Les réseaux corporels sans fil (*WBAN*) : un canal radio très particulier

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Outline

- **Introduction**
  - Market context
  - WBAN definition and applications
  - Regulation
  - Why UWB ? Context – Motivation
  - WBANs nodes and radio link types
- **EM Field – Body Interaction**
  - Electric properties of human tissues
  - Models and phantoms
  - Propagation mechanisms around the body
- **Channel models**
  - Review of Path Loss (PL) models
  - IEEE 802.15.4a
  - IEEE 802.15.6…
  - … and others
  - What should be a “good” channel model?
  - **Scenario-based models**
- **Antennas and channel...**
  - Antenna – body interaction
  - UWB specificities – Comparison to narrowband
  - Variability due to antennas
- **Measurement issues – Methodology**
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  - Principles of the approach and methodology for a better reproducibility
- ***On-on* statistical approach**
  - Parametric analyses and modelling – involved parameters
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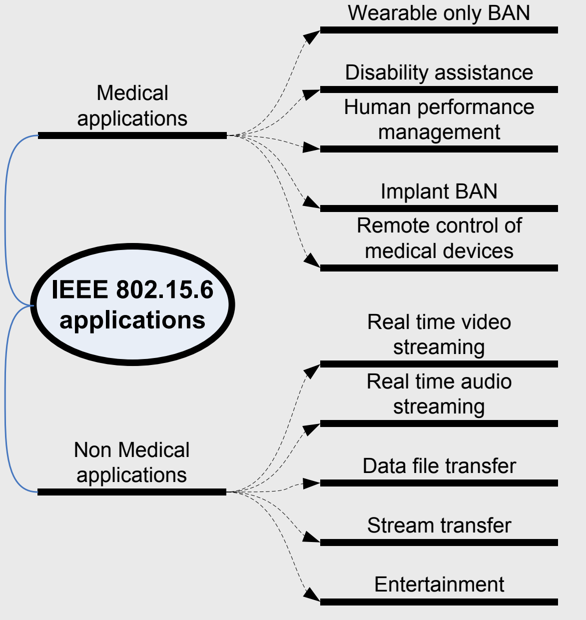
    - Desensitization techniques...
- **Conclusions & perspectives**
- **Bibliography**

INTRODUCTION

Market context – Professionals/consumers needs

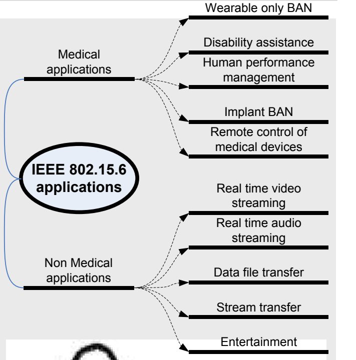
- **Upcoming applications for the wireless and semiconductor markets… [1]**
  - Health monitoring, ambient assisted living
  - Gaming, "wearable computing", fitness and sport
  - New mobile terminal peripherals
- **... introduced the WBAN terminology in the scientific community…**
  - "Wireless Body Area Networks"
- **… and led to new standardization activities**
  - … and led to new standardization activities [2]
  - Ultra low power extension of Bluetooth [3]
  - Creation of the Continua Health Alliance [4]



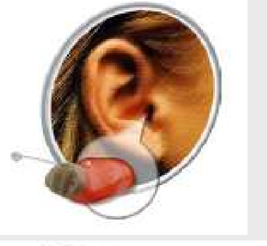
[1] The Promise of Body Area Networks, A. Astrin, ISMICT 2007, Oulu
[2] http://ieee802.org/15/
[3] http://www.bluetooth.com/bluetooth/
[4] http://www.continuaalliance.org/home

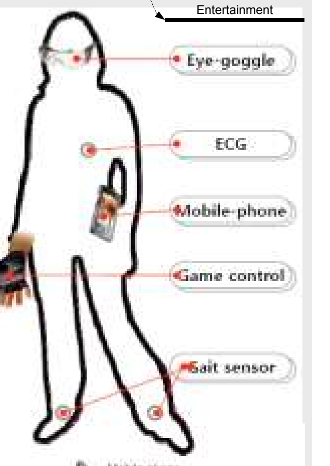
WBANs: what is this ? And what for ?

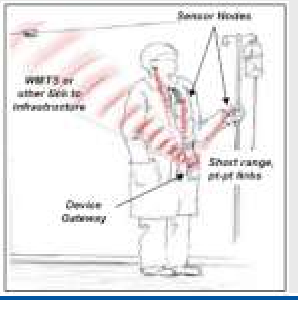
- **From IEEE 802.15 TG 6:** ***"[...] a communication standard optimized for low power devices and operation on, in or around the human body (but not limited to humans) to serve a variety of applications including medical, consumer electronics/personal entertainment and other".***

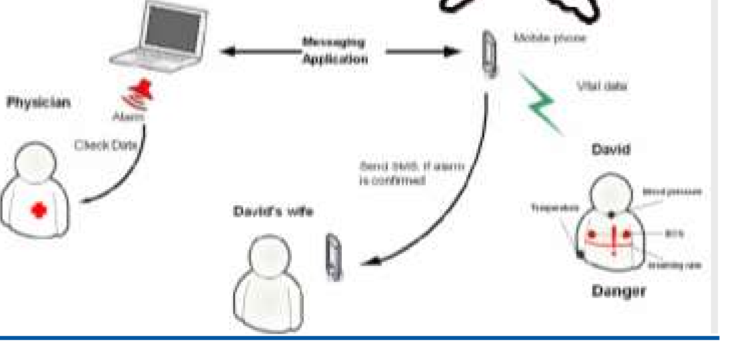


- **Applications**
  - Health monitoring, surveillance, ambient assisted living,
    - Physiological parameters measurement (heart rate, ECG, EEG blood pressure…), → WBSN type (wearable) or implantable
    - Data logging from implants (pacemaker, defibrillator…)
    - Body motion, gait, activity analysis (Parkinson, Alzheimer)
  - Telemedicine, "distributed & at-home hospital",
  - Gaming, "Wearable computing",
  - Fitness and sport
    - Motion analysis (goniometry, accelerometry, gyroscope...)
    - Vital signs,
    - Performance …



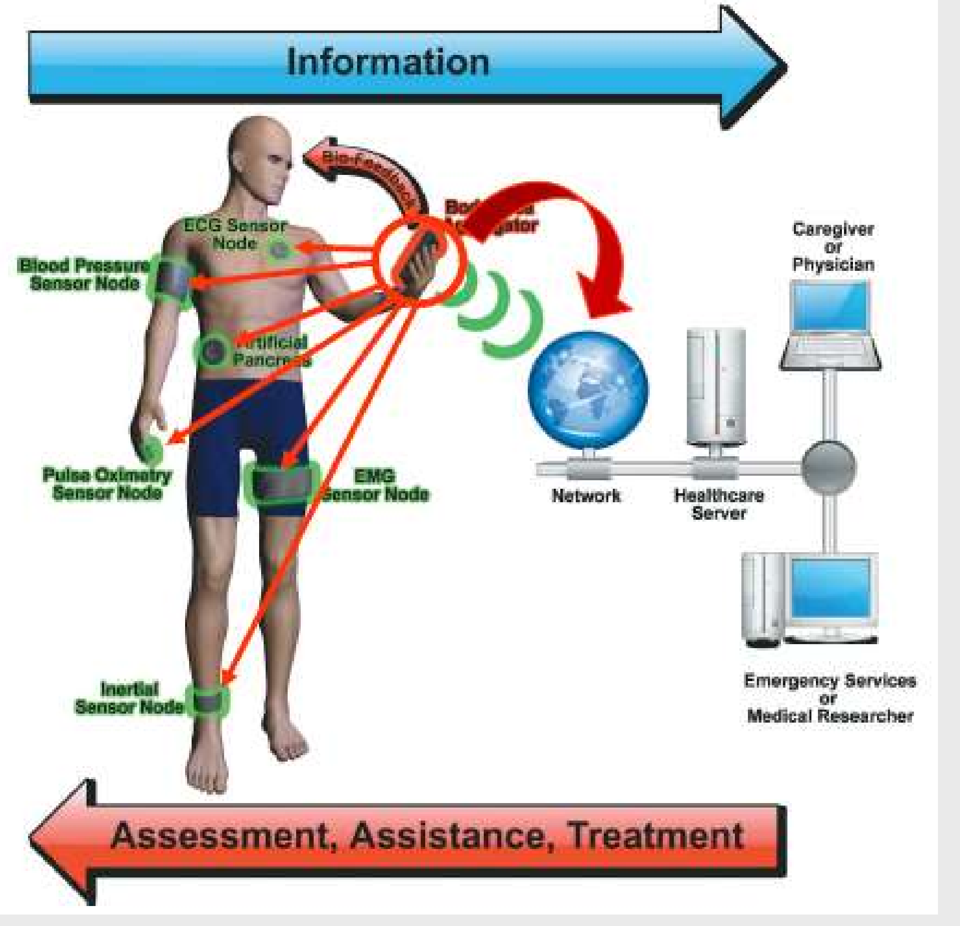






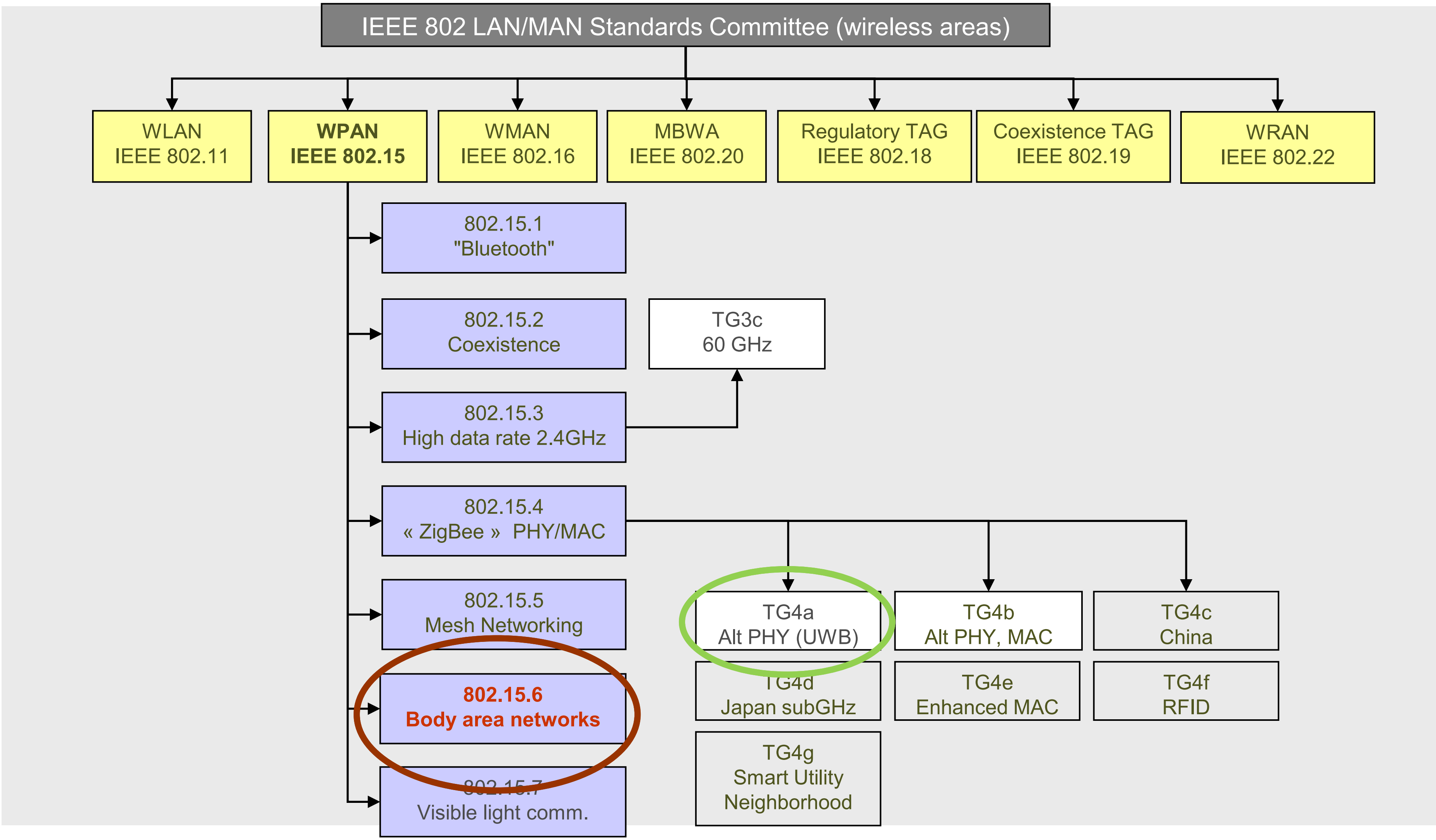
(Wireless) Body Area (Sensor) Networks

- **BAN**
  - Interconnected nodes on/within human body
  - Sensing and communication capabilities
- **Applications**
  - Healthcare
  - Fitness
  - Entertainment

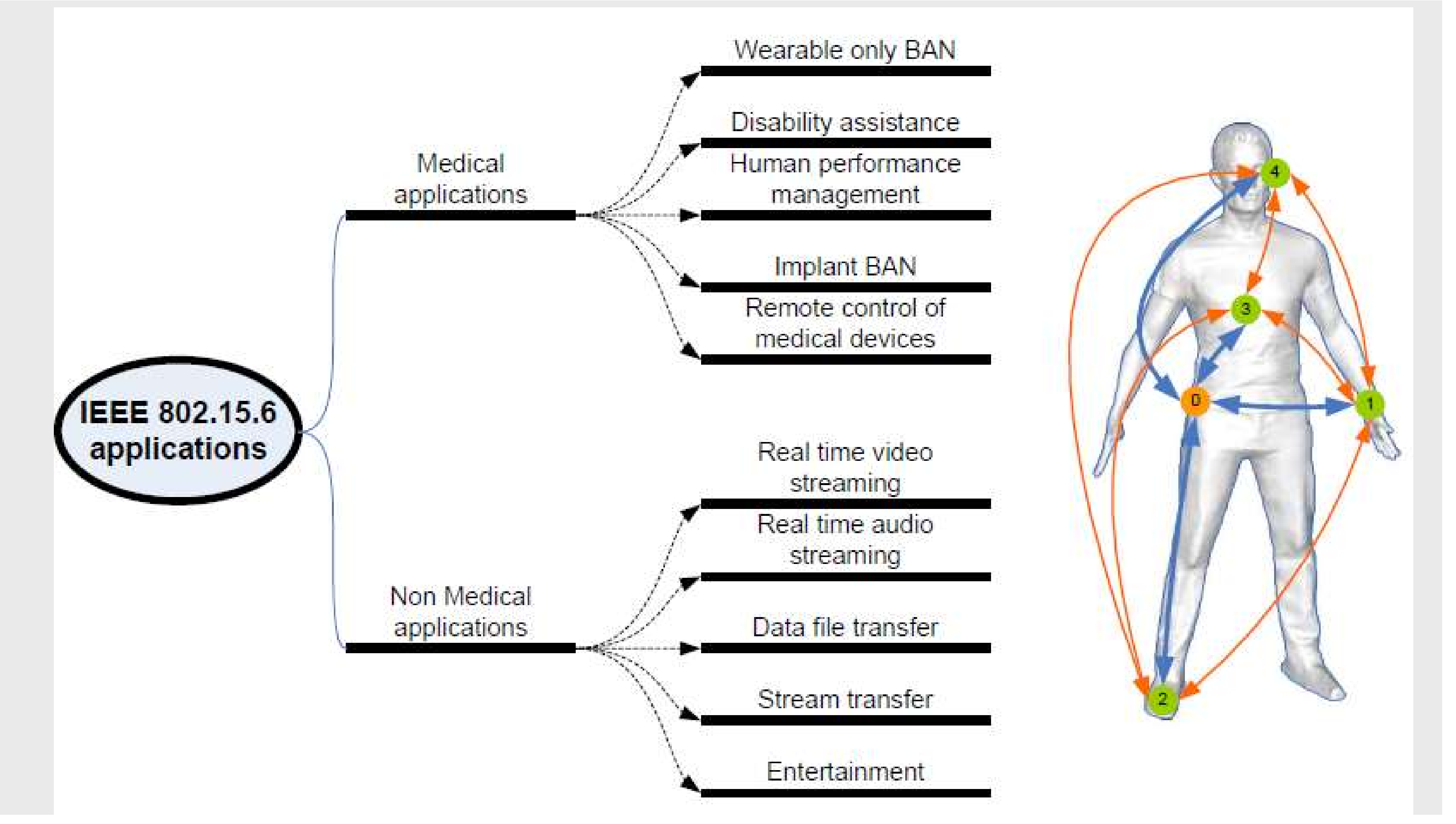


M.A. Hanson, H.C. Powell, A.T. Barth, K. Ringgenberg, B.H. Calhoun, J.H. Aylor, et J. Lach, “Body Area Sensor Networks:Challenges and Opportunities,” Computer, vol. 42, Jan. 2009, pp. 58-65.

