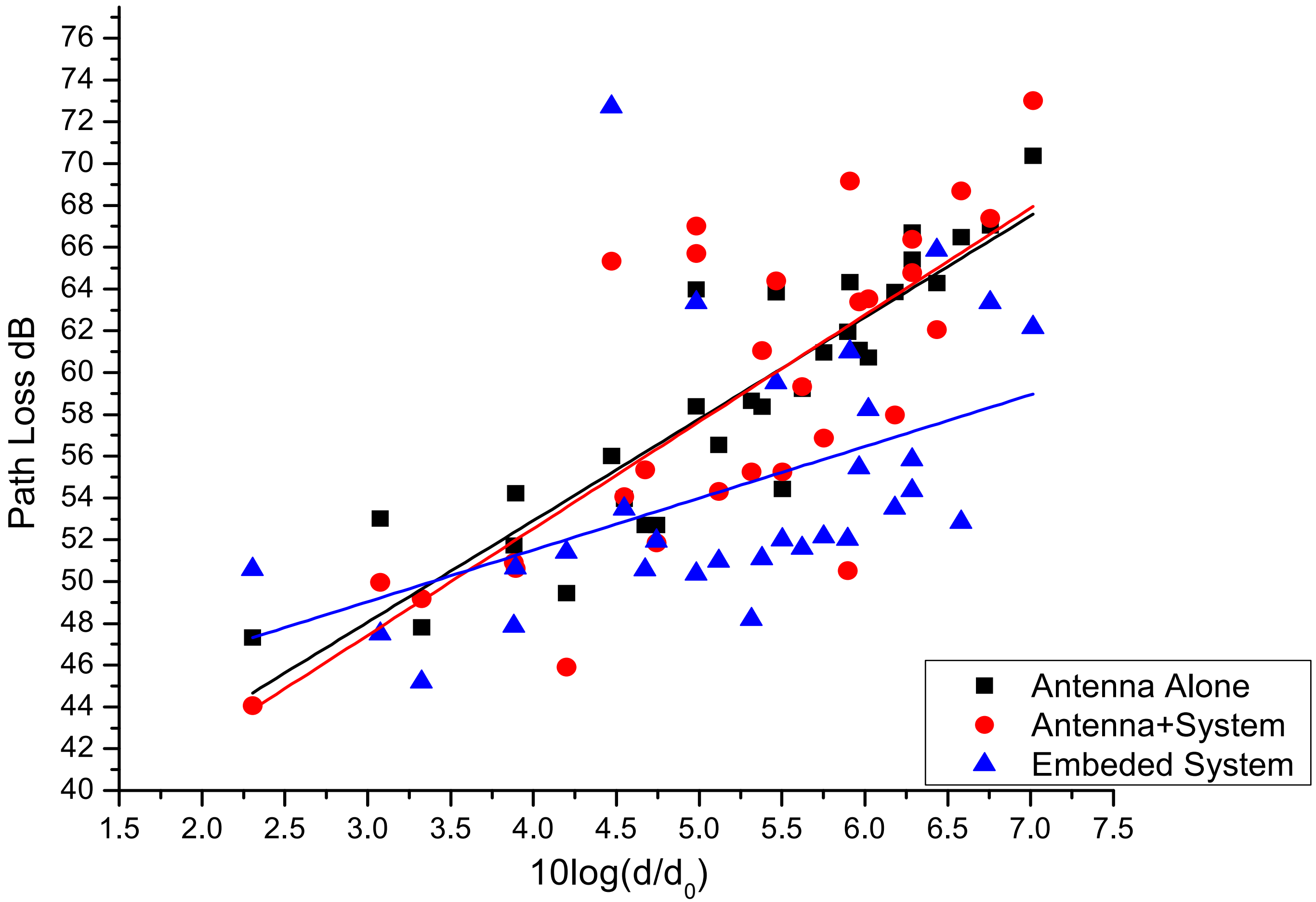
- Measures a fixed frequency (commercial systems usually work at channel 1).
- No need of coaxial cables.
- Performance of the system is not affected by the coaxial cables.
- Flexible over time, environment, activity, posture and user.

# On-Body Path Loss, $d_0$=10 cm

| | | Value | Standard Error |
|---|---|---|---|
| Antenna Alone | Intercept | **33.47825** | 2.37884 |
| | Slope | **4.86124** | 0.44563 |

| | | Value | Standard Error |
|---|---|---|---|
| Antenna+System | Intercept | **32.09894** | 4.39921 |
| | Slope | **5.11089** | 0.82411 |

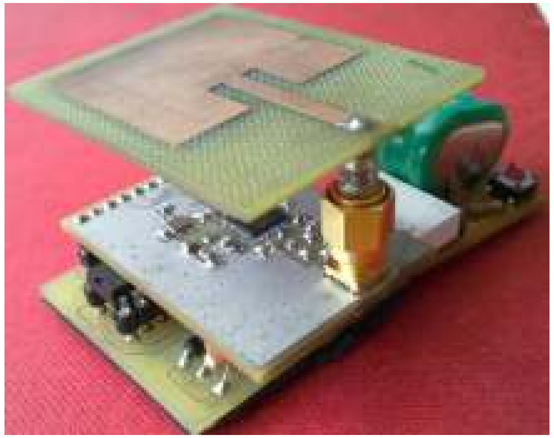
| | | Value | Standard Error |
|---|---|---|---|
| Embeded System | Intercept | **41.60945** | 4.87192 |
| | Slope | **2.47624** | 0.91266 |