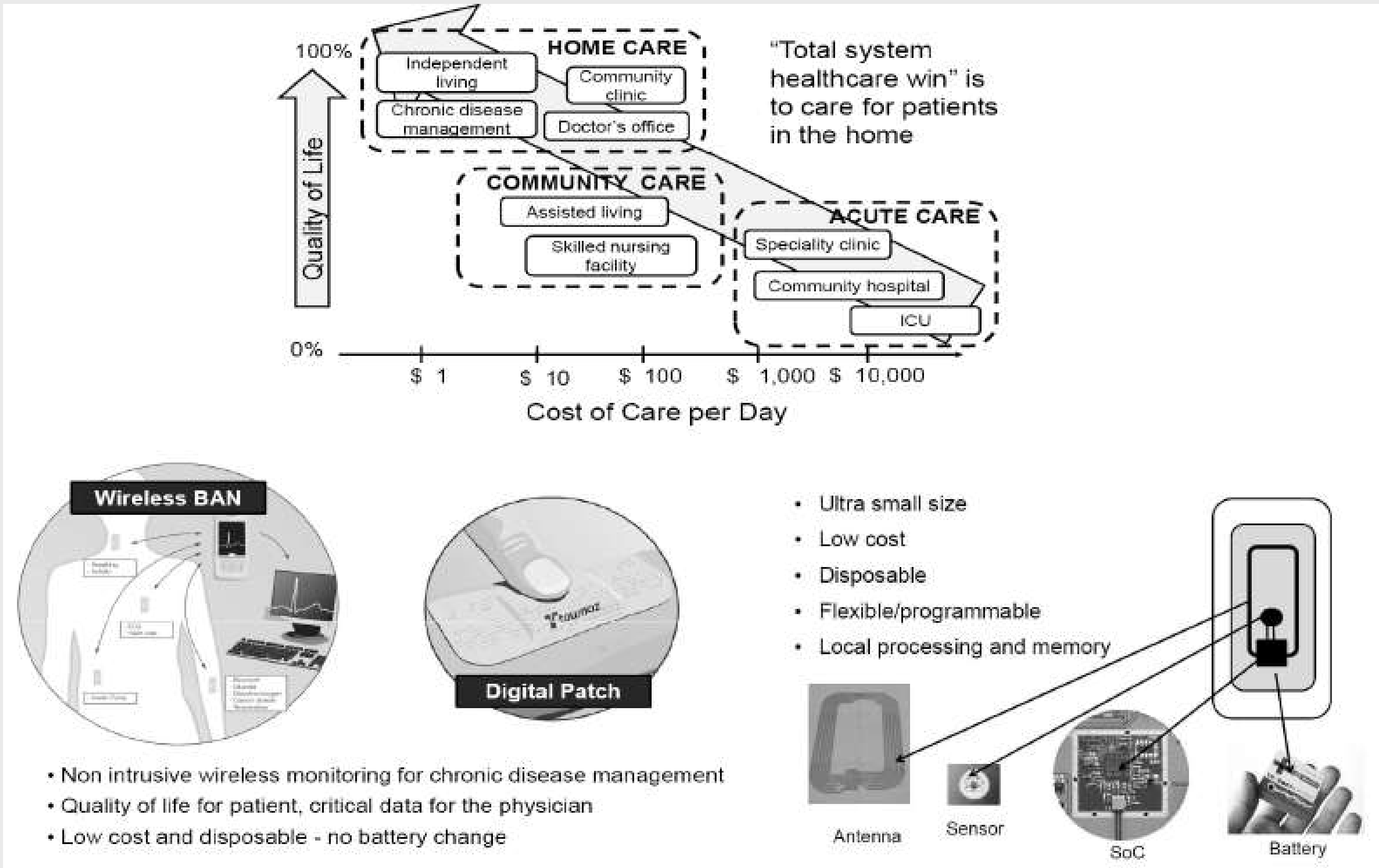
Standardisation à l'IEEE 802



BAN applications in IEEE 802.15.6



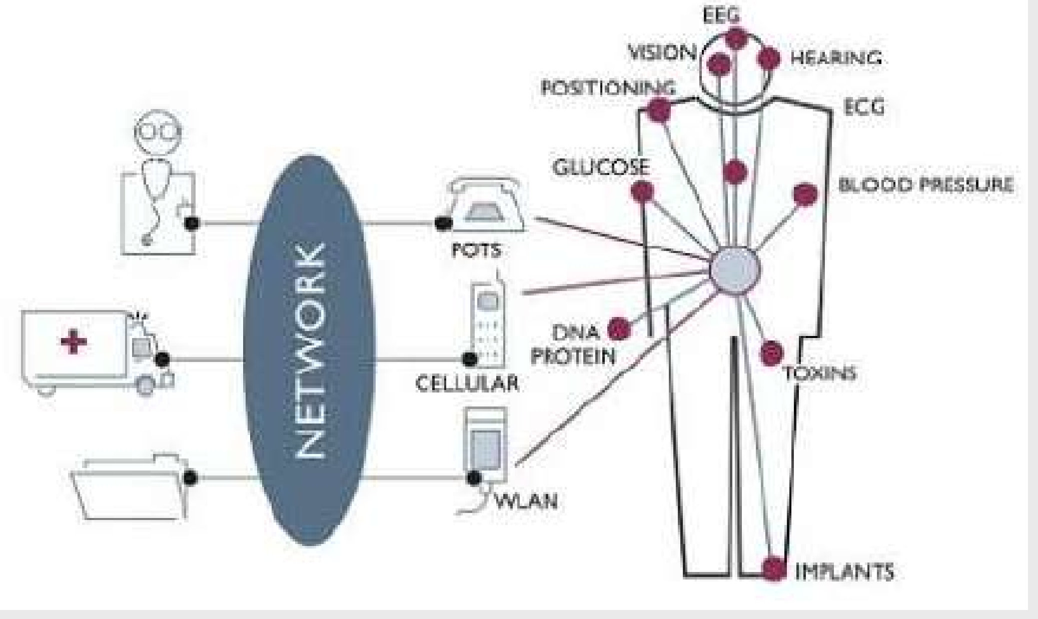
Medical monitoring



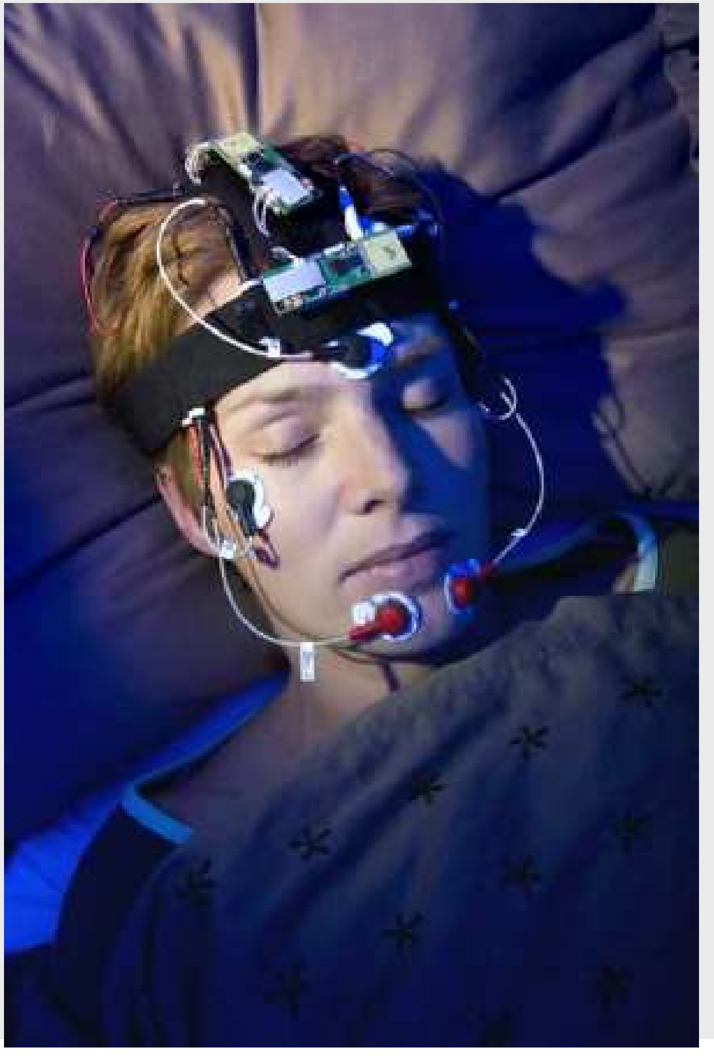
source: IEEE 802.15-08-0158-01-0000, Toumaz

Medical monitoring

- **Monitoring of parameters**
  - Ex: Glucose
  - Ex: Sleep analysis
- **Biofeedback**
  - Ex: Emotion control

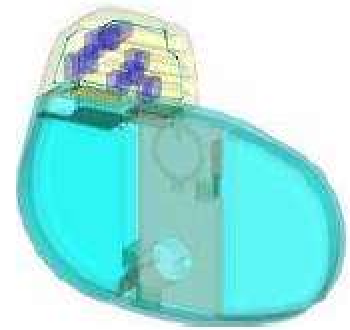


Source: IEEE 802.15-15-08-0163-00-0006, IMEC



Medical « implants »

- **Implants**
  - Pacemaker
  - Defibrillators


- **Earring aids**

- **Swallowable cameras**

Source: Sorin Group, Guidant, IEEE 802.15-08-0162-00, Zarlink

Sport, Biocinetics, Biomechanics

- ❑ **Biocinetics – Biomechanics**
- ❑ **Physiological analysis**
- ❑ **Rehabilitation after accidents**
- ❑ **Control of rehabilitation efficiency**
- ❑ **Motion capture**

Source: Movea

Multimedia Applications

- **"ON THE ROAD"**
  - A application of BAN is to connect all wireless portable devices locally to form a selfcontained network around human body
  - Devices within a BAN can then share resources such as processing power, storage space and Internet connectivity

- **"IN THE CAR", e.g.**
  - Connect portable devices to car stereo and control system
  - Monitor your health condition for a safe drive, e.g. sleeping, drunk…
  - Transmit personal profile to the car; such as seat, mirror and steering wheel positions.

source: IEEE 802.15-08-0169-01-0006, Samsung

Fashion and Wearable Applications

- One of the major trends in the fashion industry is clearly the convergence of fashion and wearable electronic device, the so called "Wearable Technologies".
- It was predicted that within the next 10 years we could see 20% of garments with electronic components in them (prediction made in 2003).
- The ISPO 2007 Summer show in Munich, Germany, was a good demonstration of the trend. The event is the world's biggest trade
- This trend strongly indicates the advent of the "wearable era" and BAN can play a big role connecting these devices wirelessly.

source: IEEE 802.15-08-0169-01-0006, Samsung

Intelligent clothes / Professional garments

Regulation (spectrum access)

- Medical Implant Communication Systems (MICS)

Frequency Band For MICS (402-405 MHz)

	Power	Channel	Remarks
Australia	< 25µW e.i.r.p	≤300 kHz	Secondary use.
	< 100nW e.i.r.p	403.56 - 403.76 MHz	Medical implant telemetry systems
EU	< 25µW e.i.r.p	25 kHz/channel, one transmitter can use up to 300 kHz.	Secondary use.
Japan	< 25µW e.i.r.p	≤300 kHz	Secondary use.
Korea	< 25µW e.i.r.p	≤300 kHz	Secondary use.
	< 100nW e.i.r.p	403.5 -403.8 MHz	
USA	< 25µW e.i.r.p	≤300 kHz	Secondary use.

source: IEEE 802.15-08-0348-01-0006, NICT

Regulation (spectrum access)

- Ultra Wide Band (> 500 MHz bandwidth)

UWB Low Bands

	PSD	Frequency Bands	Remarks
Australia	N/A	N/A	N/A
EU	-41.3 dBm/MHz	3.4 - 4.8 GHz	LDC or DAA are applied
		4.2 - 4.8 GHz	By Dec. 31, 2010
Japan	-41.3 dBm/MHz	3.4 – 4.8 GHz	DAA is applied
		4.2 – 4.8 GHz	By Dec. 31, 2008
Korea	-41.3 dBm/MHz	3.1 - 4.8 GHz	LDC or DAA are applied
		4.2 - 4.8 GHz	By Dec. 31, 2010
USA	-41.3 dBm/MHz	3.1 -10.6 GHz	
Common	-41.3 dBm/MHz	4.2 -4.8 GHz	Time limitation

Interférences
Coexistence

source: IEEE 802.15-08-0348-01-0006, NICT

Regulation (spectrum access)

- Ultra Wide Band (> 500 MHz bandwidth)

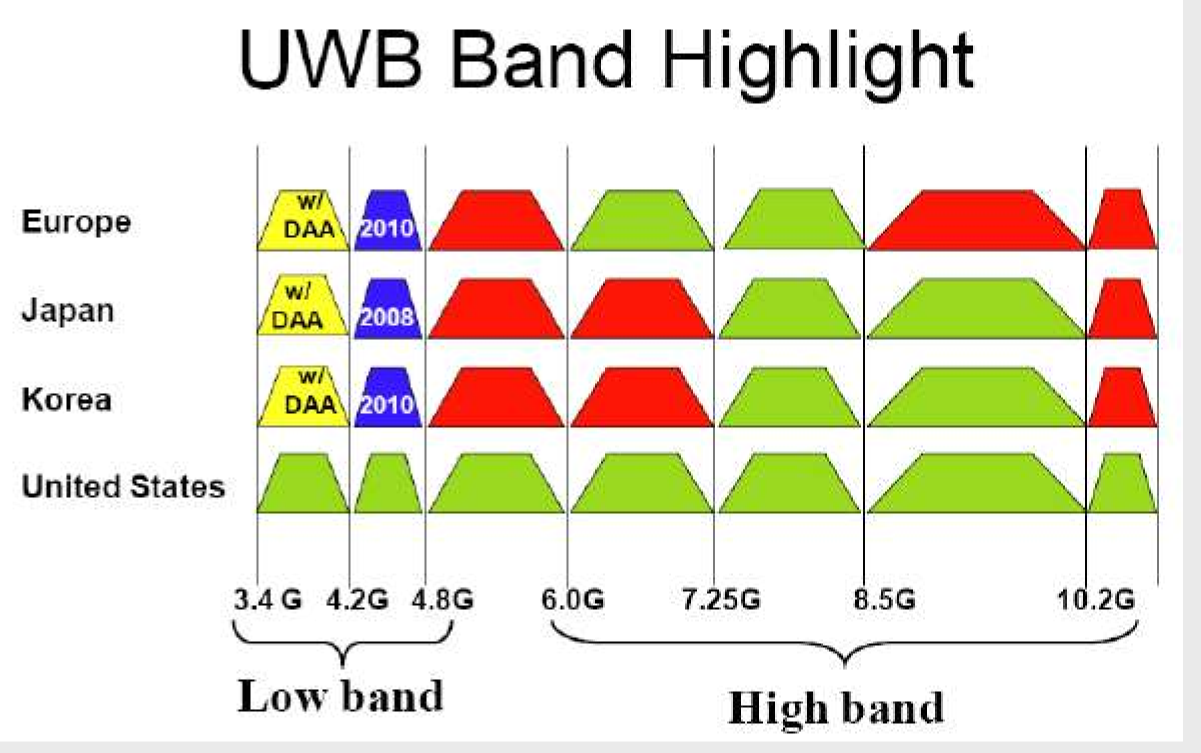
UWB High Bands

	Frequency Bands	PSD	Remarks
Australia	N/A	N/A	N/A
EU	6 - 8.5 GHz	-41.3 dBm/MHz	
Japan	7.25 – 10.25 GHz	-41.3 dBm/MHz	
Korea	7.2 -10.2 GHz	-41.3 dBm/MHz	
USA	3.1 -10.6 GHz	-41.3 dBm/MHz	
Common	7.25 -8.5 GHz	-41.3 dBm/MHz	

source: IEEE 802.15-08-0348-01-0006, NICT

Regulation (spectrum access)

- Ultra Wide Band (> 500 MHz bandwidth)

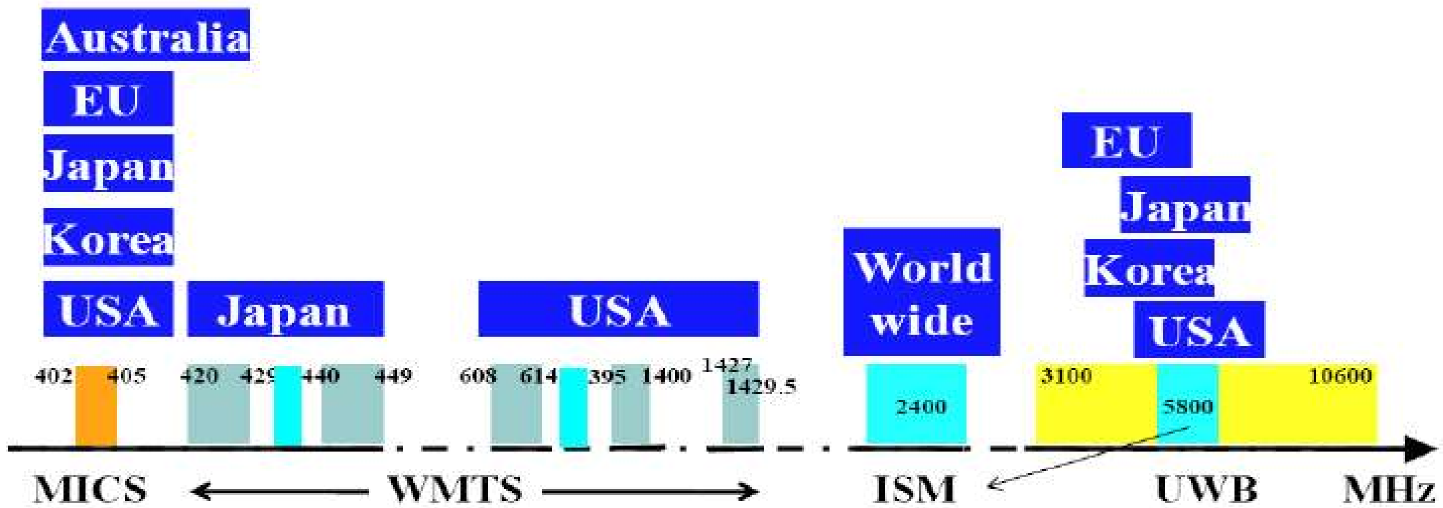


source: IEEE 802.15-08-0348-01-0006, NICT

Regulation (spectrum access)
Bands & emission levels

- **License-free bands**
  - Instrumentation, Scientific and Medical (ISM bands)
  - 433.05-434.79 MHz
    - Power: 10 mW with 10% duty cycle
  - Short Range Device (SRD) Band:
    - Frequency: 868 to 870 MHz in Europe
    - Power: 7 dBm (5mW) to 500 mW
  - Industrial Scientific Medical (ISM) Band:
    - Frequency: 902 to 928 MHz in US
    - Power: -1.25 dBm = 0.75 mW (part 15.249)
  - 2.400 – 2.485 GHz
    - Power: 10 mW EIRP
  - 5.725-5.875 GHz
    - Power: 25 mW EIRP

Regulation summary



Parameter	400 MHz	2.4 GHz
Antenna Efficiency	✗	✓
Path Loss & Body Effects	✓	✗
Power Consumption	✓	✗

Path Loss: Friis Law

$$\frac{P_r}{P_t} = e_{rad}^{\,2} \left(\frac{\lambda}{4 \pi d} \right)^2$$

Antenna Efficiency $e_{rad} = \dfrac{R_{rad}}{R_{loss} + R_{rad}}$

$$R_{rad} = 20\pi^2 \left(\frac{2\pi r}{\lambda} \right)^4$$

Radiation Resistance

$$R_{loss} \approx \frac{r}{r_o \delta \sigma}$$

Loss Resistance

source: IEEE 802.15-08-0348-01-0006, NICT; IEEE 802.15-08-0158-00-0000, Toumaz

Why UWB? Context – Motivation

- **UWB (Ultra wideband) potential and advantages**
  - Spectrum reuse (the rarefaction of the spectral ressource is becoming a real problem…): ultra-low PSD and low power
  - Coexistence with existing narrowband systems
  - UWB → potential for high data rates (short range communications – HDR): 480 Mb/s @ 5 – 10 m, 1 Gb/s @ 1m
  - Ultrawide *instantaneous* bands → high temporal resolution → high spatial resolution → potential for ranging, geo-regioning, localization and tracking (Low data rate & localization – LDR-LT)
  - Less sensitive to selective fading (Multipath Components (MPCs) Interferences)
  - Low power consumption (simpler electronic architectures and lower radiated power)
- **Applications :**
  - Indoor communications (short to medium range)
  - Wireless Sensor Networks (WSN) – Localization, low/medium data rates
  - Ground Penetrating Radars (GPR) – Sub-surface detection or tomography, buried mines detection/identification, archaeology, geology, mining, etc.
  - Through wall detection/imaging – Non invasive probing of walls, materials (concrete or bridge inspection & diagnosis…)
  - Rescue of buried persons (Earhtquake, etc.)
  - Medical imaging & Healthcare: microwave imaging, monitoring, microwave hyperthermia for breast cancer treatment…
  - **WBANs ↔ Short range ⊕ low power radio communication systems (lower power absorbed into the body → better for health), ⊕ LT (Localization & Tracking)?**
  - Reciprocally, the BAN is an interesting application for developing UWB (mainly UWB-IR)

Why UWB? Context – Motivation

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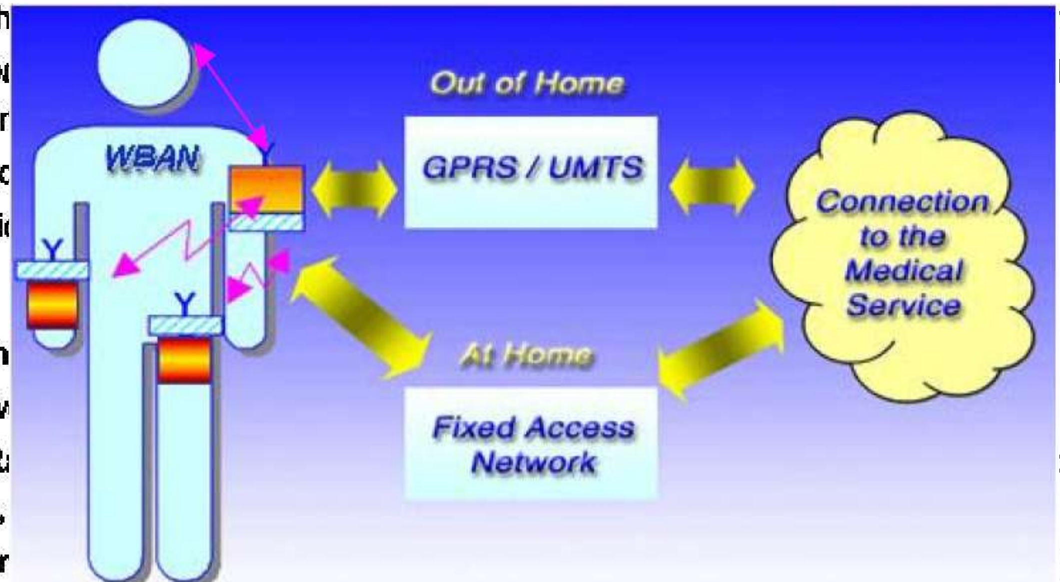

Source: Pulsers I IST-FP6 project

  - Medical imaging & Healthcare: microwave imaging, monitoring, microwave hyperthermia for breast cancer treatment…
  - **WBANs ↔ Short range ⊕ low power radio communication systems (lower power absorbed into the body → better for health), ⊕ LT (Localization & Tracking)?**
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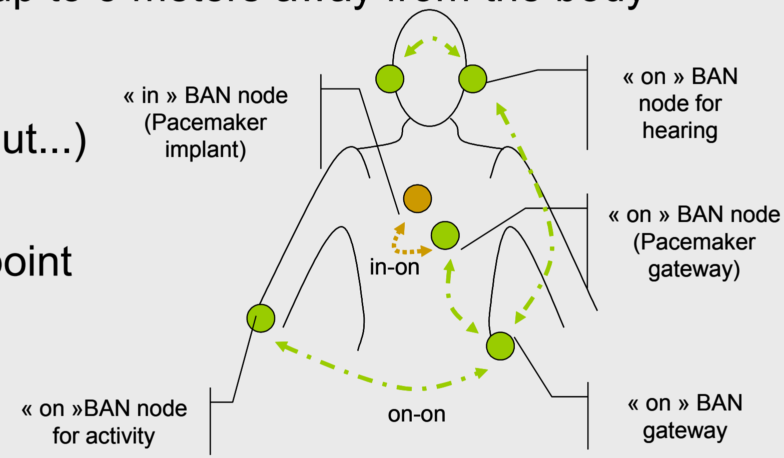
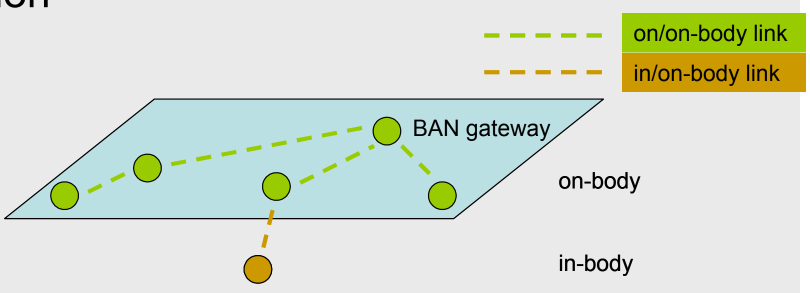
WBANs nodes and radio link types
« on-on, on-off, in-on »