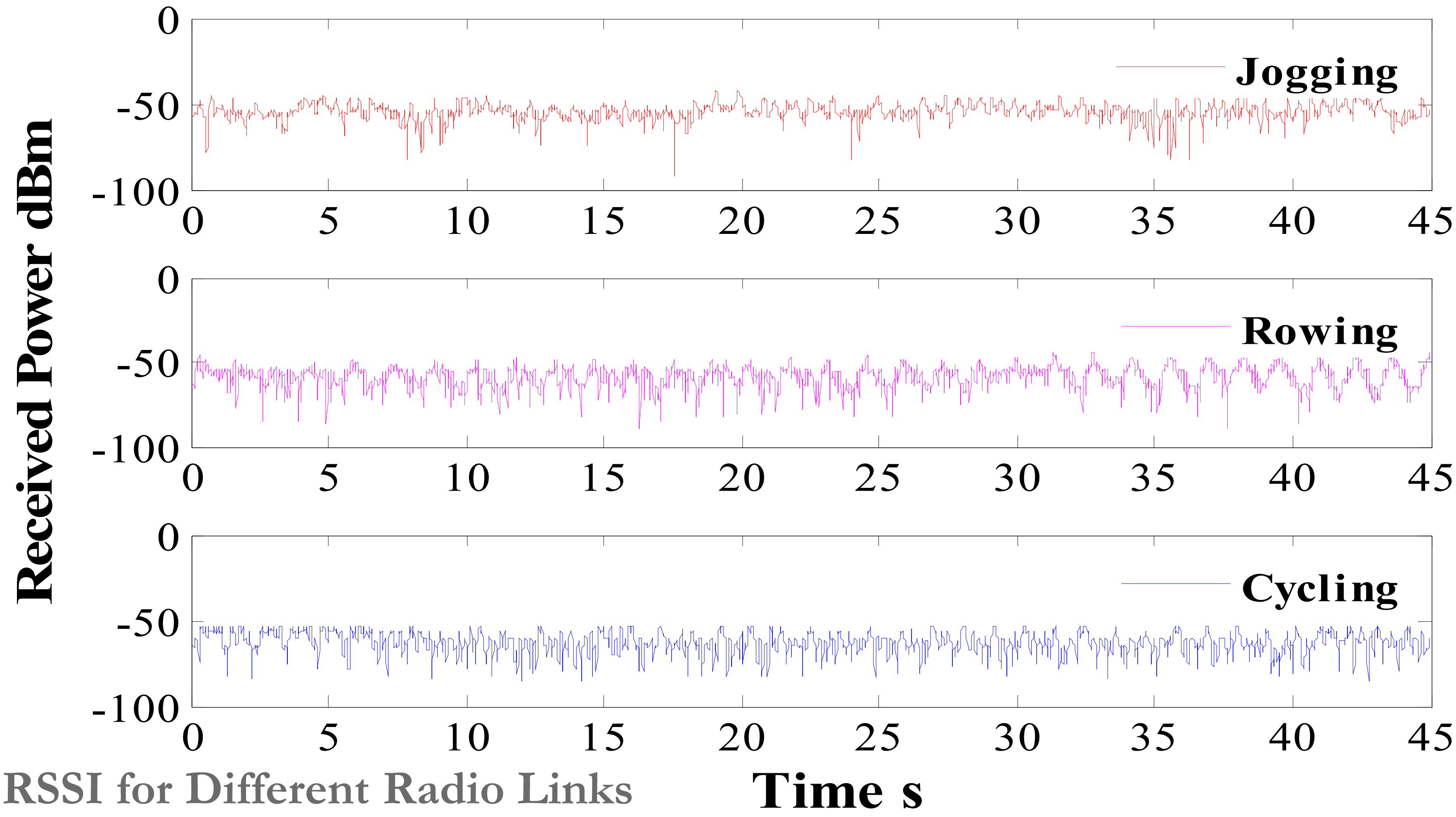

$d_0$=10cm

# Applications of Wireless Wearable Sensors (I): Sports and Physiotherapy

- **On body channels**
  - **Belt-back,Belt-wrist, Belt-ankle,Belt-chest**
- **Wireless sensor module (QMUL prototype)**
  - **IEEE 802.15.4 Zigbee-Ready transceiver**



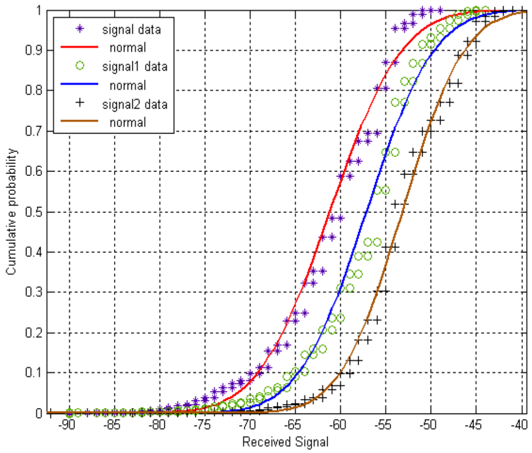
# Applications of Wireless Wearable Sensors (I): Sports and Physiotherapy



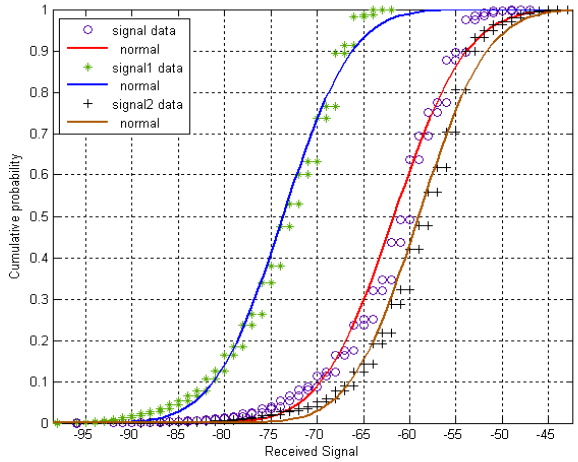

RSSI for Different Radio Links

# Applications of Wireless Wearable Sensors (I): Sports and Physiotherapy

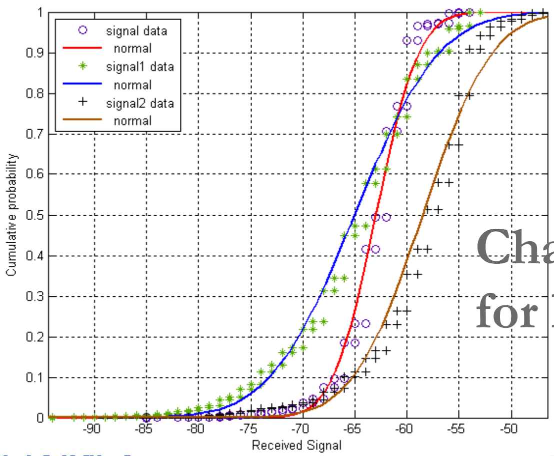
**Belt-Chest Channel**



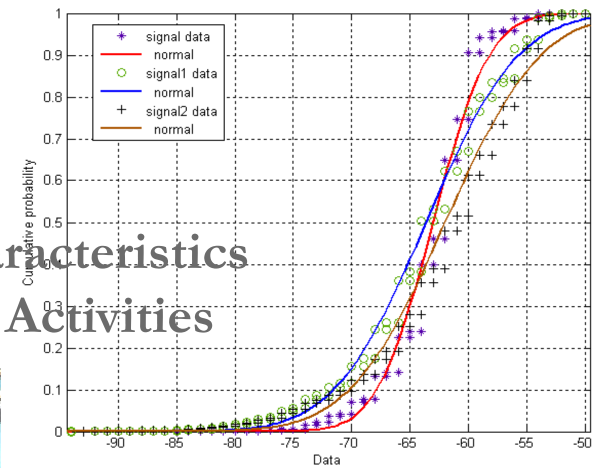

**Belt –Ankle Channel**




**Belt-Wrist Channel**



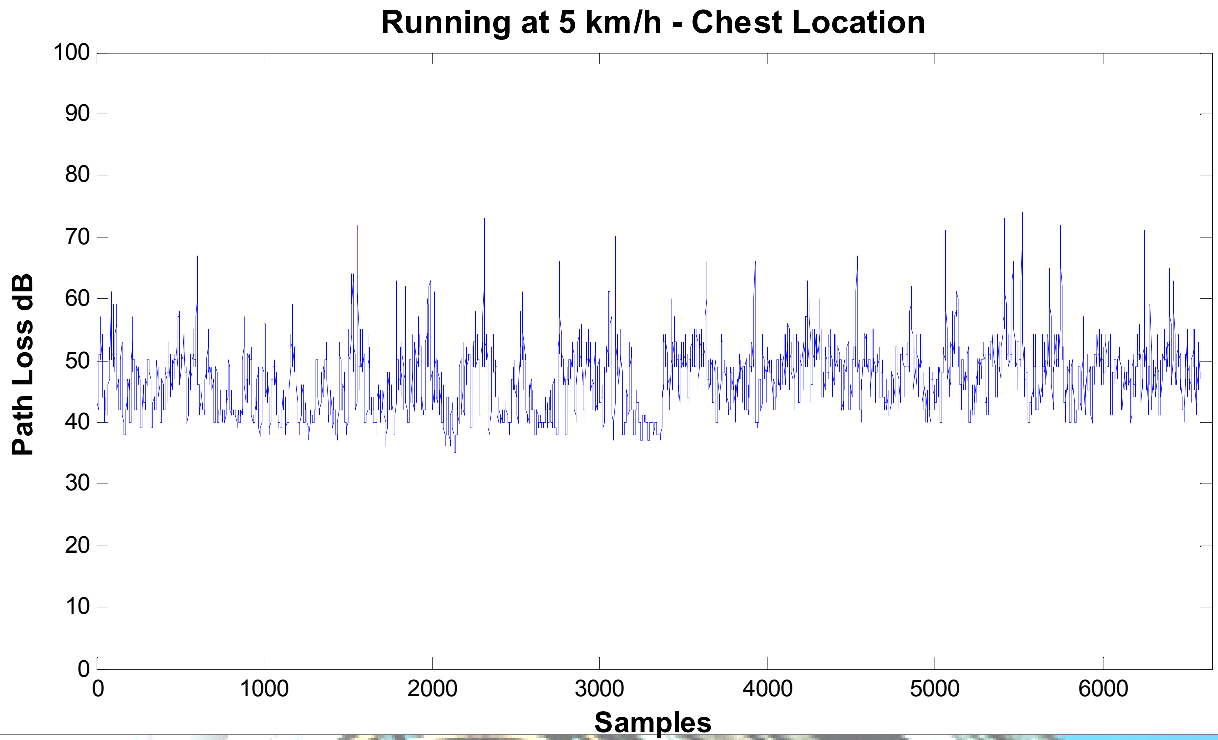