- **3 types of nodes with distinct propagation features can be defined**
  - Implant nodes, placed inside the body
  - Surface nodes, placed on the skin surface or at most 2 centimetres away
  - External nodes: between a few centimetres and up to 5 meters away from the body
- **⇒ 3 types of radio links**
  - *In-on* → implants or swallowable (+ *in-in*, *in-off*, but...)
  - *On-on* → sensor to worn central node (gateway)
  - *On-off* → sensor or gateway to external access point

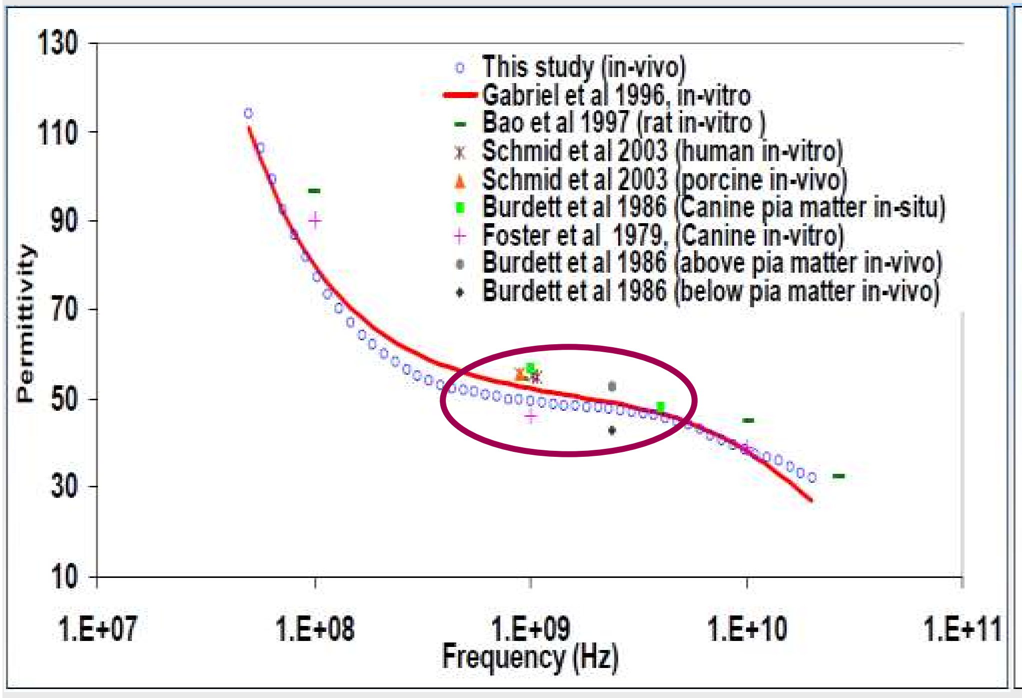


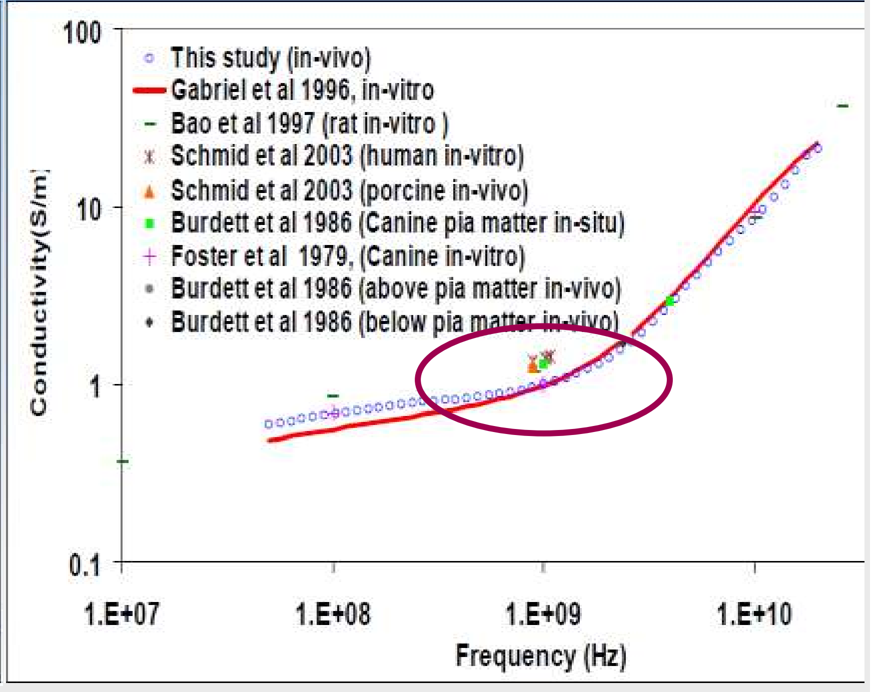
- ***In-on***
  - Difficult – 1. Antenna miniaturization & matching
  - 2. Channel mainly governed by the strong attenuation
- ***On-on* (& partly *On-off*)**
  - Antenna/body near field coupling
  - Difficult channels : PL, Slow fading (shadowing), Numerous sources of variability, Special Doppler



Propriétés électriques des tissus des… mammifères
Eh oui, nous avons plus de 95 % de gènes en commun avec le…

- **Expérimentations in vivo (rat) et in vitro (la plupart)**
  - Gabriel & Gabriel, "Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies". Brooks Air Force Technical Report AL/OE-TR-1996-0037



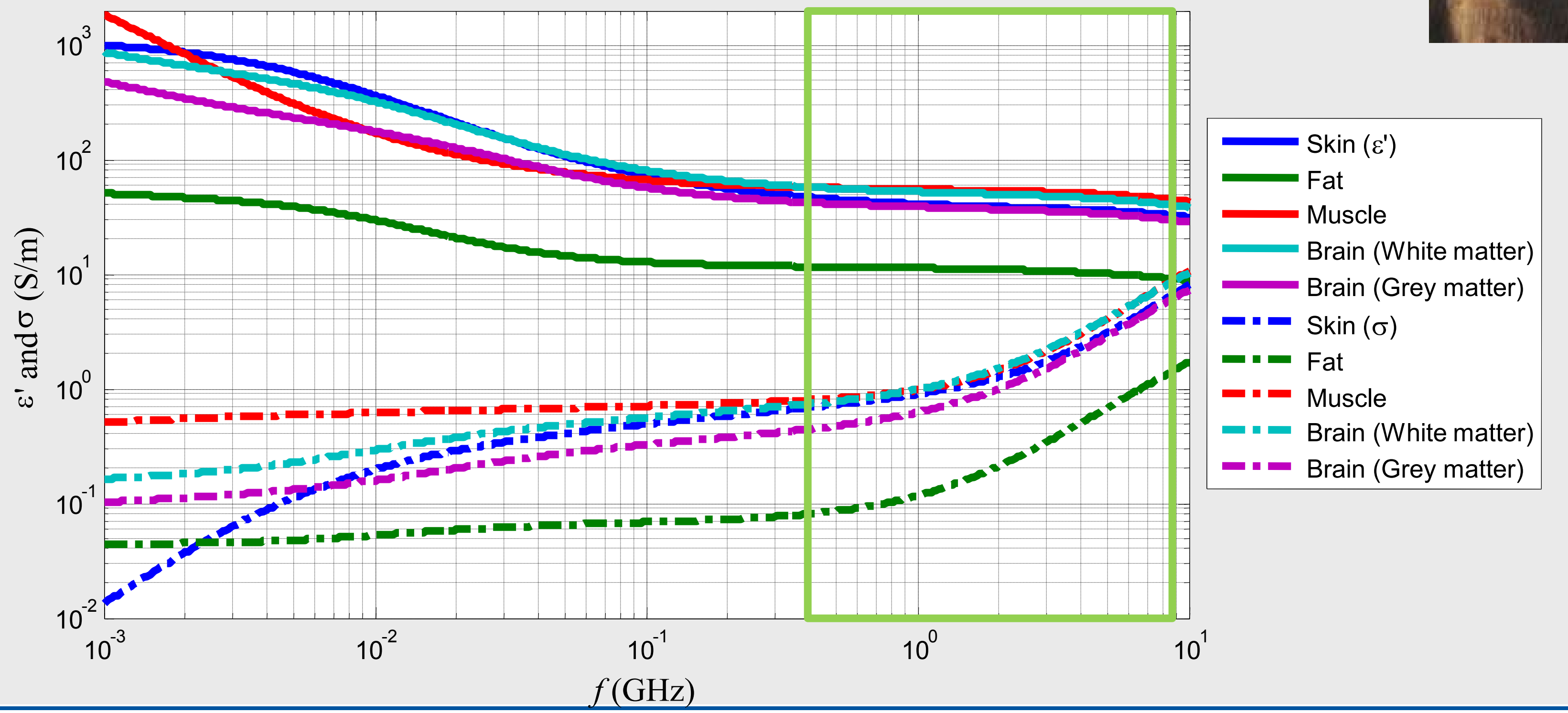


Propriétés électriques des tissus
Modèles pour la simulation

- **Modèle Cole-Cole (inhomogène, tissus, organes)**
  - Polarisation dipolaire (temps de relaxation τ_m), conductivité ionique (σ_i)

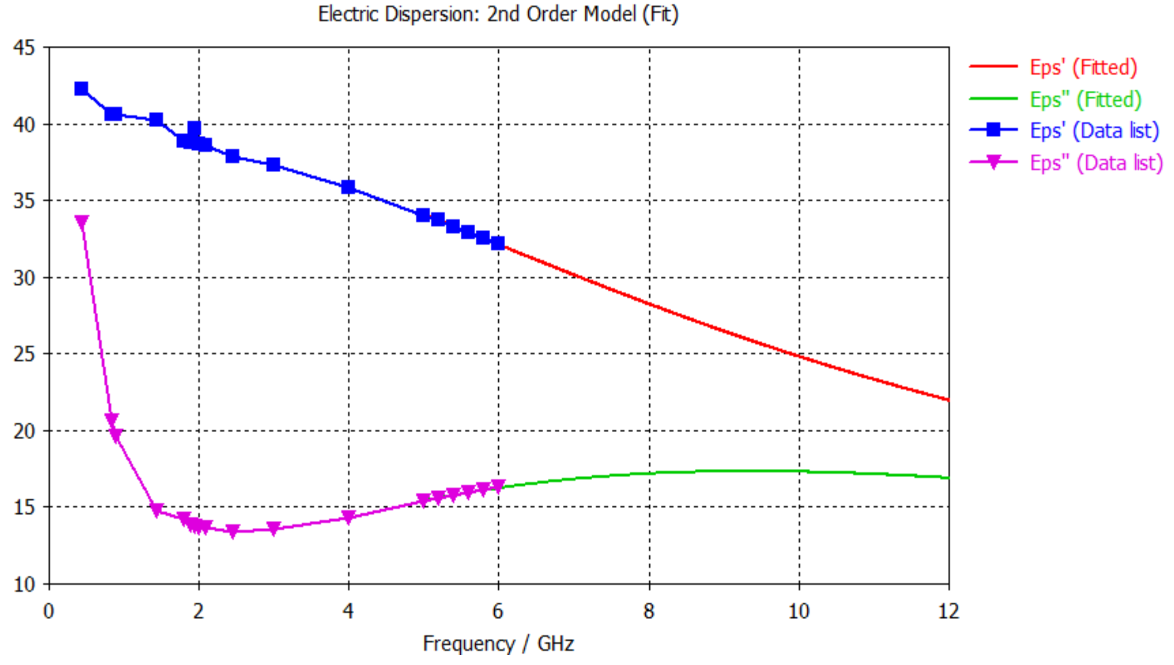
$$\varepsilon(\omega) = \varepsilon_\infty + \sum_m \frac{\Delta\varepsilon_m}{1+(j\omega\tau_m)^{1-\alpha_m}} + \frac{\sigma_i}{j\omega\varepsilon_0}$$

Skin (dry), Fat, Muscle, Brain (White and Grey matter) Relative Permittivity and Conductivity



UWB characteristics of body tissues: Homogeneous and 2nd order models – dispersion

- **Source: MCL-T Broadband tissue equivalent liquid (measured)**
  - Compliant to IEC 62209-2, CENELEC–EN 62209:2006 and IEEE Std 1528T-2003
  - 2nd order model fit in CST® (extension of Debye 1st order model): extrapolation up to 12 GHz



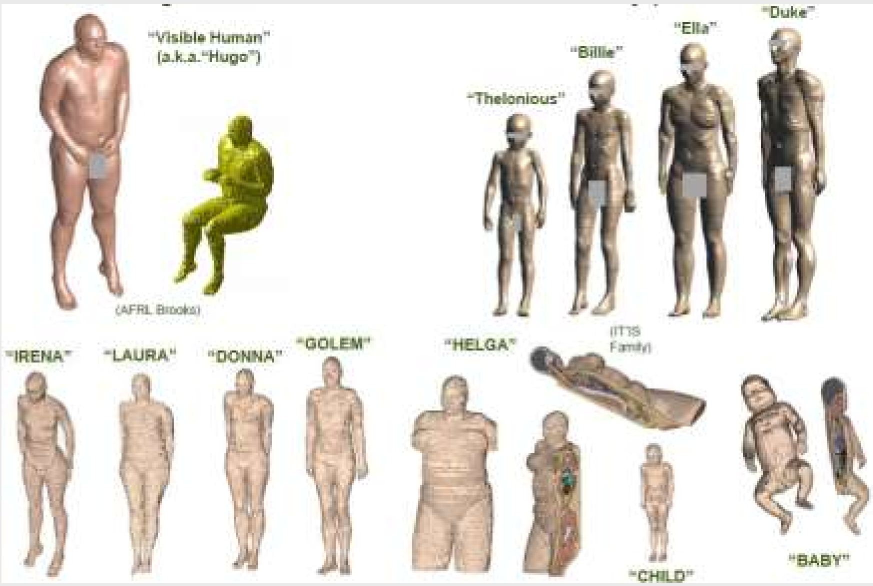
$$\varepsilon(\omega) = \varepsilon_\infty + \frac{\beta_0}{\alpha_0 + j\alpha_1\omega - \omega^2}$$

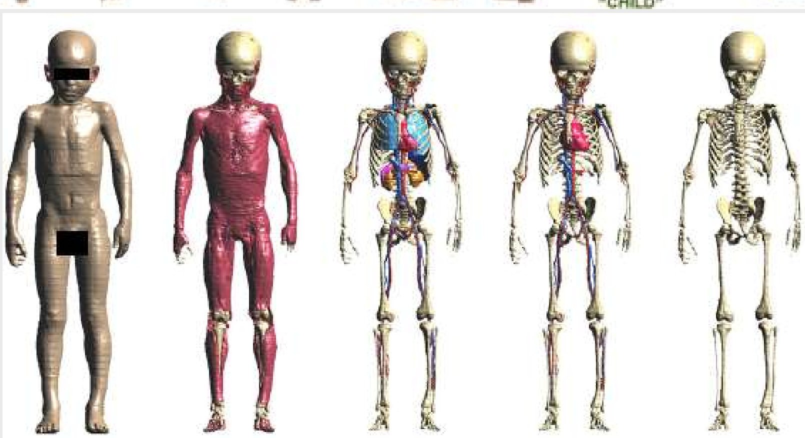
Note: 4-Cole-Cole model is better but more complex (important for internal problem such as dosimetry (SAR). The point here is to show the general trend, not to be very accurate → *on-on*, *on-off* WBANs

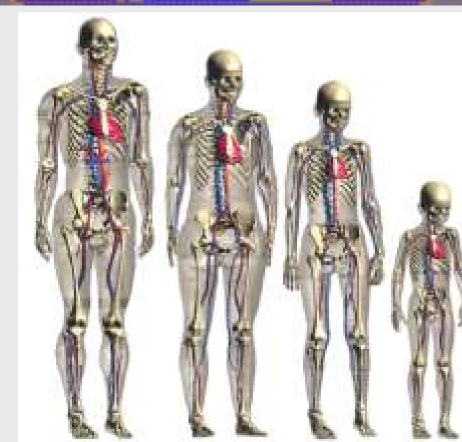
- **Dielectric properties of body tissues are highly dispersive**
  → Particularly important for UWB antennas and radio links

Fantômes numériques et expérimentaux
Fantômes inhomogènes – Modèles « Voxel »

❑ ~20 Modèles « morphologiques » inhomogènes (IRM) → réalistes, précis



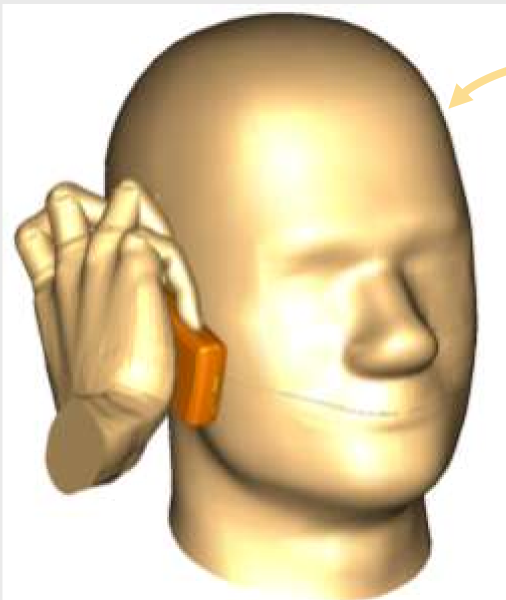


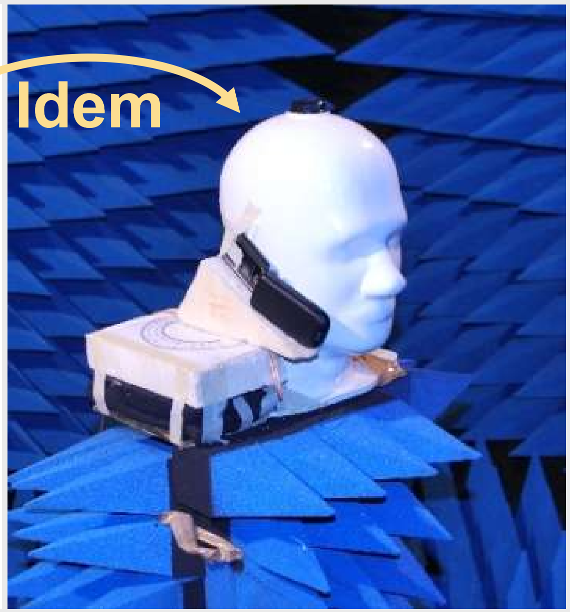


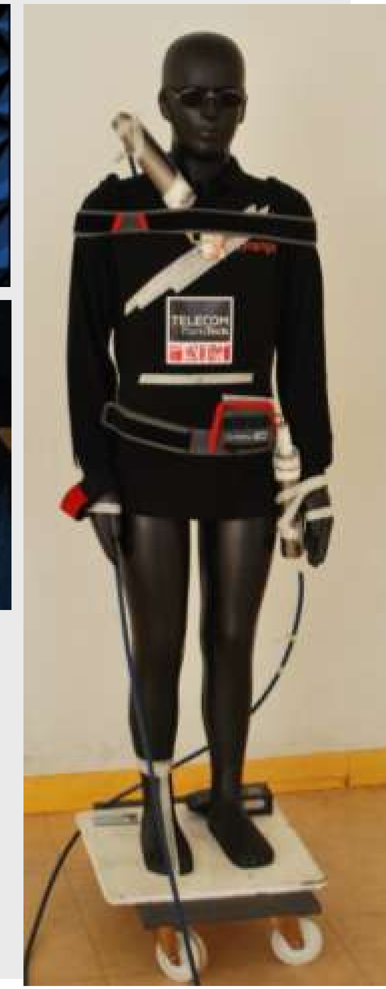
Virtual Family (IT'IS Foundation)

Fantômes numériques et expérimentaux
Fantômes homogènes morphologiques & « canoniques »