**Belt-Back Channel**



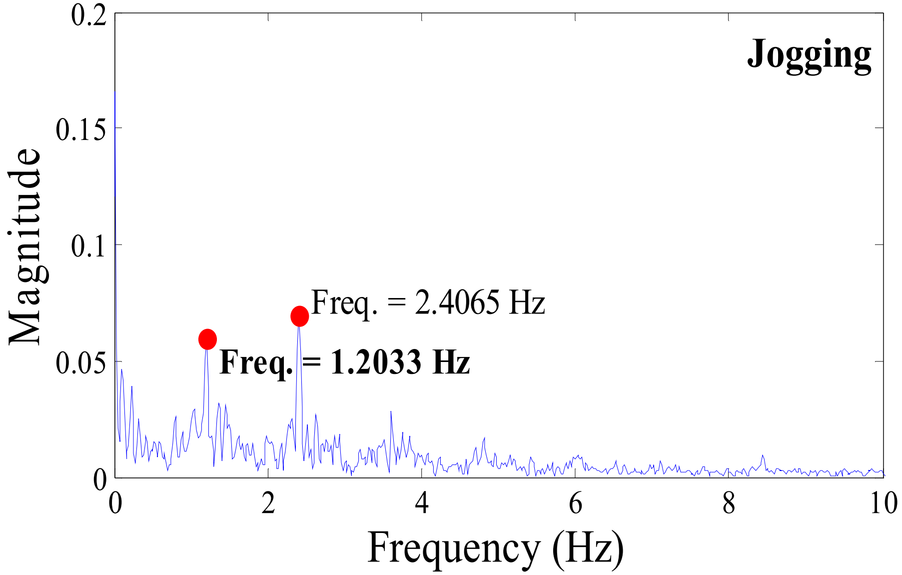

**Channel Characteristics for Different Activities**

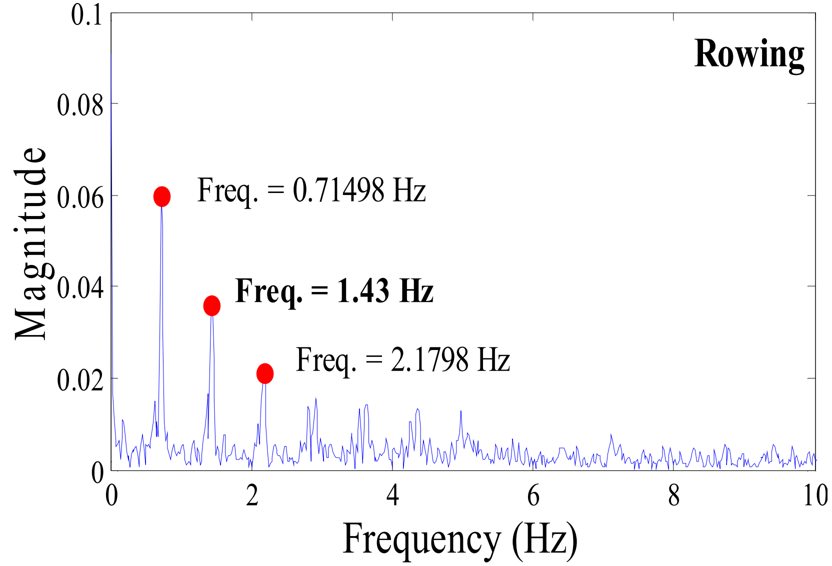
# Applications of Wireless Wearable Sensors (I): Sports and Physiotherapy

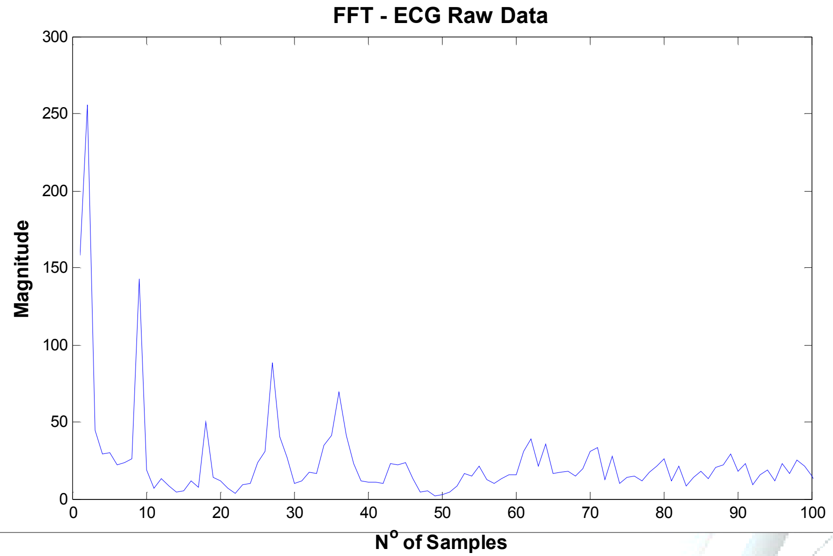
Detecting Heart Beat Signals
from Wireless Wearable Sensors