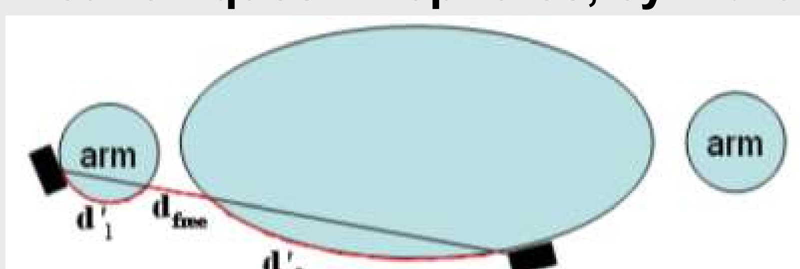
- ❑ **Specific Anthropomorphic Mannequin (SAM) : géométrie numérique/réel id.**





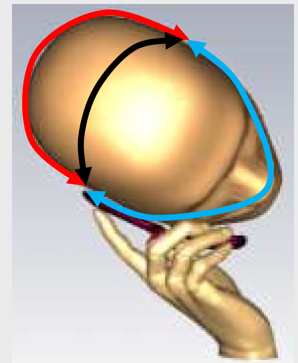


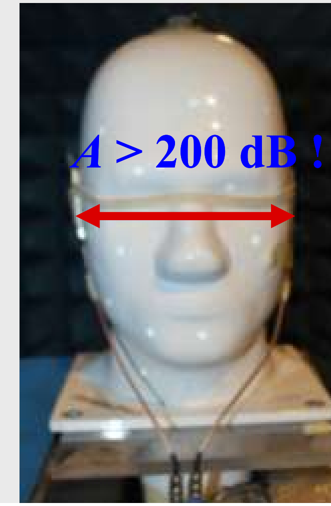
- ❑ **Modèles « canoniques » : sphères, cylindres, ellipsoïdes**



Un peu de physique
Mécanismes de propagation le long du corps

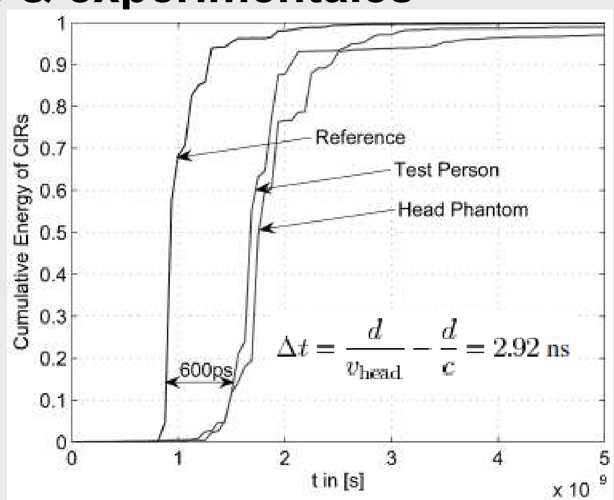
- **Aucune propagation *à travers* le corps (~>2 GHz)**
- **Propagation autour, le long du corps**
  - Ondes rampantes (diffraction), $v_\varphi = c$!
  - Modes de surfaces (~LOS, ex. torse)
- **Propagation en espace libre**
  - Hanche/poignet, réflexions sur le corps
  - Environnement (réflexions du sol, des murs)



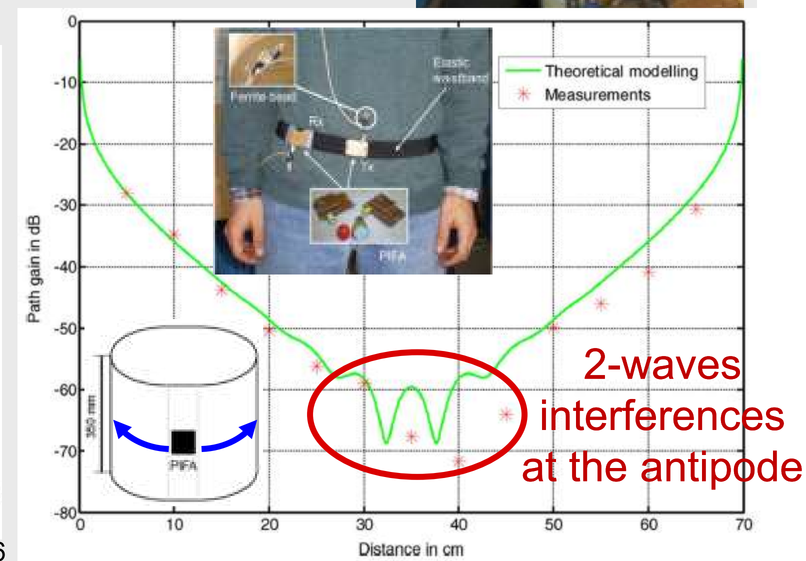


- **Preuves théoriques & expérimentales**

$PL_{mes} \sim 40 - 70$ dB



T. Zasowski et *al.*, "UWB Signal Propagation at the Human Head," IEEE Trans. AP, Apr. 2006



T. Alves et *al.*, "Analytical Propagation Modeling of BAN Channels Based on the Creeping-Wave Theory," IEEE Trans. AP, Apr. 2011

WBAN: Review of PL measurements and models

- **Power law model**

$$PL(d_{[mm]})_{[dB]} = a \cdot \log(d_{[mm]}) + b + N$$

a & *b* depend on the:
- Frequency band
- Environment

- **Exponential model (anechoic chamber)**

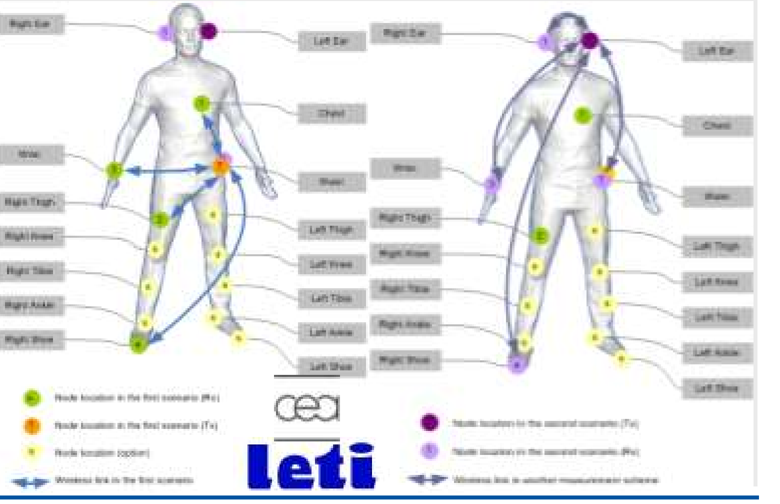
$$PL(d)_{[dB]} = P_0 + \gamma \cdot (d - d_0) + N$$

Main drawback of *PL*(*d*): completely different radio links are merged ⇒ very different PL for same *d* → Very high variances

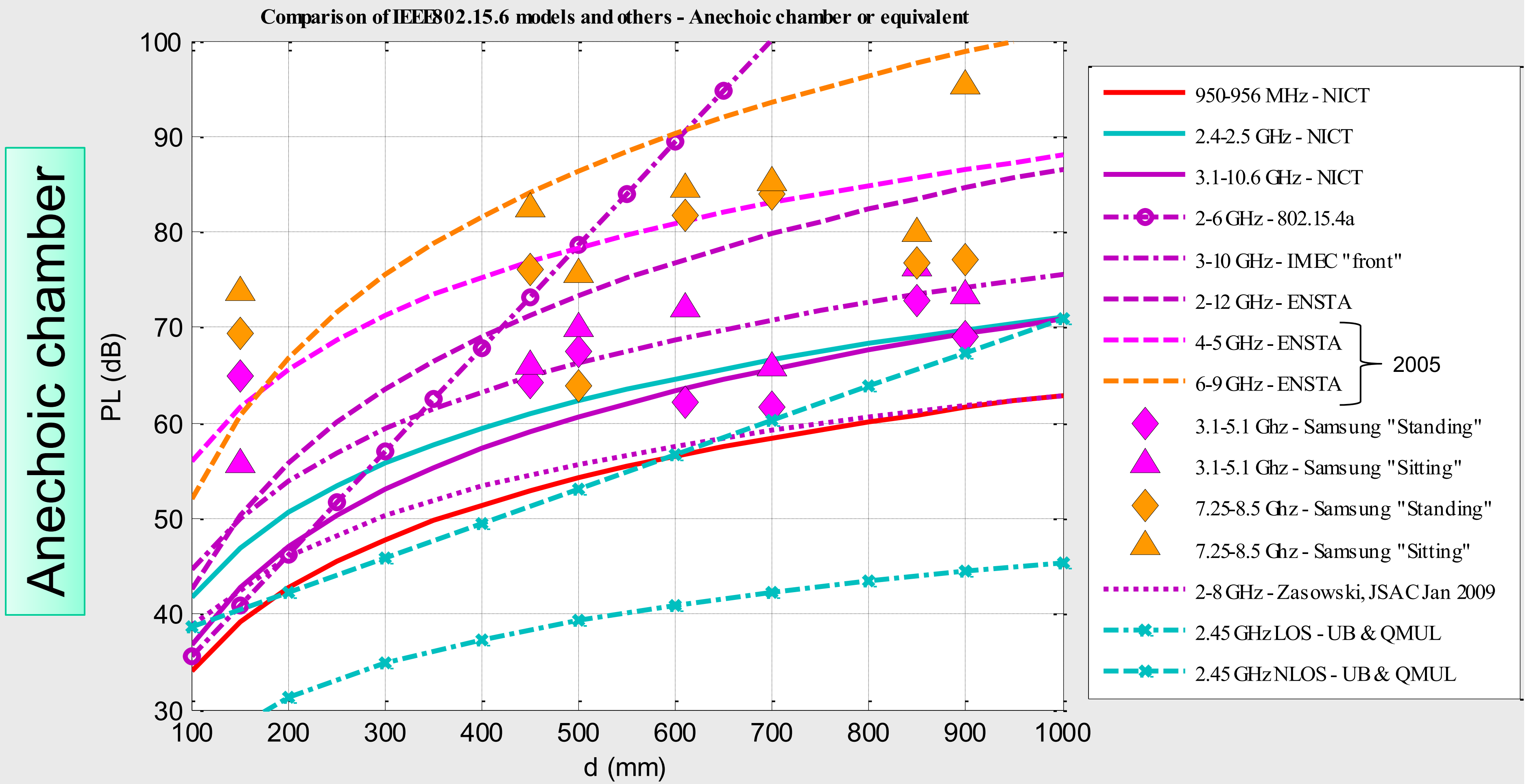
- **« Saturation » model (Indoor**, 915 MHz, 2.45 GHz)

$$PL(d_{[cm]})_{[dB]} = -10 \cdot \log(10^{P_0/10} e^{-(M_0 d_{[cm]})/4.343} + 10^{P_1/10}) + \sigma_P n_P$$

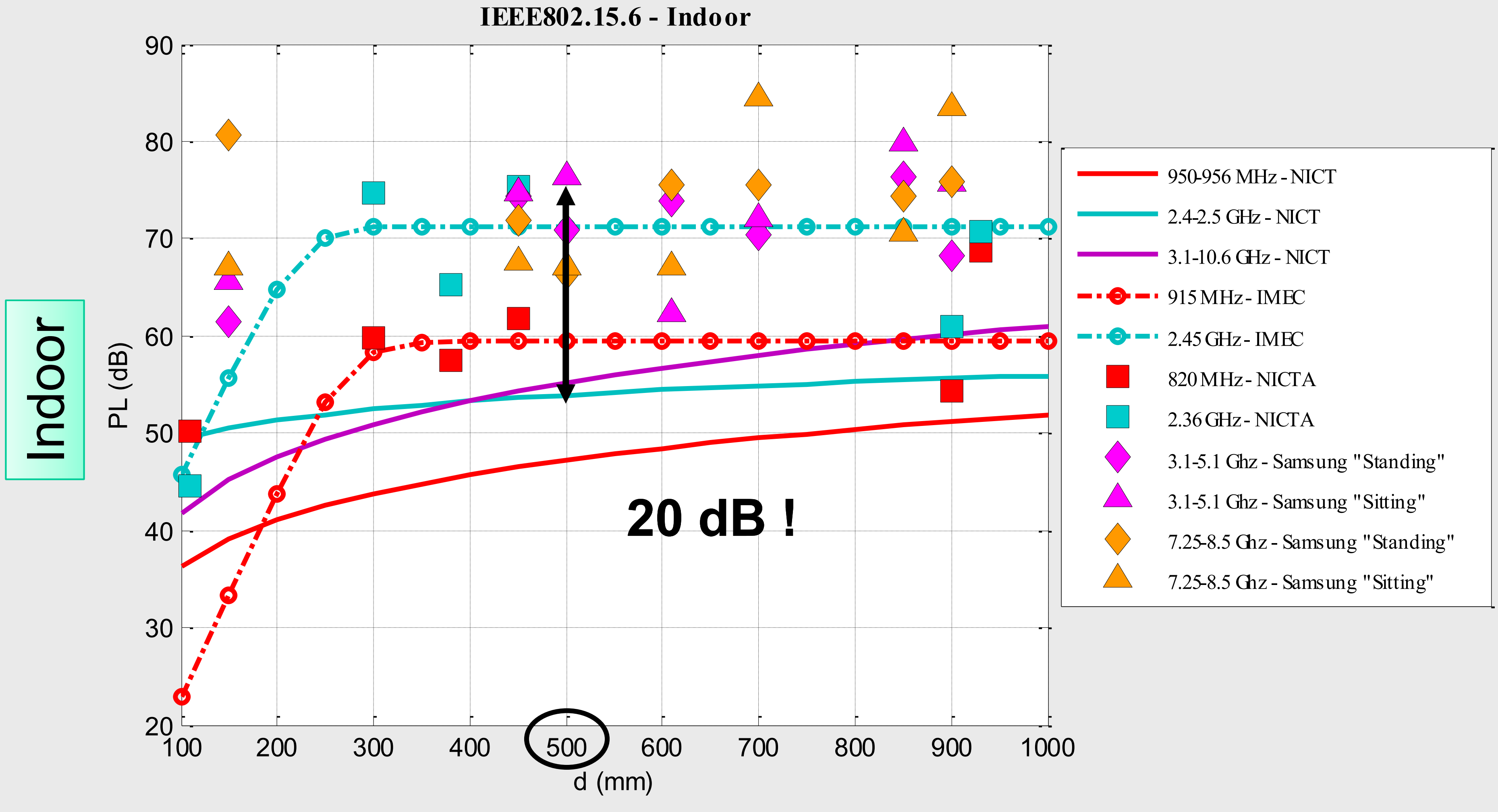
- **« Scenario-based » models**
  - "Hybrid" approach considering scenarios, but still modelling PL as $PL(d)$
  - A promising approach: application-dependent radio link "scenarios", e.g. belt to chest for ECG, etc.



WBAN: Review of PL measurements and models



WBAN: Review of PL measurements and models



WBAN: Review of PL measurements and models

Mainly IEEE802.15.4a & 802.15.6

- **General remark: large dispersion of results >> each σ**
- **Anechoic chamber**
  - For low distances (< 60 cm) 15.4a exp model compatible with others
  - Samsung over [3.1-5.1] Ghz close to « IMEC-front »
  - Close PL exponents for NICT & IMEC-front but with different PL_0 → Antennas…
  - UWB Samsung & ENSTA: same trend with regard to frequency behaviour
- **Indoor**
  - Excellent agreement IMEC/NICTA at ~900 MHz & 2.45 GHz
  - NICT seems « underestimated » w.r.t. IMEC/NICTA 900 & 2.45
  - Samsung [3.1-5.1] coherent with IMEC/NICTA 2.45 GHz
  - NICT (hospital room, « layered ») data could be as well (better ?) represented by a « saturarion » model
    - → Particularly true at 400 MHz : PL almost constant (off reflections probably the dominant mechanism)

Small scale statistics – IR – PDP

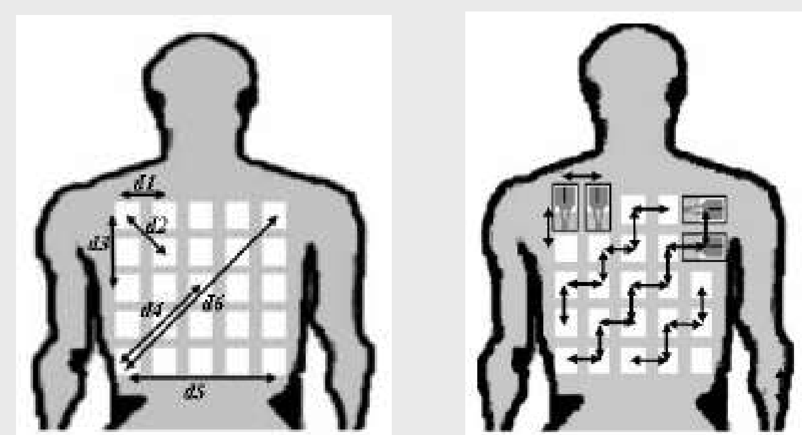
UWB BAN Channel

- **IEEE 802.15.4a**
  - Amplitude distribution → **Lognormal**, bin to bin correlated (adjacent mainly) (≠ conventional Rayleigh or Ricean)
  - Number of clusters fixed to 2 (on-body diffraction + ground)
  - Inter-cluster arrival time fixed (0.5 ns)
  - Inter-path arrival time fixed (7-8 ns)
  - 3 « scenarios » : «front», «side», «back» → different parameters
- **Improvements to account for the environment**
  - On-body + **modified SV**
  - Extracted after time gating the 1st cluster (on-body paths)
  - Dual-slope inter-cluster PDP decay; intra-cluster unchanged
  - Small-scale fading: Nakagami-m or lognormal
  - Cluster arrival time: Weibull instead of Poisson (or mixed Poisson)
  - « Large scale » statistics of energy reflected from env.: lognormal

- IEEE 802.15.6
  - From NICT
  - Tapped delay line
  - Single cluster
  - Path amplitude → exp. decay with Ricean factor
  - Path arrival time: Poisson
  - Number of paths: Poisson (<L> ~5-6 in anechoic chamber and ~38 for Hospital room)

Qu'est-ce qu'un « bon » modèle statistique de canal ?

- **Bon compromis entre précision, représentativité et complexité**
  - précision : dispersion "raisonnable" compatible avec les besoins applicatif, systèmes, etc.
  - représentativité : "général" vs "spécifique", environnement dépendant ("site-specific") ou non, etc.
  - ⇒ Crédibilité (pour les 2)
  - complexité : l'un des points les + importants ; un modèle doit être suffisamment simple pour être utilisable efficacement dans les simulations "système" (couche PHY, lien radio, etc.)
- **Les premiers modèles**
  - Approche « classique » en distance
  - Dispersion très importante : agrégation de liens radio très différents
  - 802.15.6 --> multiplication des modèles ("mosaïque"...)
  - Mais, ont contribué à la compréhension des mécanismes



H. Ghannoum and C. Roblin, "Investigation of the UWB Body Area Propagation Channel," ICUWB, Waltham, MA, USA, Sept. 2006

Conclusions on IEEE802.15.6 channel models

- **Large dispersion of path loss results and models**
  - Lack of standardization of measurement protocols ?
  - Too specific measurements ?
  - Lack of comparisons of the models with each other
- **Variability sources were not really studied**
  - Population: morphology (heigth, corpulence, etc.), internal factors (tissues proportion, skin fat, muscles, etc.)
  - Antennas (types, distance to body, polarisation, orientation, sensitivity to proximity effects)
  - Influence of movements (breathing, walking, running)
  - Influence of the environment (anechoic chamber, indoor premises)
- **A path loss law depending on distance is meaningless**
  - **Distance is NOT the dominant factor**
  - Shadowing is the essential contributor
    - Temporal dependency due to movements
  - **A scenario based approach is suitable**

Roblin C., D'Errico R., Gorce J.M., Laheurte J.M, Ouvry L., « Propagation channel models for BANs: an overview », COST 2100, 16/02/2009 - 18/02/2009, Braunschweig , Germany

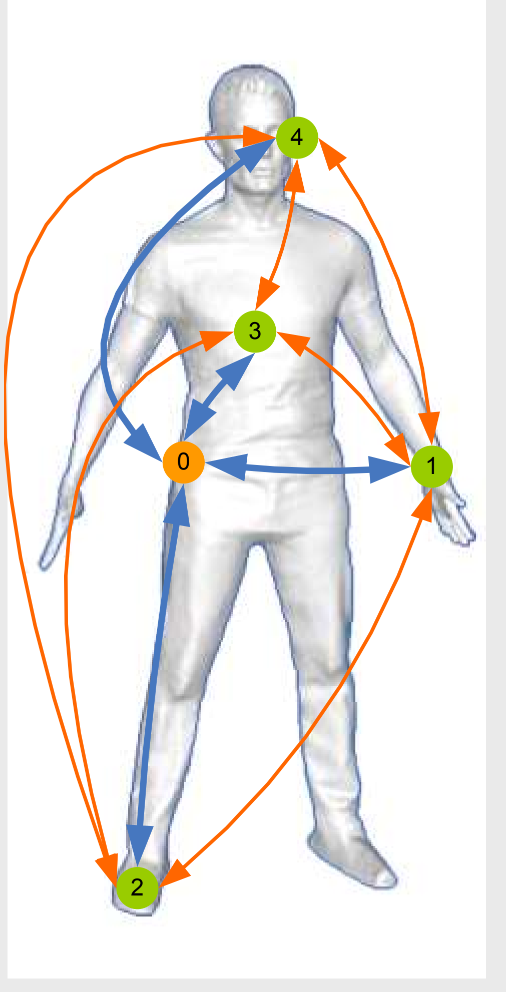
Channel characterisation: A scenario-based approach

❑ A scenario identifies

- ❑ The transmitting antenna on-body position
- ❑ The receiving antenna on-body position
- ❑ The movement condition
  - ➢ Still (but breathing...)
  - ➢ Walking
  - ➢ Running
- ❑ The environment
  - ➢ Anechoic chamber
  - ➢ Indoor

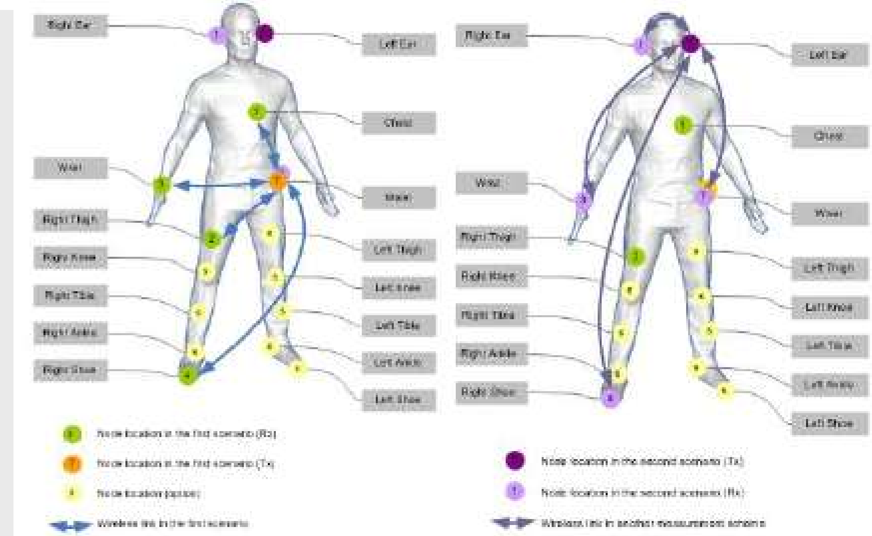
❑ Band of interest

- ❑ ISM 2.4 GHz
- ❑ UWB 3-5 GHz



On-on channel measurement campaign (CEA-Leti)

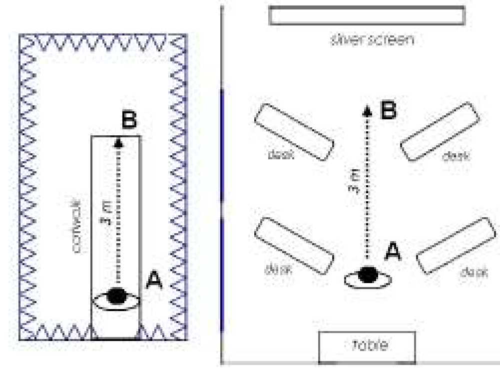
- **TX on Hip (left)**
  - Chest
  - Right Thigh
  - Right Wrist
  - Right Foot
- **TX on Left Ear**
  - Right Ear
  - Hip (left)
  - Right Wrist
  - Right Foot

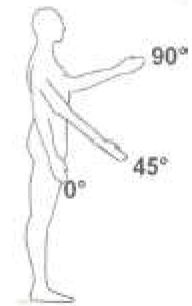


On-on channel measurement campaign (CEA-Leti)

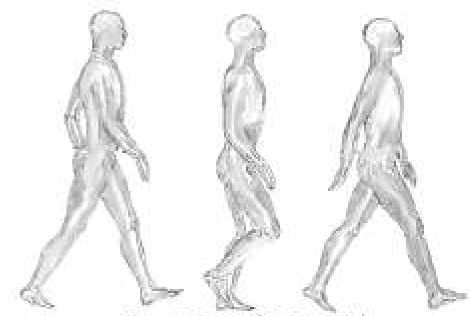
- 2 environments
  - Anechoic chamber
  - Indoor
- 3 types of movements
  - Still (3x4 s)
  - Walking
    - Anech. Ch. (4x4 s)
    - Indoor (3x4 s)
  - Running on spot (1x16 s)
- 7 human subjects
- Total of mesures: **~235k CIRs**

- Reminder : A **scenario** identifies
  - The transmitting antenna on-body position
  - The receiving antenna on-body position
  - The movement condition
  - The environment





Still



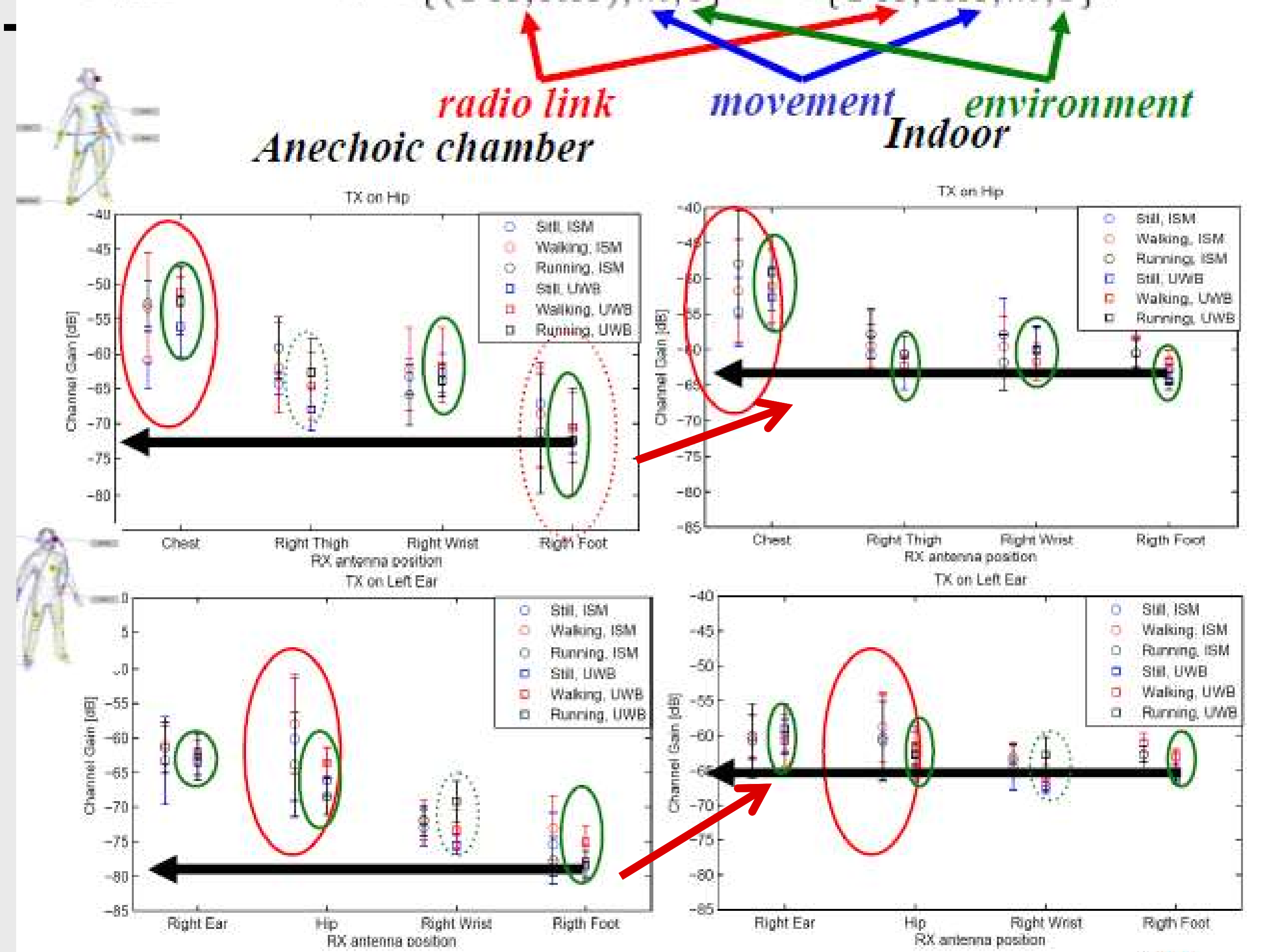
Walking (0.7 m/s)

Running on a spot

Mean channel gain

- A great variability given by discrepancies of diffe-rent human bodies
- A great variability on Hip-Chest, Ear-Hip
  - Propagation mainly on human body: no “on-air”
- Higher gain in Indoor
  - Propagations by the surrounding environment
    - Up to +10 dB in Hip-Foot
    - Up to +15 dB in Ear-Foot
- Generally smaller (or equal) dispersion in UWB (vs NB)

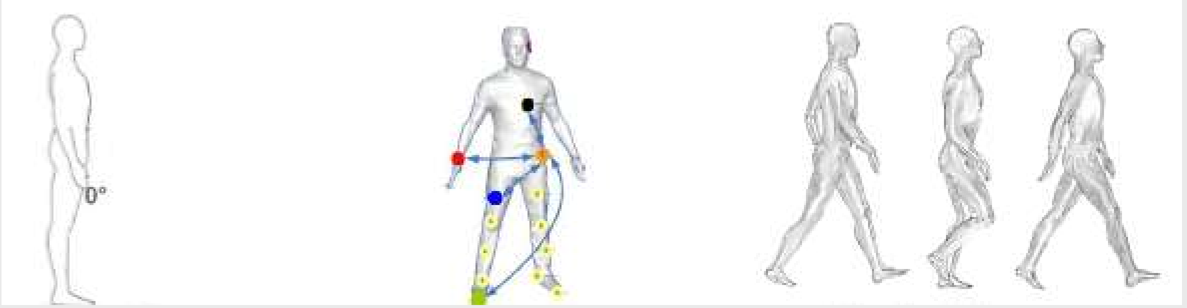
$$G_0|_{dB} \sim \mathcal{N}(\mu_{0_{\{(TX,RX);m;e\}}}, \sigma_{0_{\{TX,RX,m,e\}}})$$

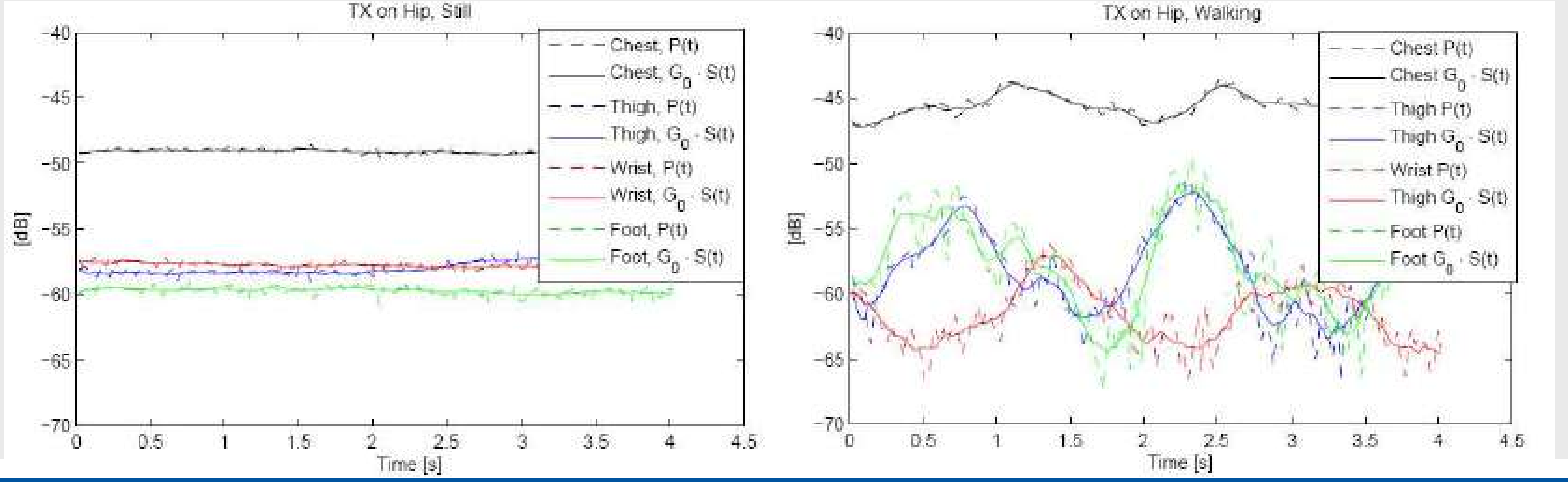


Fading components

- One can distinguish a slow fading component $S(t_n)$ and a fast one $F(t_n)$ in the time dependent power transfer function:

$$P(t_n) = G_0 \cdot S(t_n) \cdot F(t_n)$$





Time-variant channel modelling

- **A great variability given by discrepancies of different human bodies**
  - Statistics on human bodies (only 7 subjects here...)

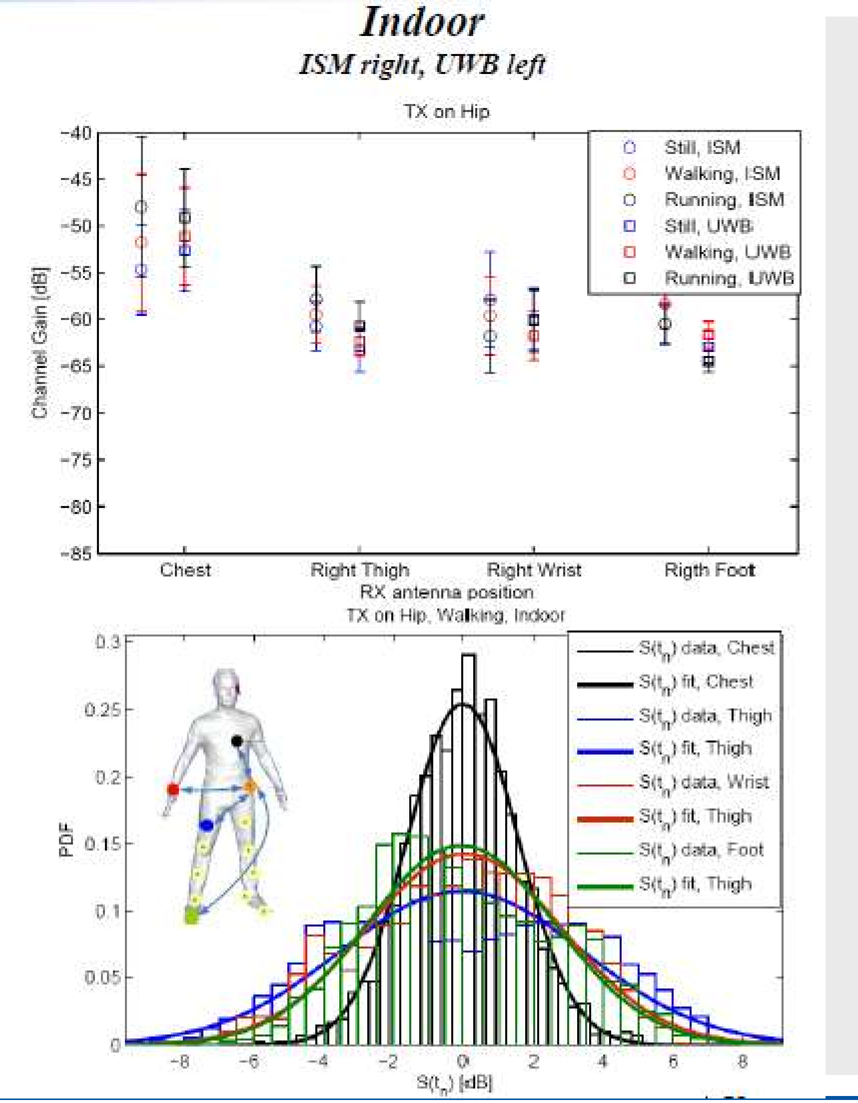
$$G_0|_{dB} \sim \mathcal{N}(\mu_{0_S}, \sigma_{0_S})$$

- **For a specific scenario shadowing is modelled by a log-normal distribution**

$$S(t_n)|_{dB} \sim \mathcal{N}(0, \sigma_{s_S})$$

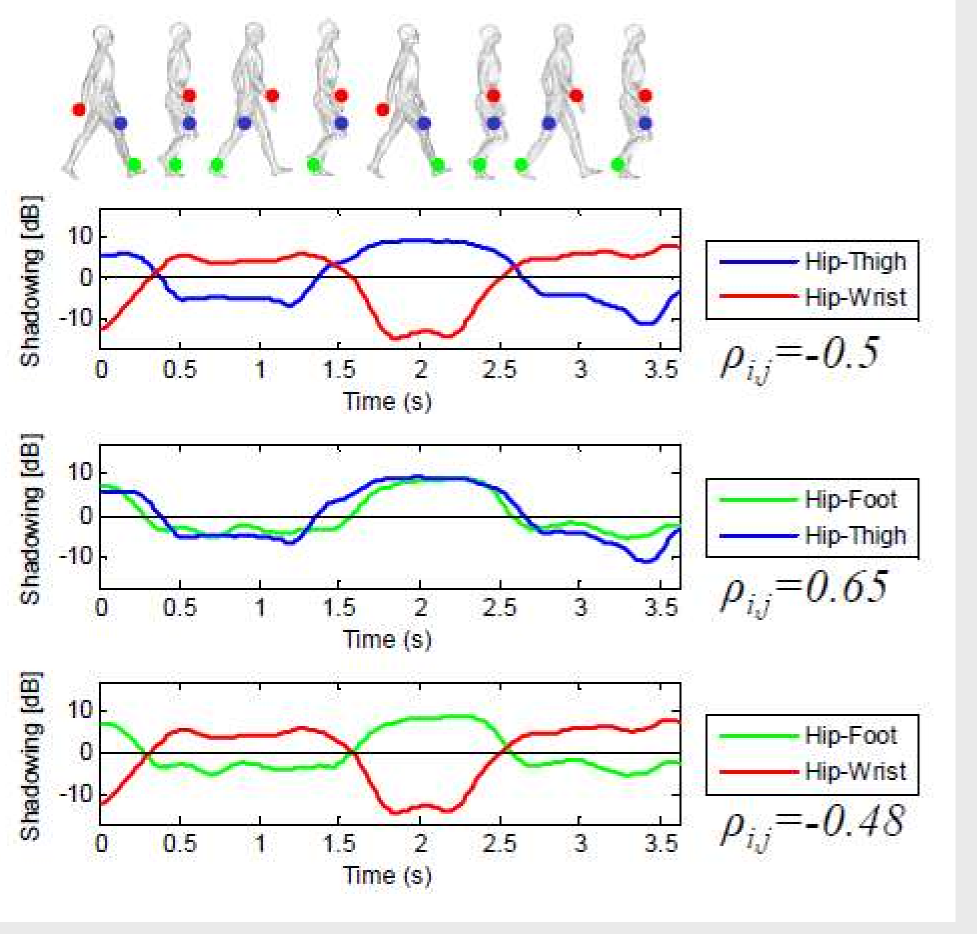
- **Fast fading → Rice**

R. D'Errico & L. Ouvry, "Time-variant BAN channel characterization," *PIMRC 2009, Best Paper Award*



Shadowing correlation and human movement

- Correlation is slightly higher in anechoic chamber than in indoor
- Shadowing correlation is relatively high when the human body does not move
- The scenarios which present high shadowing (generally when one antenna is on a limb) present the highest correlation
- Thigh and Foot experience "synchronous" shadowing, but inverted with respect to Wrist



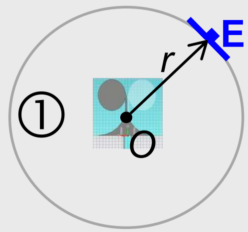
R. D'Errico & L. Ouvry, "Time-variant BAN channel characterization," *PIMRC 2009, Best Paper Award*

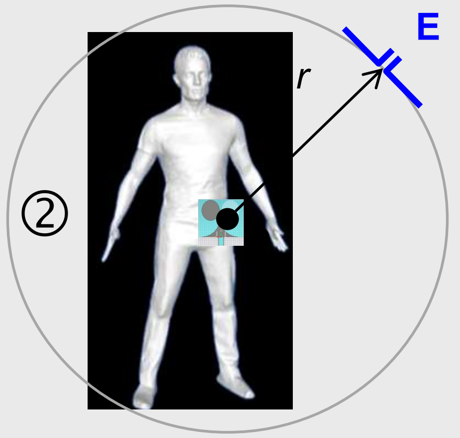
Antennas in (for?) WBANs
Framework – Perimeter – Objectives

- UWB antennas (for communications mainly)
- On-body antennas: body proximity effects – comparison to NB
- Parametric analysis
- Numerous sources of variabilities plaid for a statistical approach
- How to get models?
- Which guidelines for antenna design?