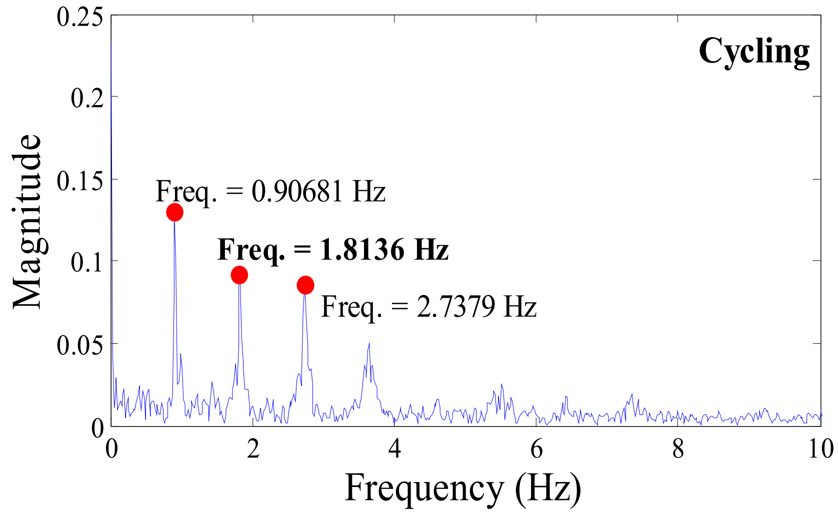



# Detecting Heart Beat Signals from Wireless Wearable Sensors



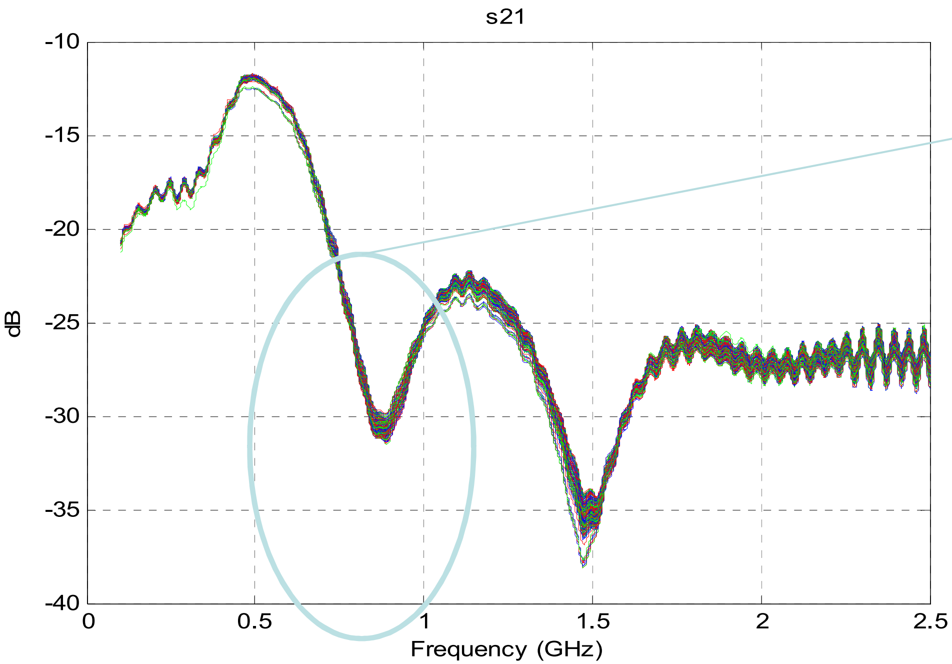



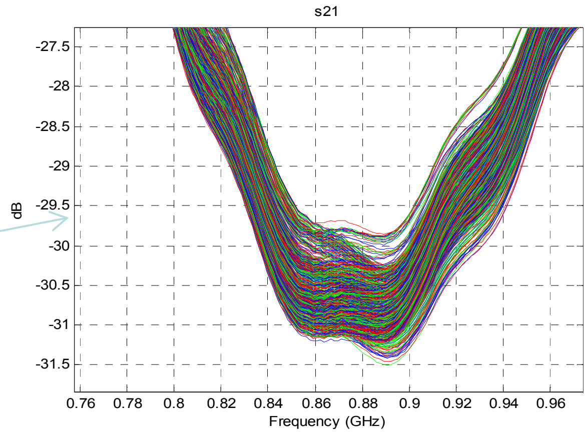



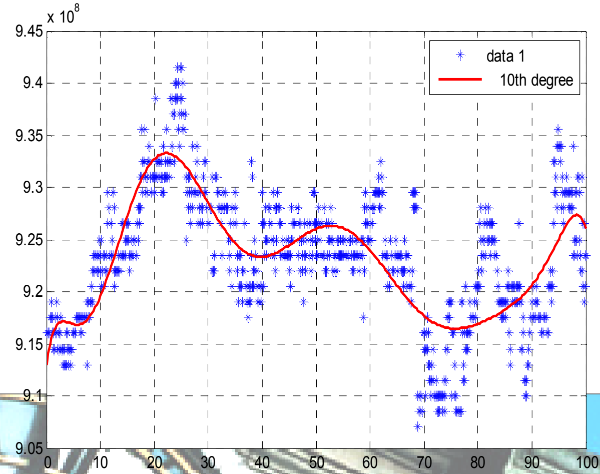



# Applications of Wireless Wearable Sensors (II): Biosensing

- Dielectric Properties of blood is changing with the alterations in blood glucose levels
- The permittivity of the blood is decreasing with the increase in blood glucose levels.
- Soda test includes a healthy subject to fast for at least eight hours and consume a soda drink with high sugar content.



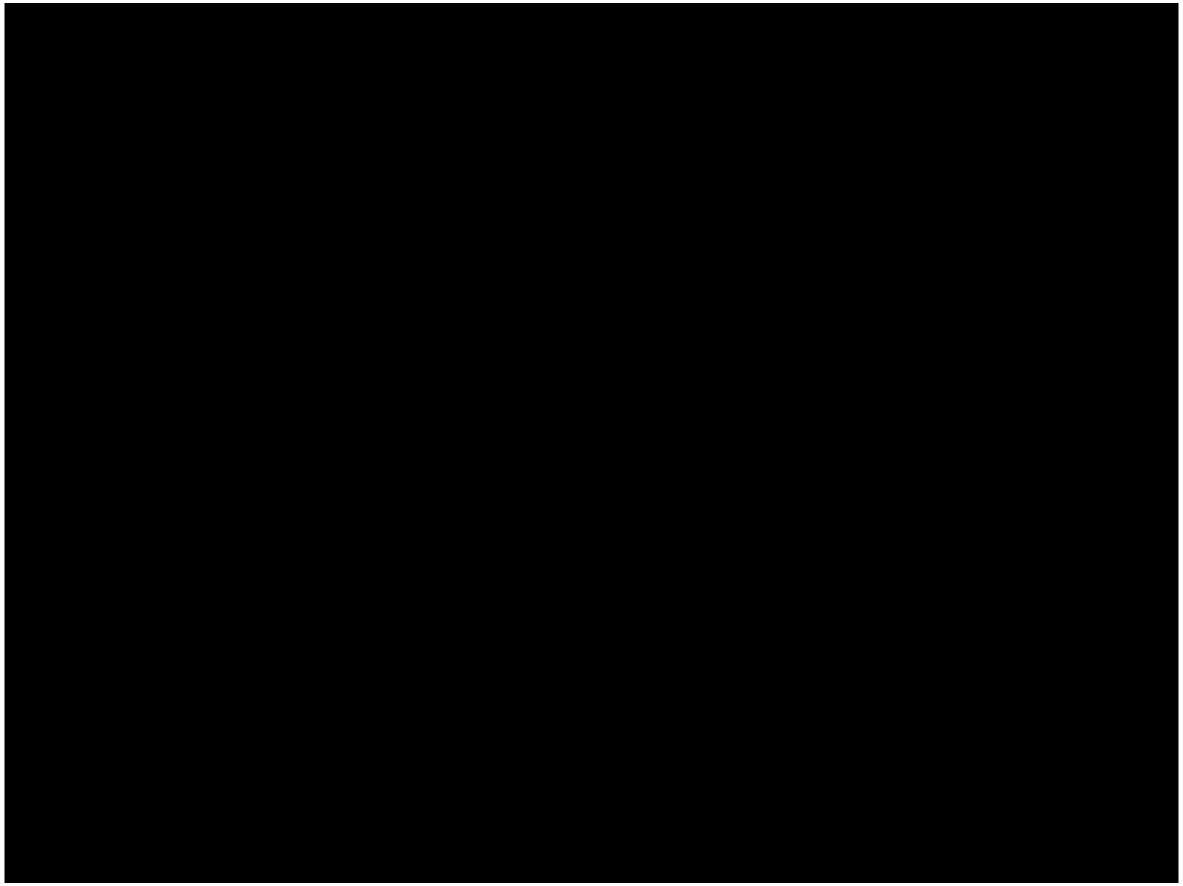

## Non-invasive Blood Glucose Monitoring

# Applications of Wireless Wearable Sensors (III): Telemetry

- Current approach typically uses wires:
- Initial concept of individual sensors:
- Already similar system available commercially (8 EMG channels)
  [http://www.btsbioengineering.com/Electromyography/FREEEMG.html]

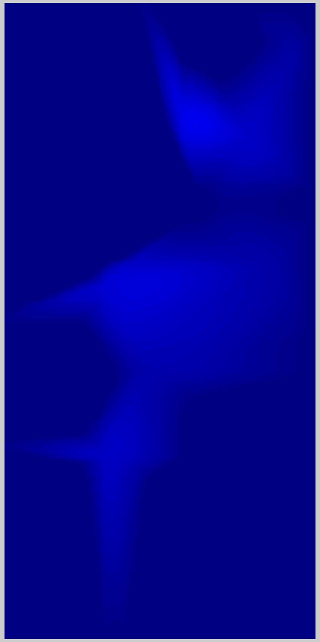
# Applications of Wireless Wearable Sensors (III): Telemetry

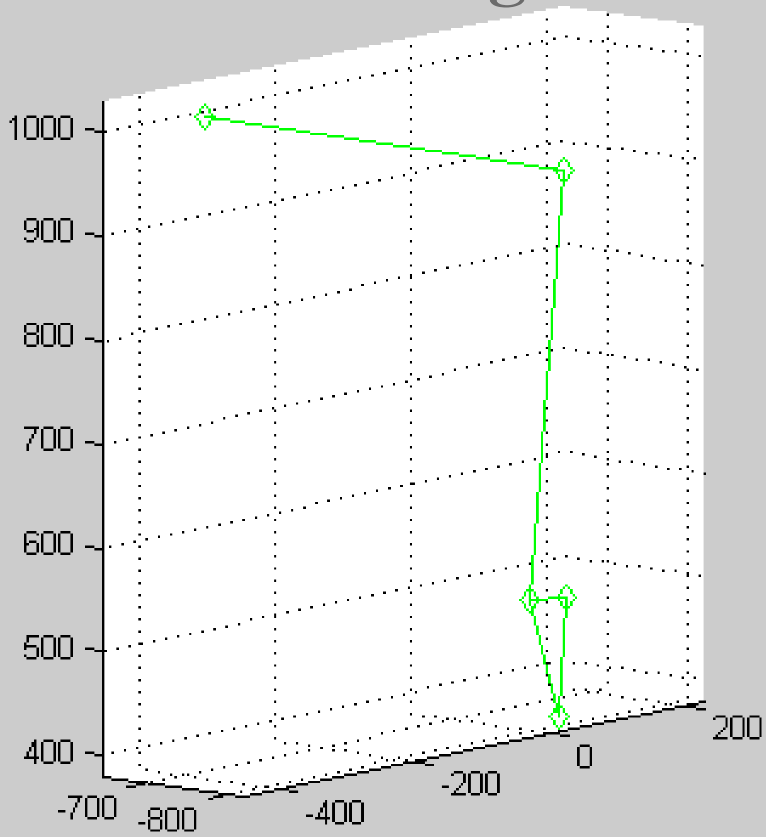
Channel placement on hamstring



# Applications of Wireless Wearable Sensors (III): Telemetry

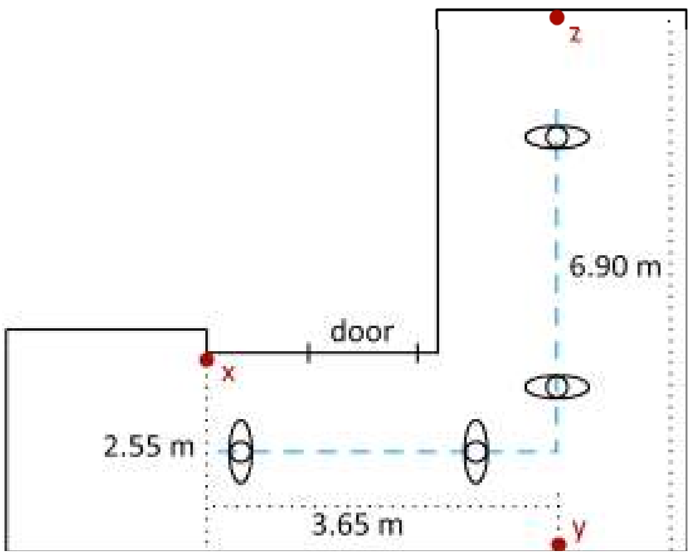
## Channel placement on hamstring

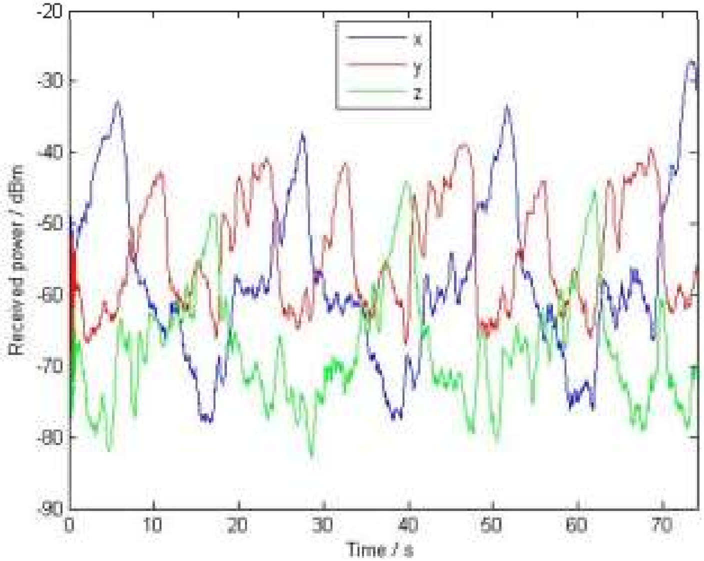




# Applications of Wireless Wearable Sensors (IV): RF Positioning

- Investigate wireless location techniques
  - RSSI-based solutions
  - Primary focus on path-loss models; also apply finger-printing methods