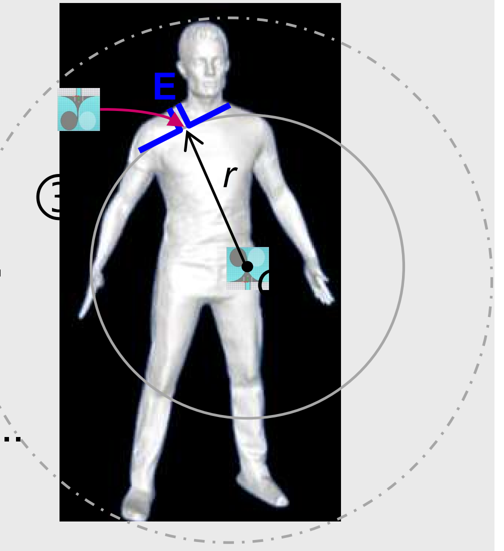
On-body Antennas: problematic of some concepts

- **How to found the conceptual definitions of :**
  - Energy transfer
  - Time spreading, etc.
- **... for (UWB) antennas which are:**
  - ① Isolated (“free” space)
  - ② On-body to off-body
  - ③ Both on-body





- **For ① the field is measured (probed) on any circumscribing sphere (enclosing the antenna) ⇒ clear definitions of ATF, AIR, Time spreading, etc.**
- **For ② antenna body ⇔ new antenna ⇒ same concepts**
- **For ③ it’s more complicated: how to define the sphere ?...**
  - If you want to probe the field on “the” relevant sphere, the probe is perturbed by near field effects due to the body proximity ⇒ measurement depends on the probe/body coupling → not intrinsic!...
  - ⇒ analyse directly the radio link, i.e. the 2-antenna/body system
- **The controversy about the “intrinsic channel”...**



UWB Antenna – Body Interaction

UWB specificities – Comparison to narrowband

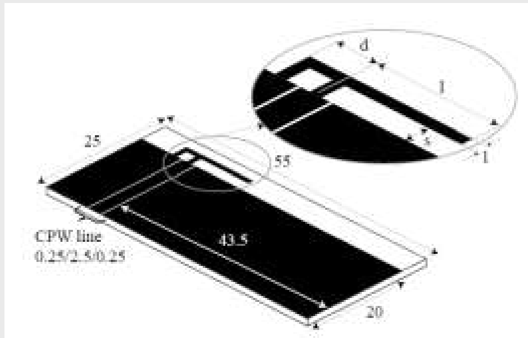
- **UWB versus Narrowband (or moderate band) → Main issues:**
  - **Narrowband →** *Input matching* (strong « detuning ») ⇒ sensitivty to the b proximity effects should be reduced → desensitization techniques are requ
    - **Widening** of the BW
    - EM **Screening** with: a ground plane, ferrite sheets
  - **UWB →** *Energy transfer* performance (although input matching remains important)
- **Classes of UWB antennas**
  - Balanced, grounded (low profile NP), small (quasi-)planar (nor balance grounded), chip antennas, magnetic (quasi-)planar (« slot-like »), loops
  - Tangent (« Horizontal » or « Vertical ») or Normal Polarization (NP)
- **Conclusion: Antenna « *categorization* » (wide sense) is mandatory**

Reflection (S_{11}) 1st

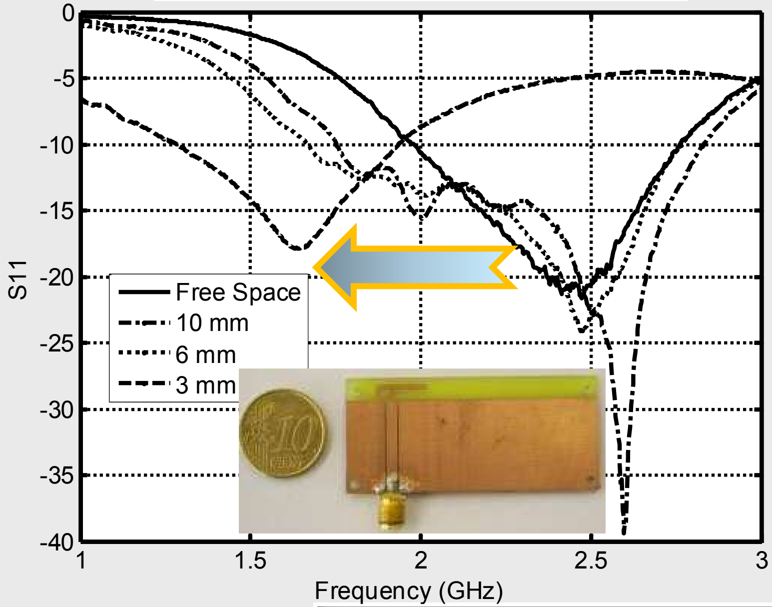
Transmission (S_{21}) 1st

Narrowband Antenna – Detuning/Desensitization

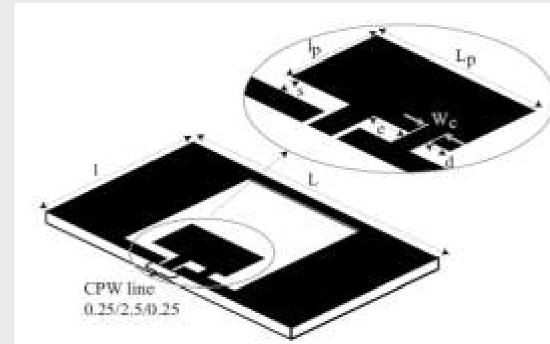
IIFA detuning

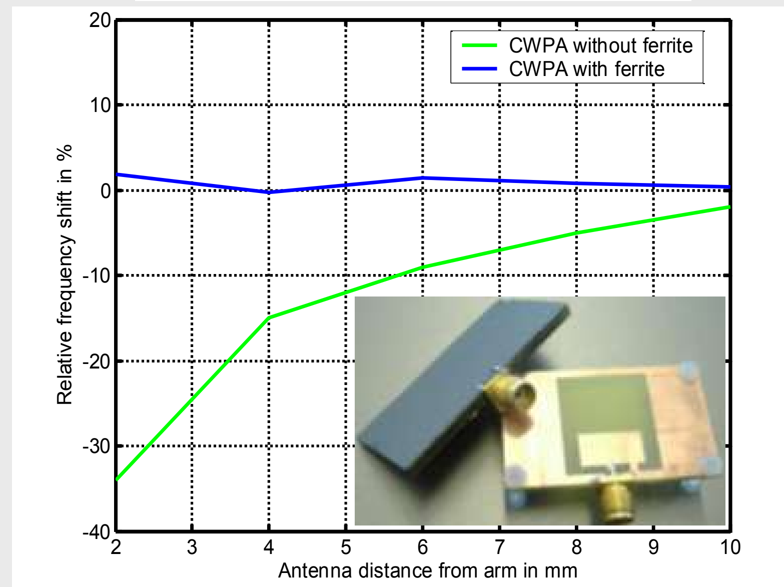


$f_0 \sim 2.4$ GHz



CPWA desensitization technique

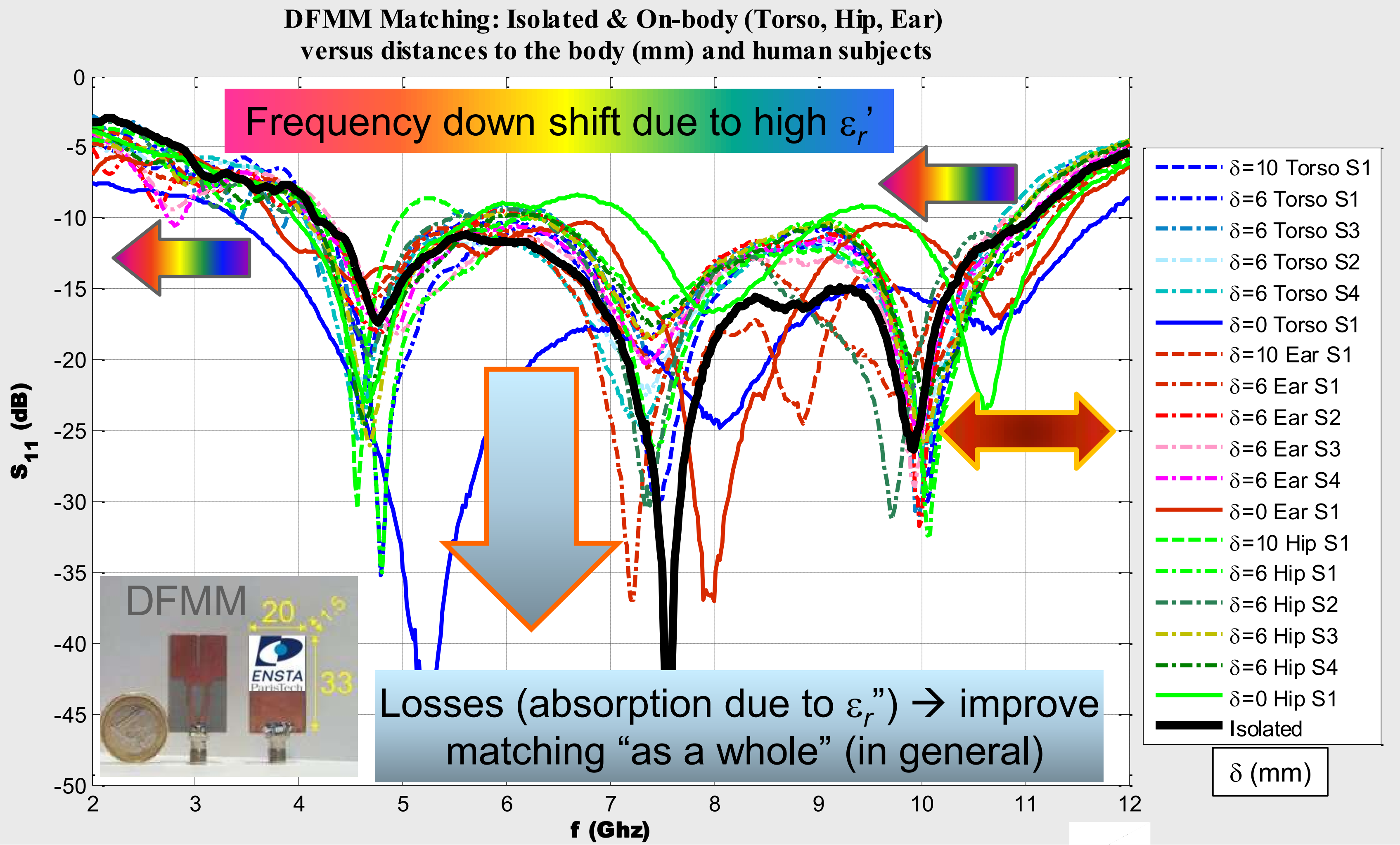




Courtesy of J. M. Laheurte & T. Alves, UMLV/ESYCOM, France

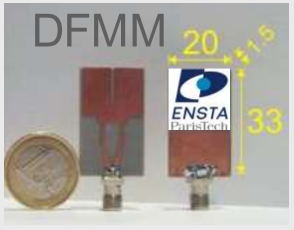
UWB Antenna: Effect on the input matching

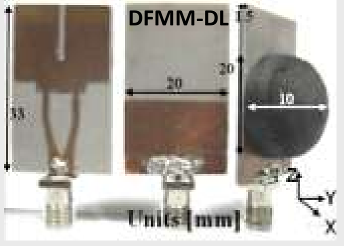
- Input matching (usual) trend (small (quasi-) planar unbalanced antennas)

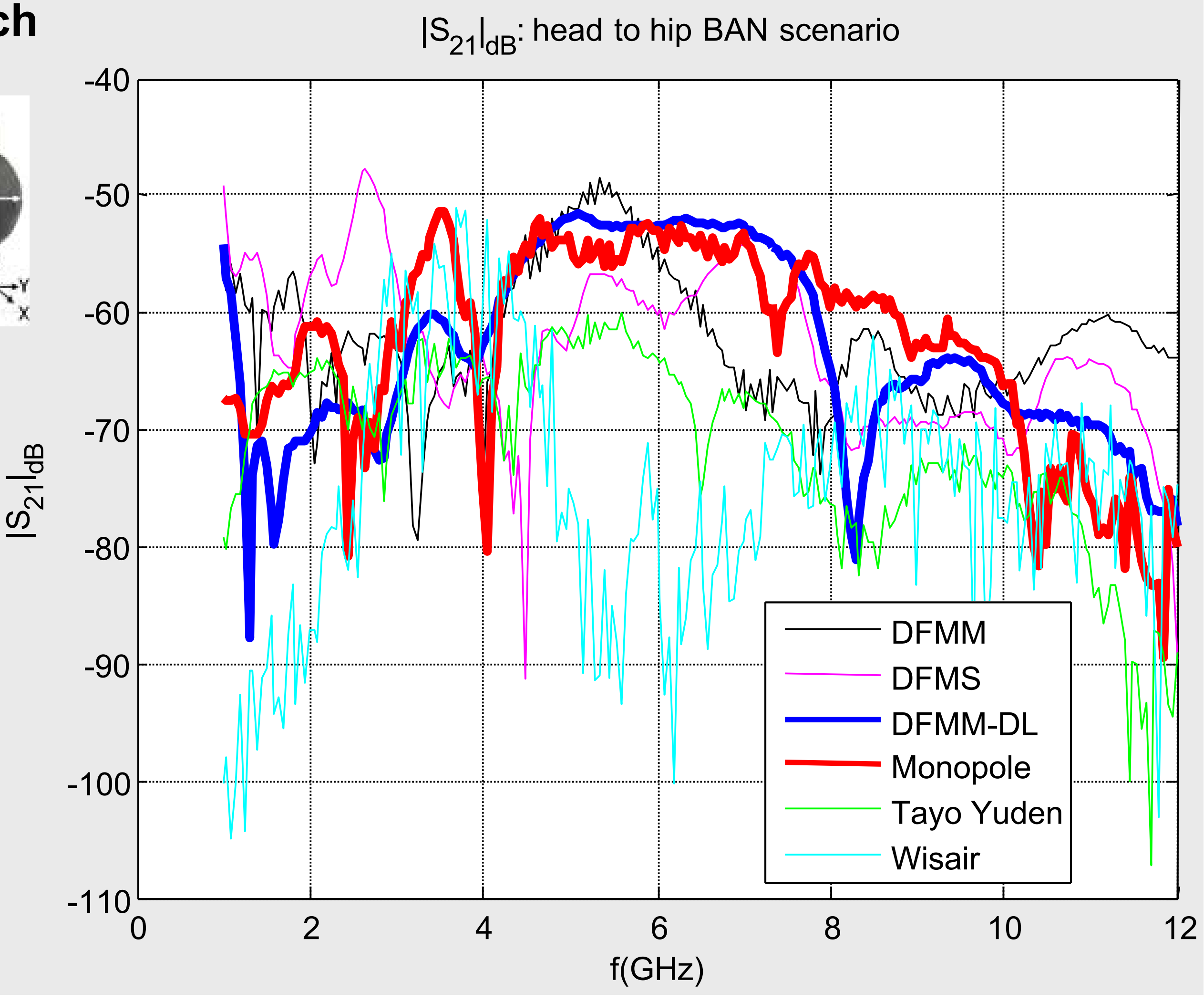


WBAN: variability due to antennas (1)

❑ Scenario-based approach

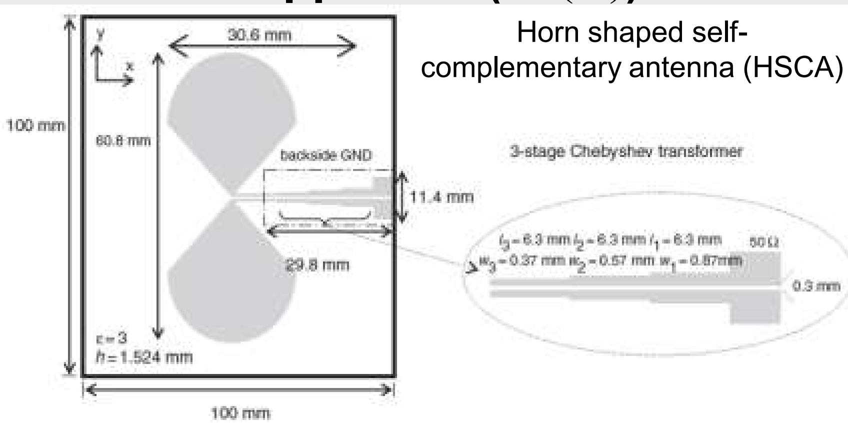




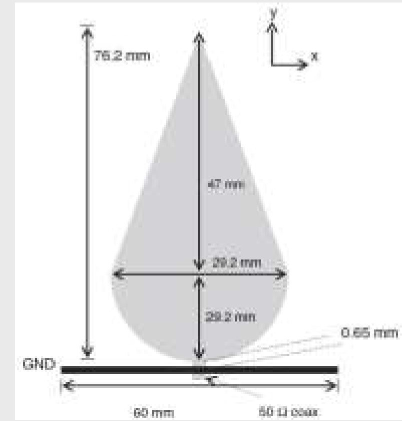


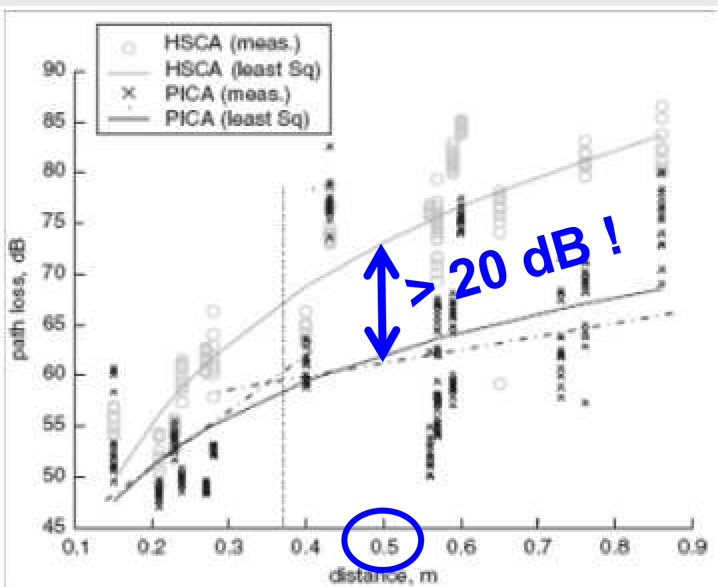
WBAN: variability due to antennas (2)

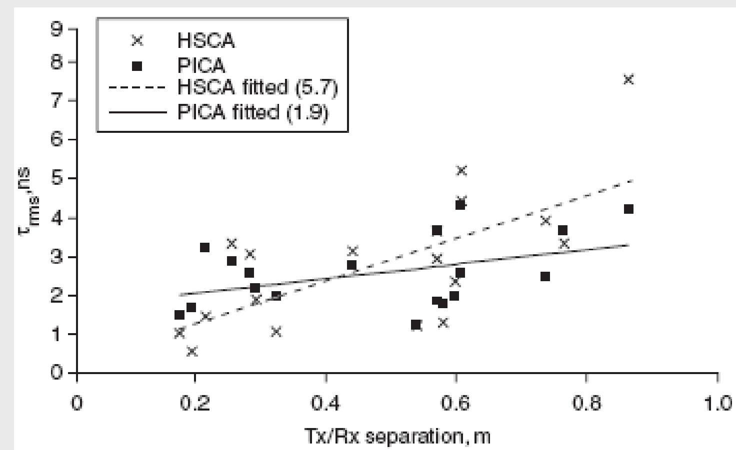
- "Classical" approach ($PL(d)$)



Planar inverted cone antenna (PICA)





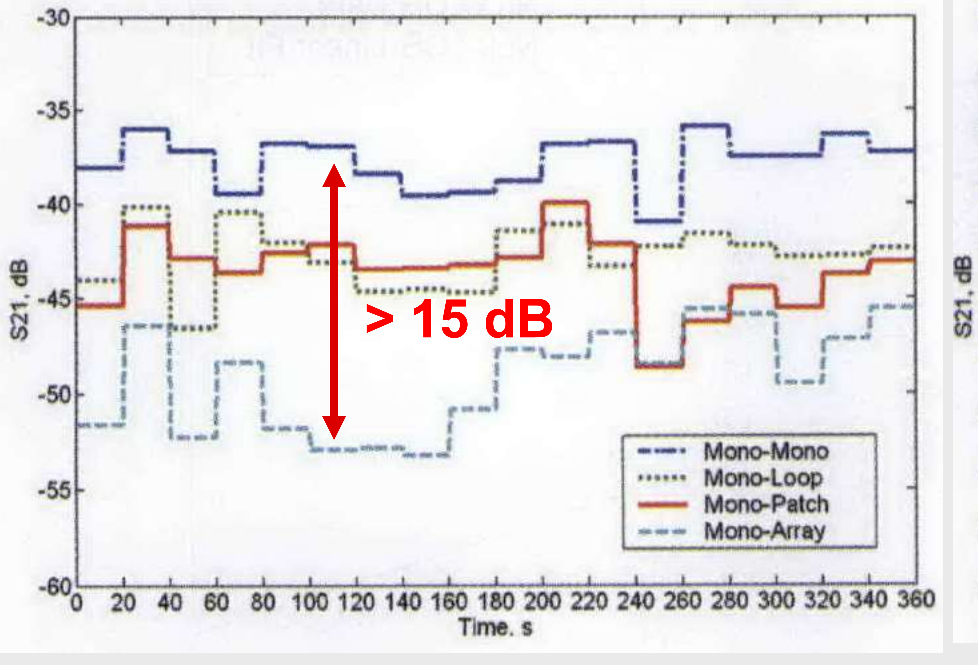


A. Alomainy, Y. Hao, C. G. Parini, and P. S. Hall: *UWB on-body radio propagation and system modelling for wireless body-centric networks,* IEE Proc.-Comm., vol. 153, n° 1, Feb. 2006.