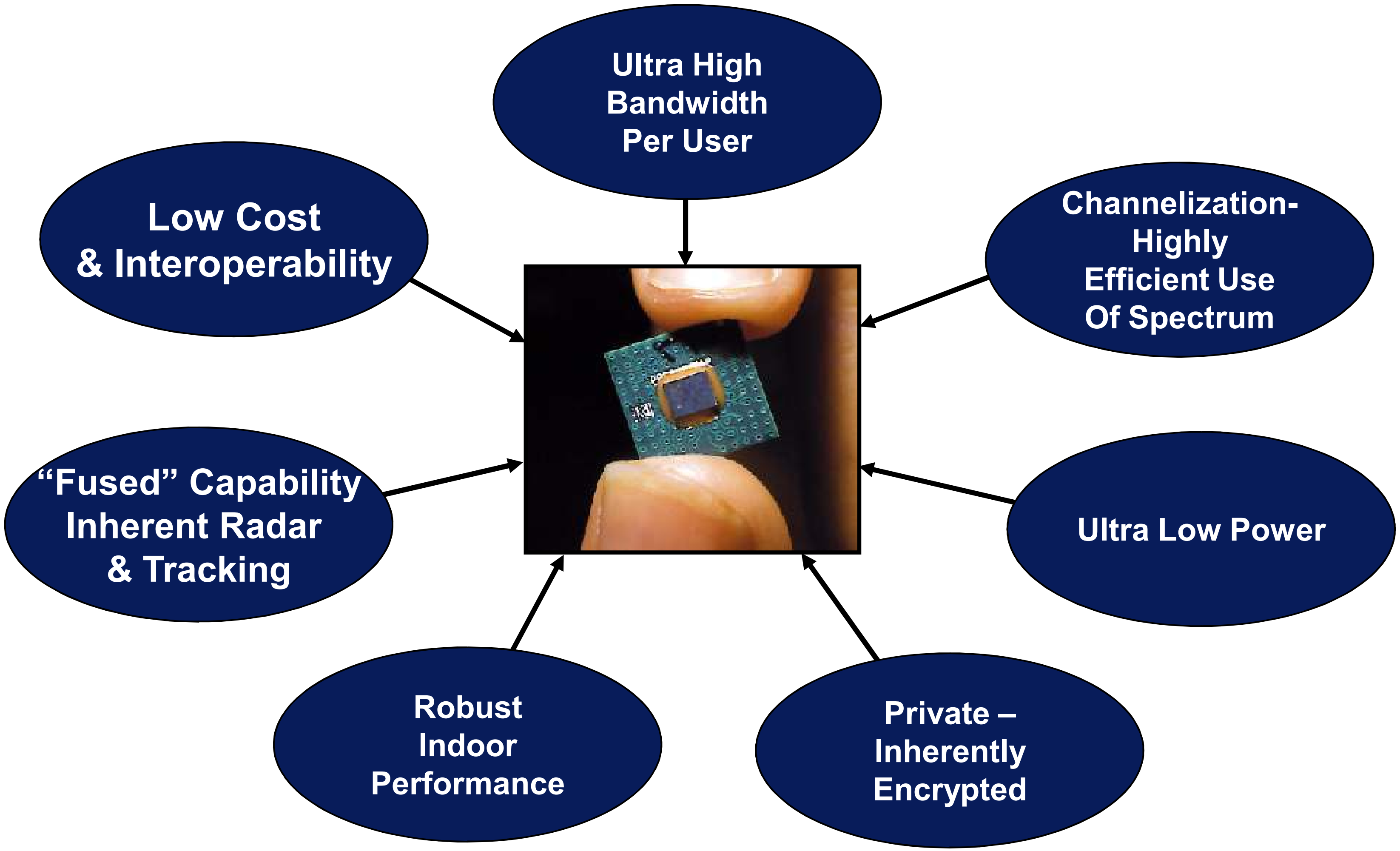
# Applications of Wireless Wearable Sensors (IV): RF Positioning

| Parameter | Node | | |
|---|---|---|---|
| | *x* | *y* | *z* |
| Known separation / m | 3.87 | 1.28 | 5.63 |
| Estimated path loss exponent: sample 1 | 2.52 | 2.07 | 2.50 |
| Estimated path loss exponent: sample 2 | 2.39 | 2.02 | 2.76 |
| Estimated path loss exponent: sample 3 | 2.29 | 1.90 | 2.76 |
| Mean estimated path loss exponent $\overline{n}$ (all six samples) | 2.44 | 2.01 | 2.65 |
| Estimated separation using $\overline{n}$ : sample 1 / m | 4.72 | 1.50 | 3.92 |
| Estimated separation using $\overline{n}$ : sample 2 / m | 3.46 | 1.32 | 7.34 |
| Estimated separation using $\overline{n}$ : sample 3 / m | 2.64 | 0.98 | 7.46 |
| % error: sample 1 | 22.1 | 17.7 | -30.2 |
| % error: sample 2 | -10.6 | 3.3 | 30.6 |
| % error: sample 3 | -31.6 | -23.6 | 32.6 |

# Outline

- Overview of Body-Centric Wireless Communications
- On-body Radio Propagation Modelling and Measurement
- On-body Antennas Design
- Demonstration and Applications of Zigbee Sensors.
- Summary and Future Challenges

# Beyond Zigbee Sensors: Ultrawide Band



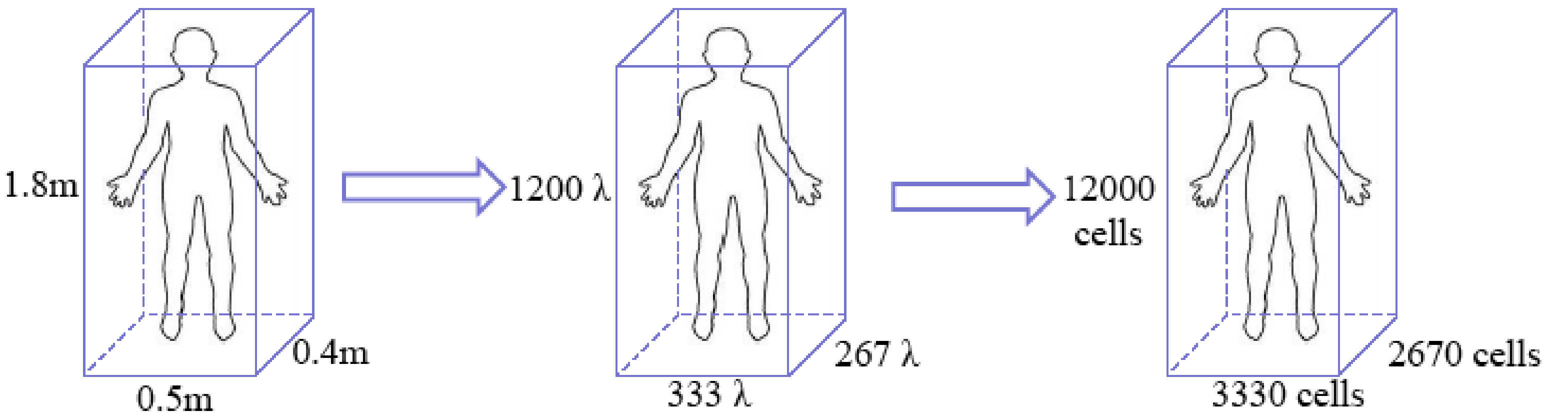
# Beyond Zigbee Sensors: Millimeter Waves

? Why use millimetre wave frequencies (30GHz-300GHz) for BANs?