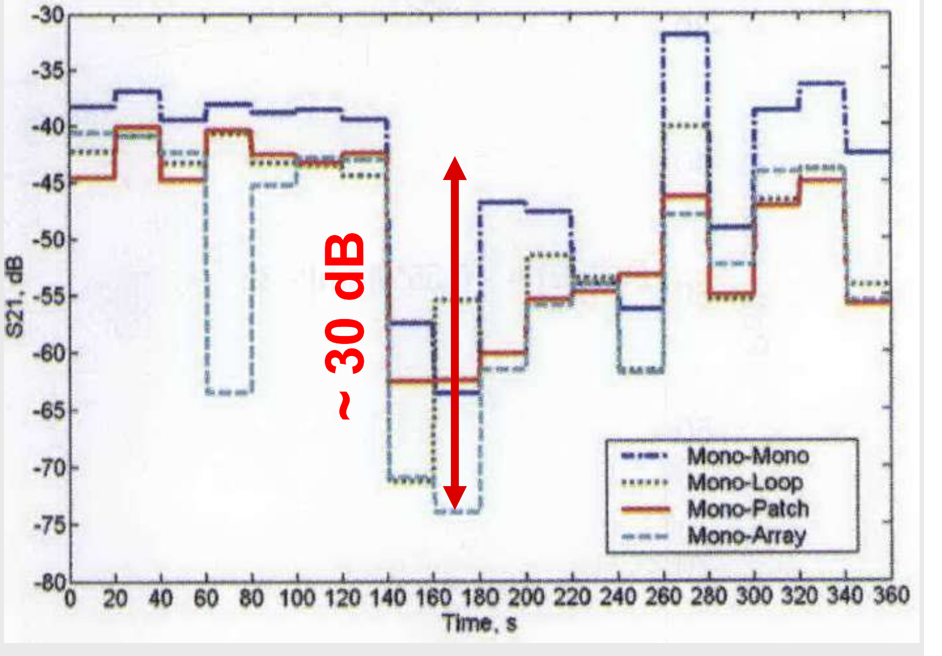
WBAN: variability due to antennas (3)

- Comparison with narrowband (2.45 GHz): (time) varying postures context

Belt-to-chest



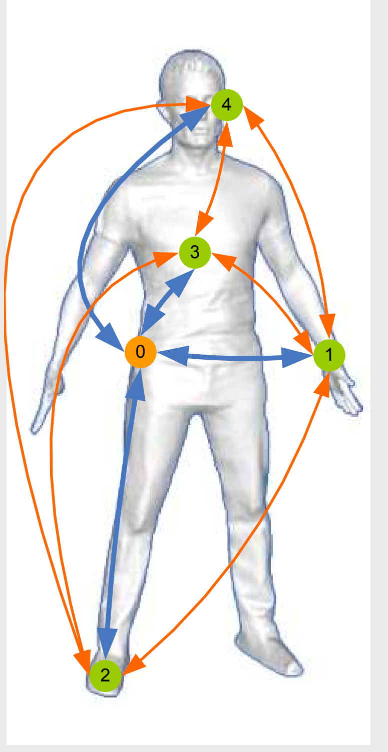
Belt-to-wrist



P. S. Hall, Y. Hao, Y. I. Nechayev, C. Constantinou, C. Parini, M. R. Kamarudin, T. Z. Salim, D. T. M. Hee, R. Dubrovka, A. S. Owadally, W. Song, A. Serra, P. Nepa, M. Gallo, and M. Bozzetti: *Antennas and Propagation for On-Body Communication Systems*, IEEE AP Mag., vol. 49, n° 3, June 2007.

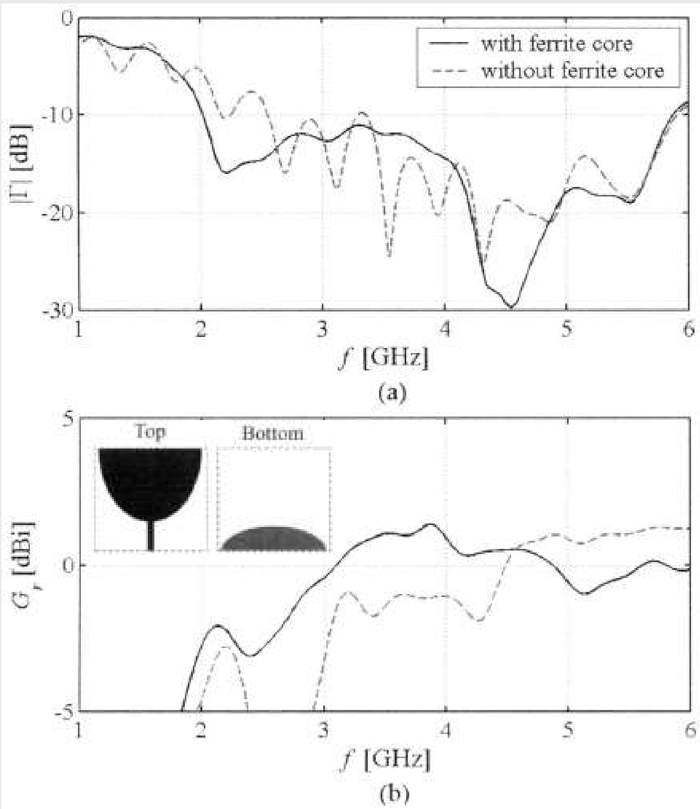
Measurement issues – Methodology

- **Impact of the measurement methodology and protocols**
  - Importance of the measurement methodology
    - Balanced/Unbalanced antennas
    - « Cable effects »
    - Parasitic environmental effects: residual MPCs
    - Reproducibility → clearly defined measurement protocols
  - Taking care of the « *effective dynamic range* »
  - A Scenario-based approach: a bridge from measurement protocols, processing and modelling and eventually relevant applications
  - This allows a better…
- **Statistical & parametric Channel analysis**
  - Antenna «*effects*» in a controlled environment (Anechoic Chamber)
  - Quasi-deterministic parametric behaviour & scenarios
  - Indoor environments contribution (not presented today)

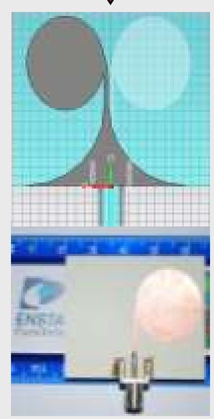


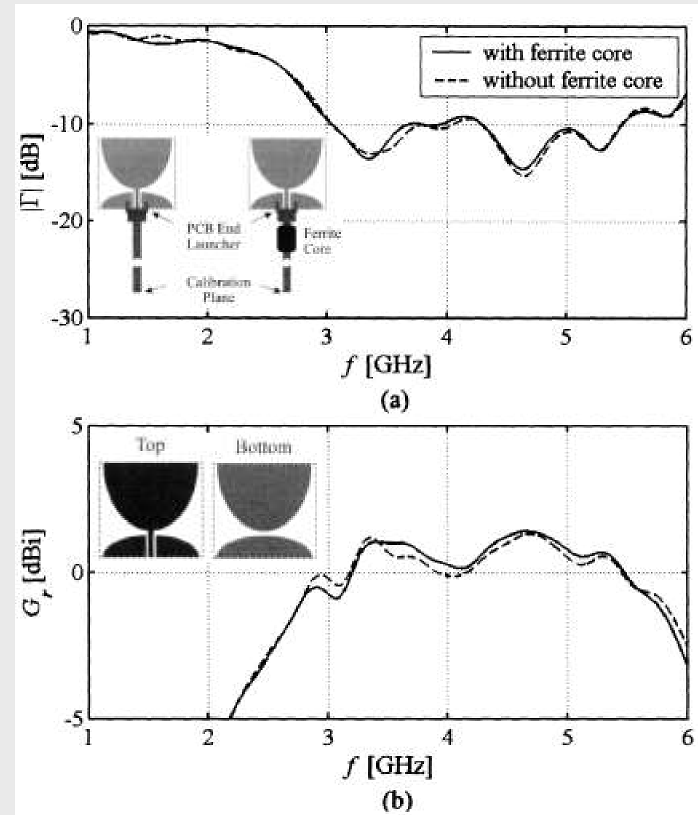
Effect of feed cables: common current mode

❑ **Unbalanced feed line** **Balanced feed line**



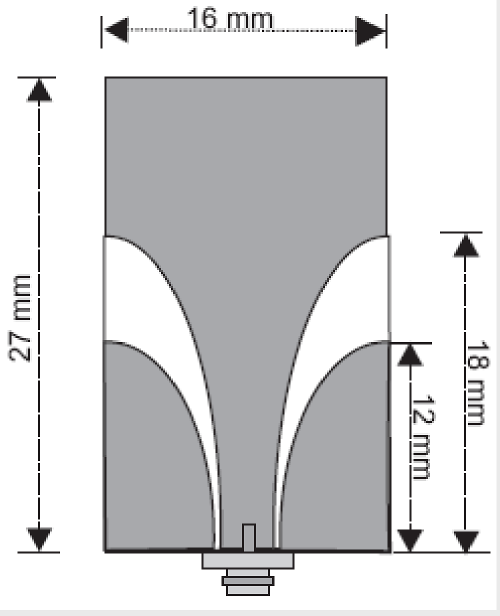
CONCLUSION

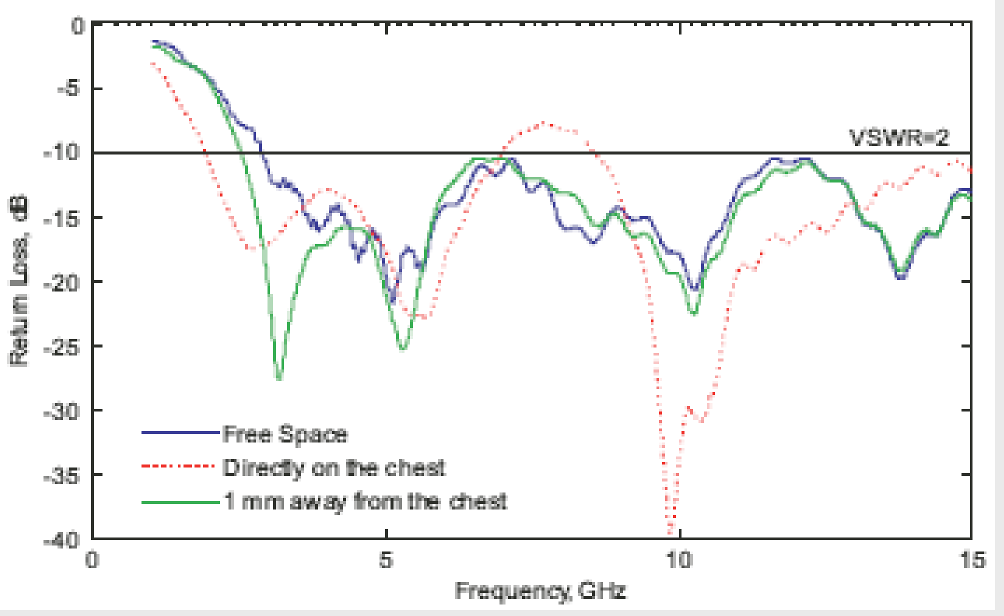




Th. W. Hertel: *Cable-Current Effects of Miniature UWB Antennas*, IEEE AP Symp., vol. 3A, pp. 524-527, July 2005.

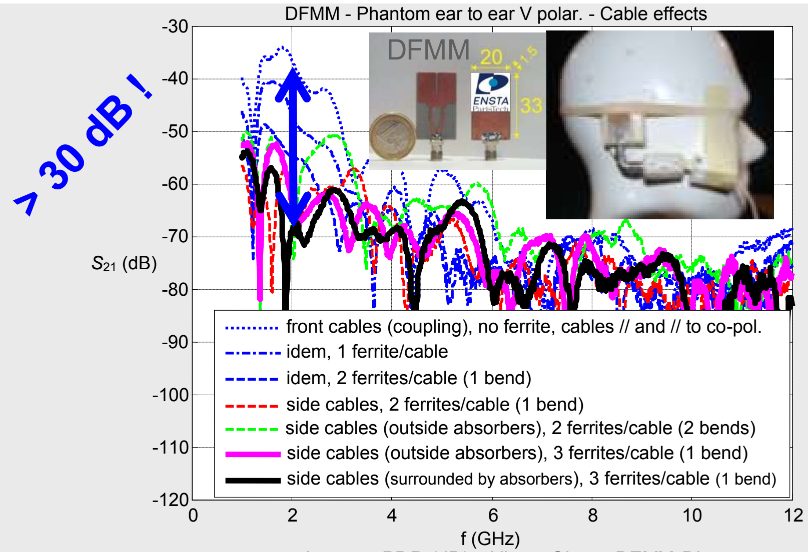
Another balanced planar antenna designed for WBANs

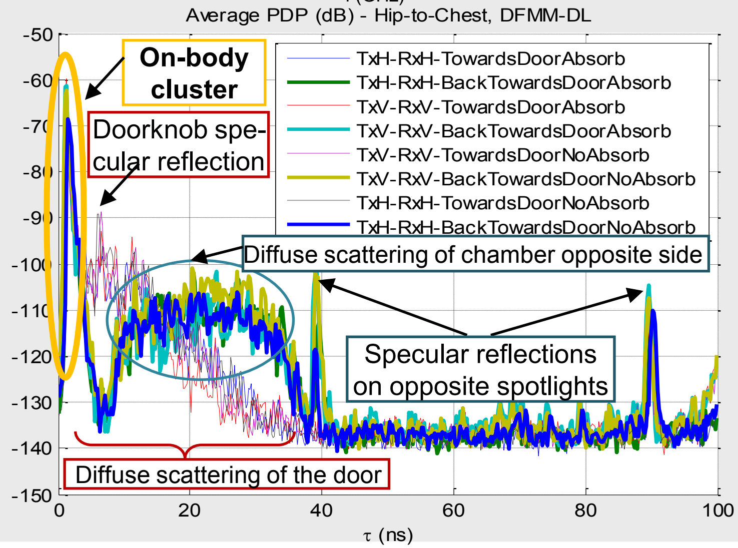


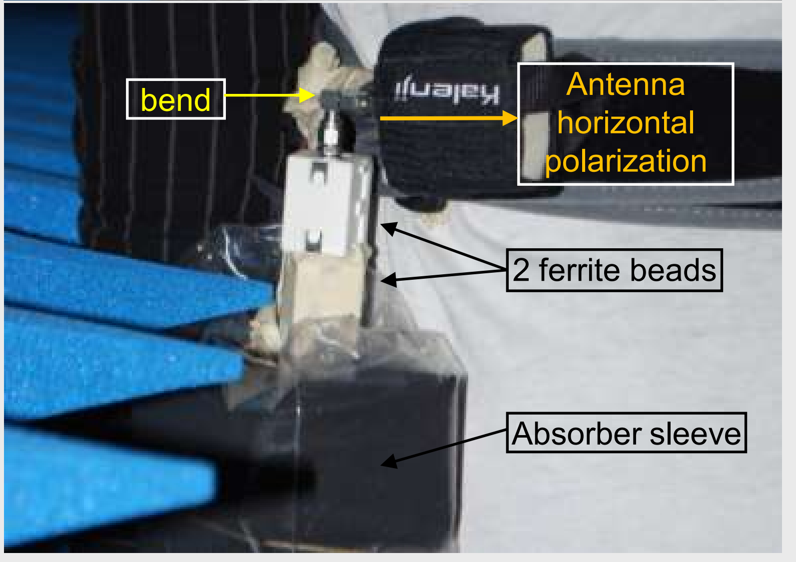


Atiqur Rahman, Akram Alomainy and Yang Hao: Compact Body-Worn Coplanar Waveguide Fed Antenna for UWB Body-Centric Wireless Communications, EuCAP 2007.