- ! *Larger amount of data (audio and video streaming, entertainment)*
- ! *Unlicensed frequency bands*
- ! *Lower transmission time*
- ! *Energy confinement: reduction of interference and signature (military)*
- ! *Data encryption*

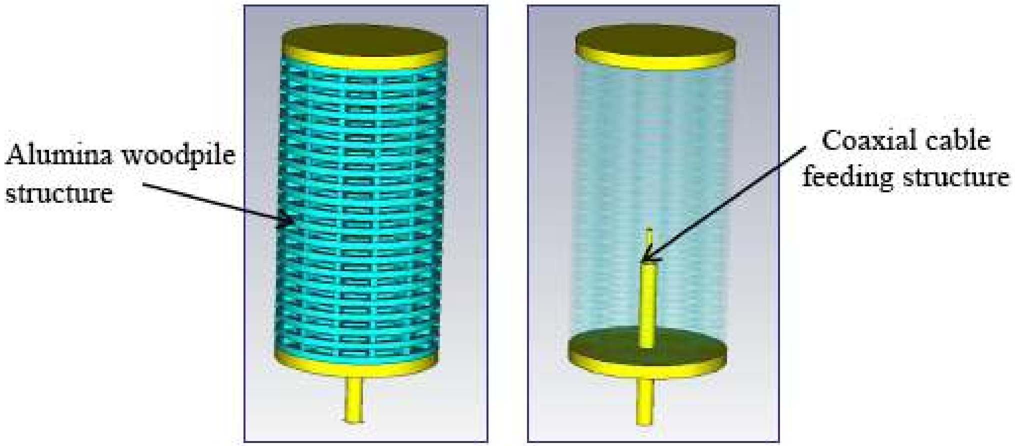
# Modeling Challenges

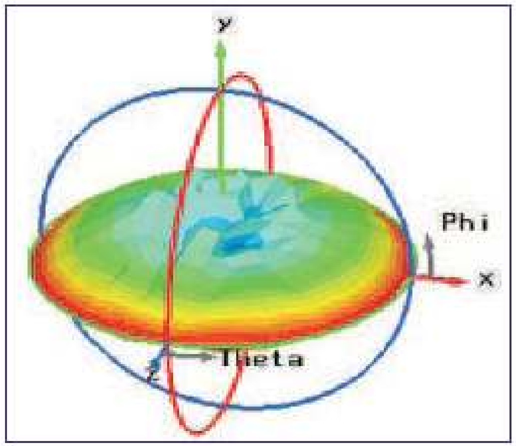
- Main challenge for numerical simulations at mm wave frequencies: human body is very large in terms of wavelength:
  - The average human body can be inscribed in a parallelepiped with dimensions 1.8m x 0.5m x 0.4m [6]
  - Considering dry skin ($\varepsilon_r$=36.4), the wavelength $\lambda$ at 60GHz is about 1.5mm
  - Therefore, the above mentioned parallelepiped has electric dimensions of 1200 $\lambda$ x 333 $\lambda$ x 267 $\lambda$
- FDTD has been widely used at lower frequency bands [2, 3, 7], but this approach seems hardly repeatable at the frequencies of interest, because of the number of cubic cells required to discretise the human body:



# Measurement Challenges

- On the measurement side, the set-up presents significant challenges.
- Choice of the antenna:
  - If the gain is too low, the investigation area around the body could be extremely limited, due to the high losses at mm wave frequencies (free space pathloss for a 1 m link is 68dB and 72 dB at 60GHz and 94GHz respectively).
  - If the antenna is too directive, the pathloss might be affected more by the misalignment of the receiving and transmitting antenna than by the presence of the human body.



# Conclusions

- Time variation measurements of path gain provide vital information for on-body communications system design, such as outage rates and channel variation rates
- An on-body propagation channel can noticeably vary with the posture of the body (variability is most severe when two antennas are mounted on different parts of the body moving in respect to each other)
- Power efficient wireless sensor design can be achieved by a combined understanding of antennas, radio channel modelling as well as the transceiver design.

# Conclusive Remarks

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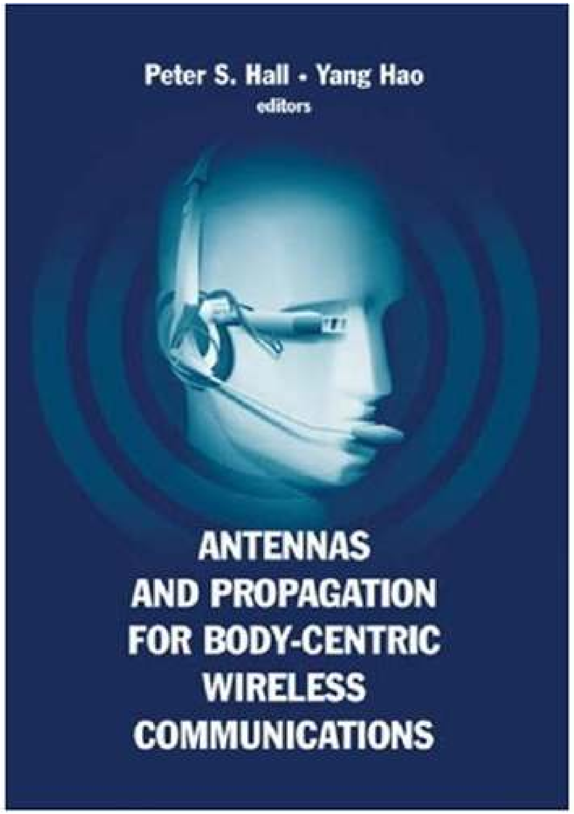

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# Any Questions?

***Contact: yang.hao@elec.qmul.ac.uk***

Queen Mary
University of London