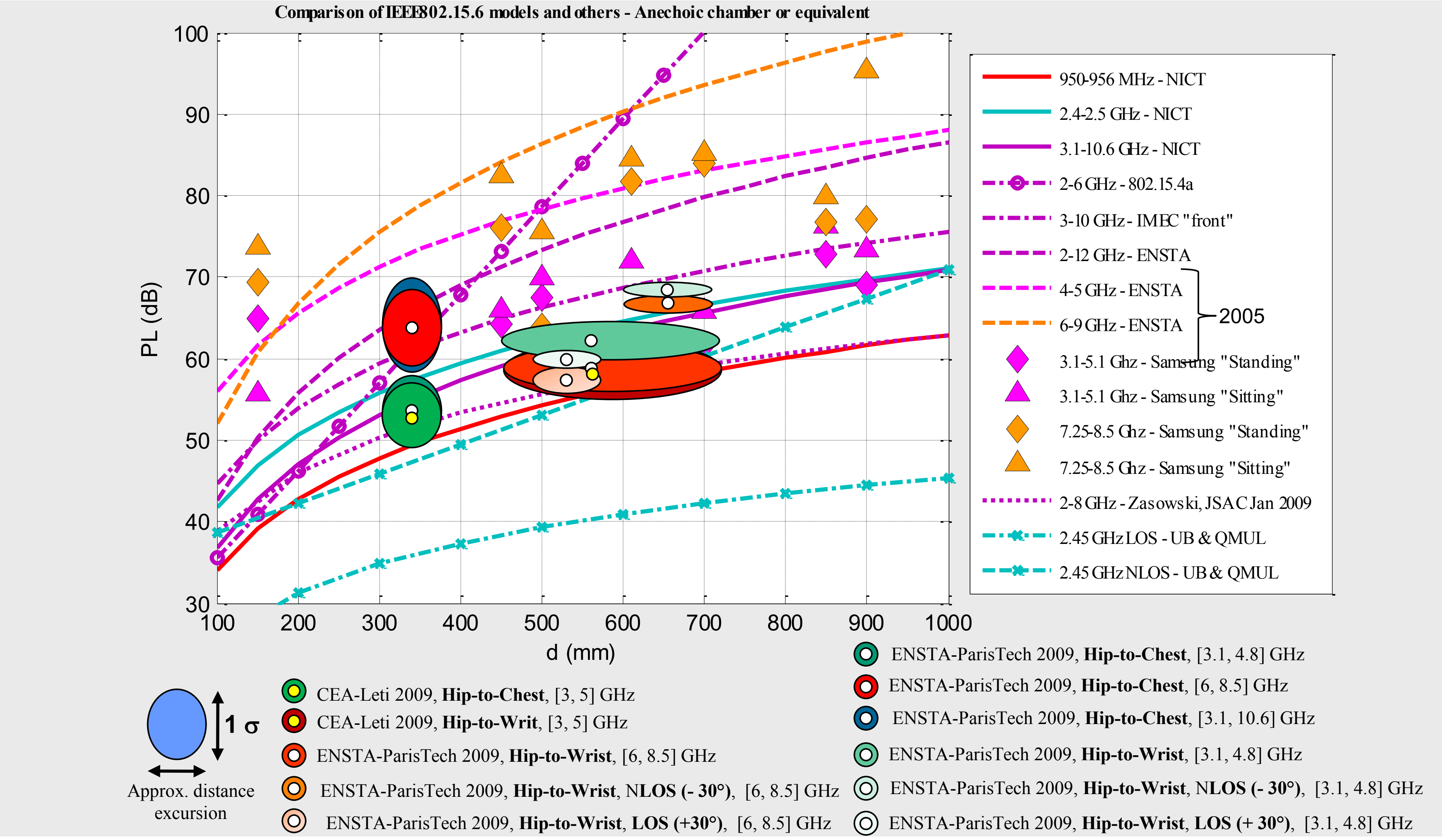
Measurement methodology





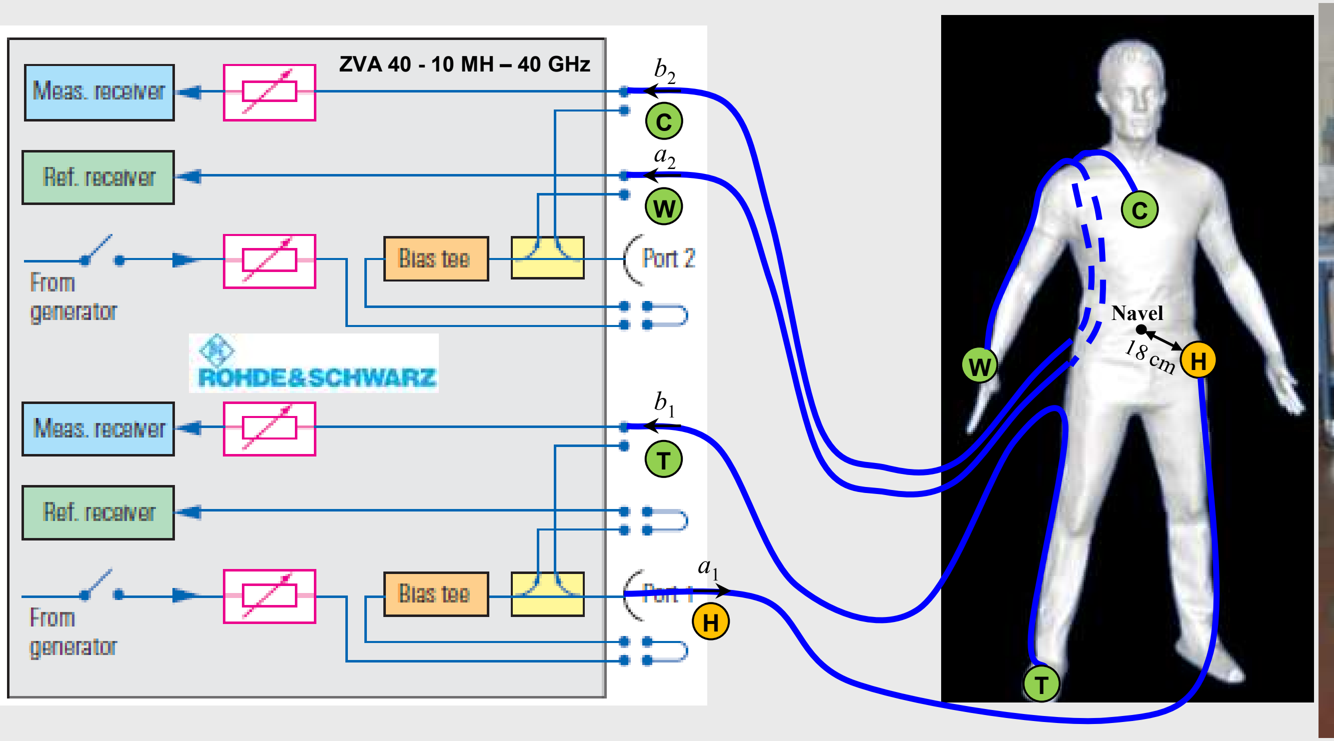


Measurement methodology → improved reproducibility and cohesion



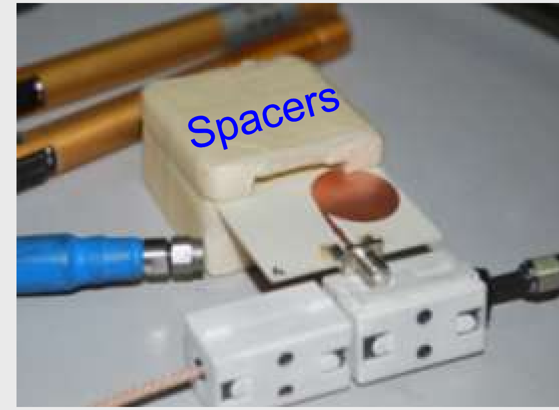
Transmission measurement setup (in the FD)

- Simultaneous measurement of 3 channels with post-calibration
  → 3 independent receivers used



ON-ON STATISTICAL APPROACH

A parametric analysis

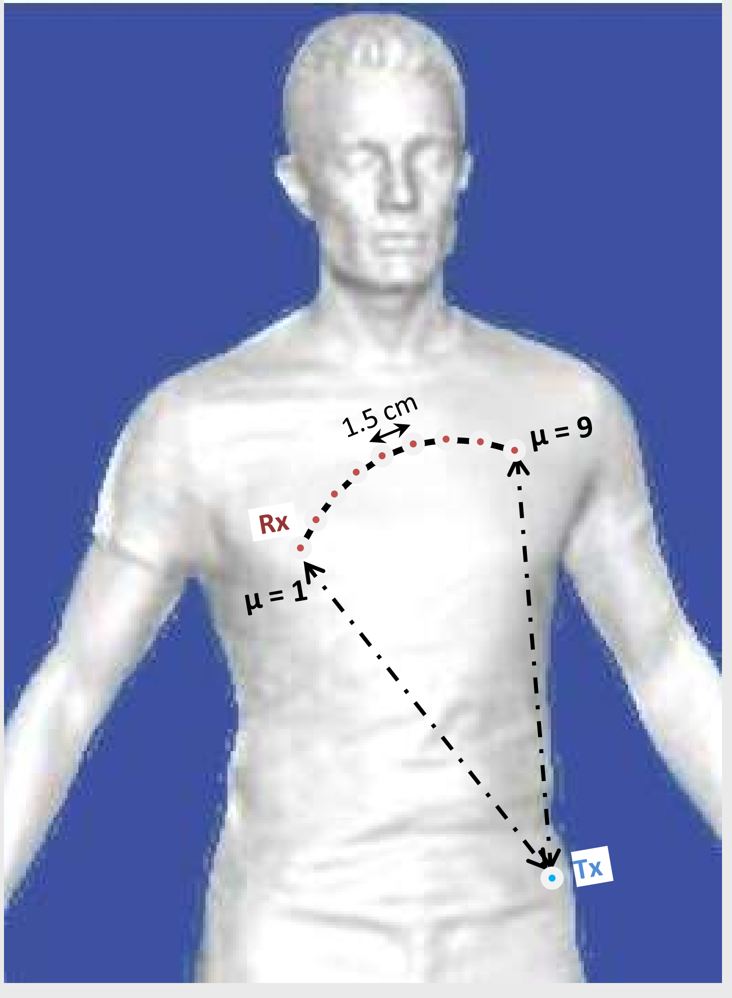


- **For various scenarios (H2C & H2W as examples)**
- **Comparison of various antenna types**
- **Varying geometrical parameters:**
  - Distance δ to the body
  - Walking/running postures → arm angle ϑ
- **For 1 or 2 Human Subjects** S
- **First in a well controlled environment: anechoic chamber**
- **Statistics over:**
  - Micro-positioning μ (10 for H2C and 3 for H2W)
  - Repetitive frequency sweeps s (10 here)

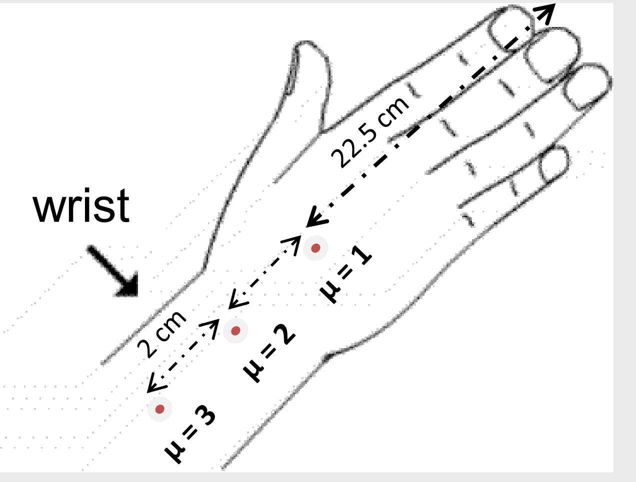
$$\rightarrow \quad S_{21}^{a}(Sc, f, S, \delta, \vartheta, \mu, s)$$

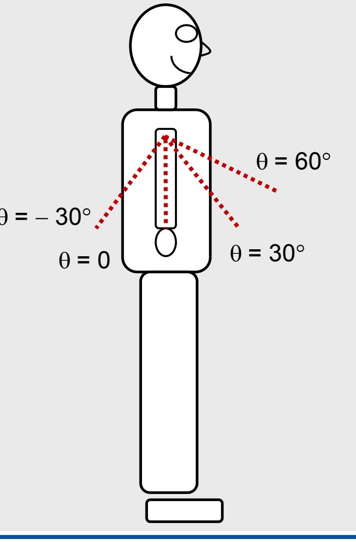
Statistical sampling for two scenarios

- Hip-to-Chest (H2C)

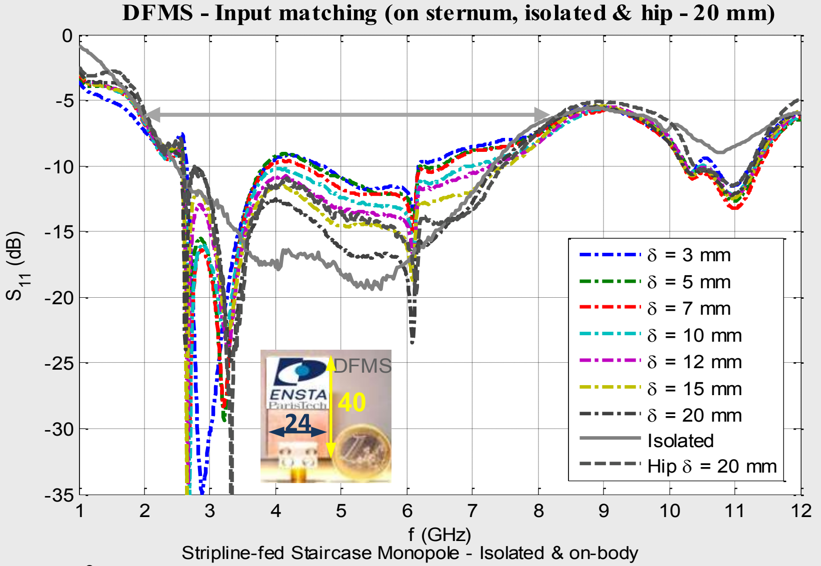


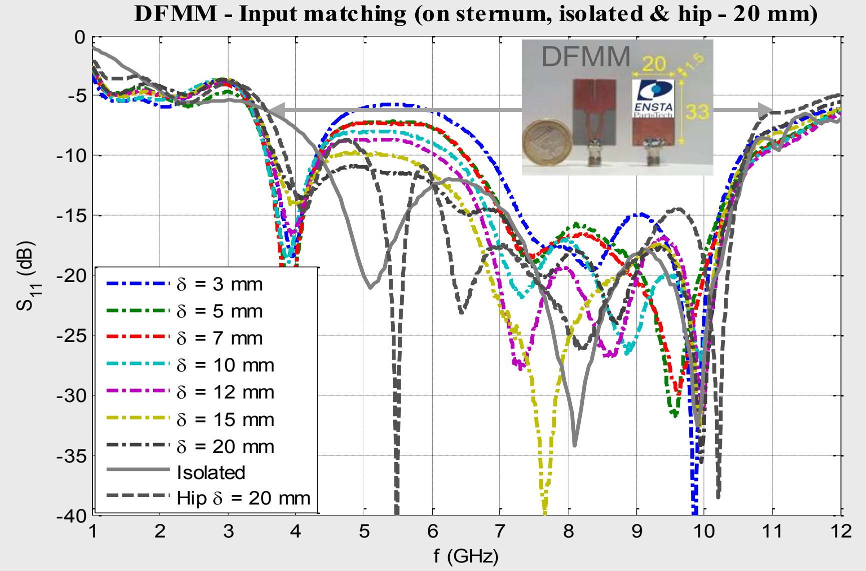
Hip-to-Wrist (H2W)

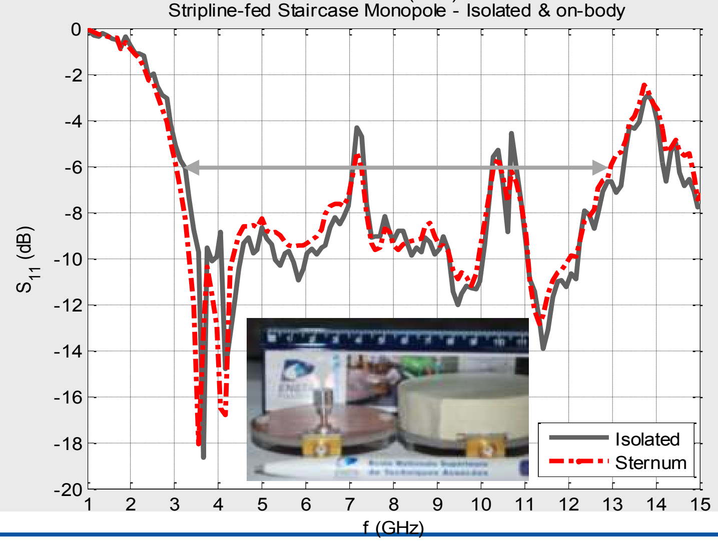


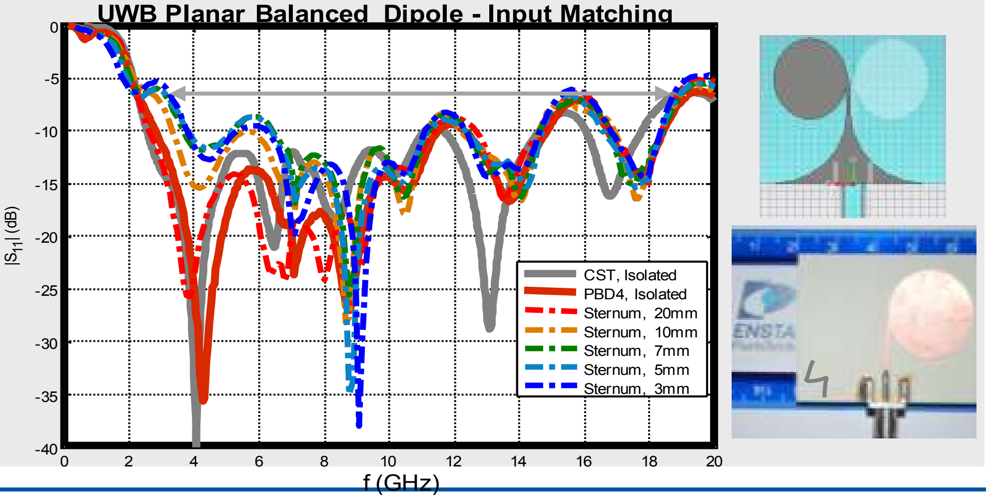


Comparison of on-body antennas: input matching (1)

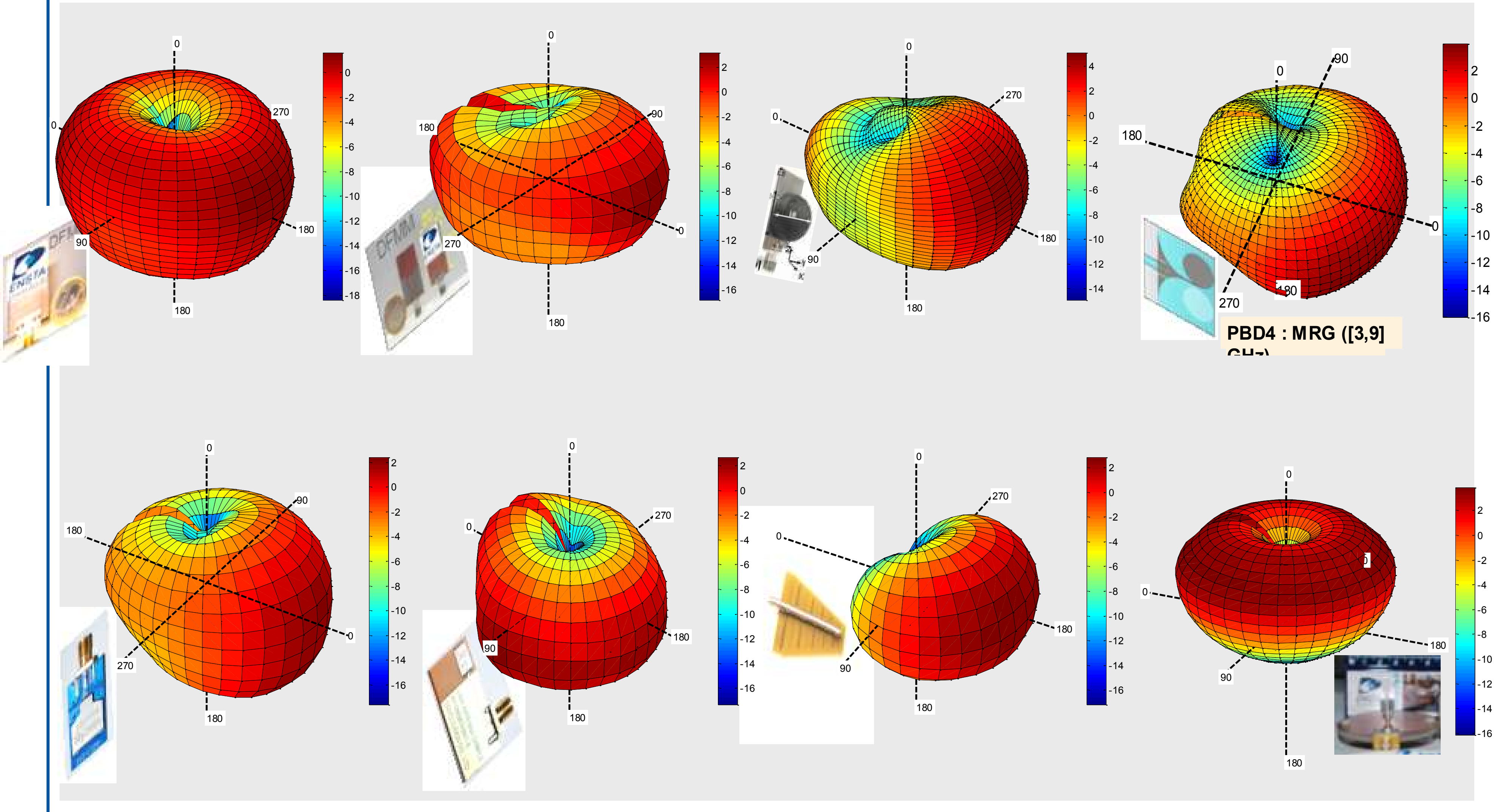




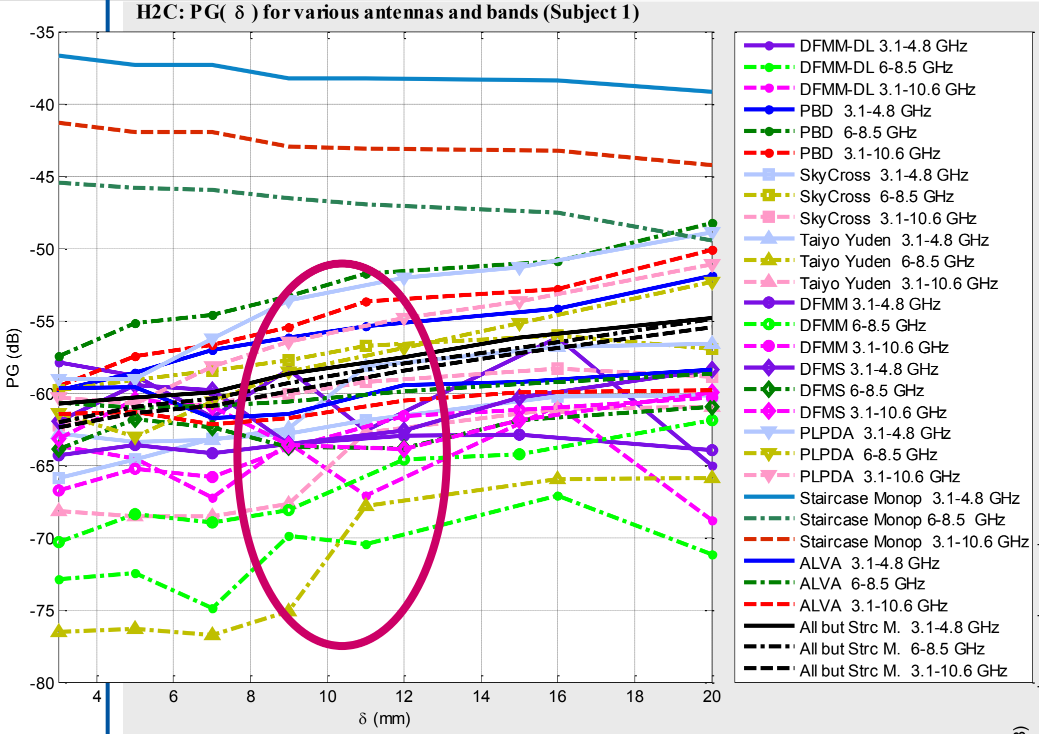




MRG of isolated antennas

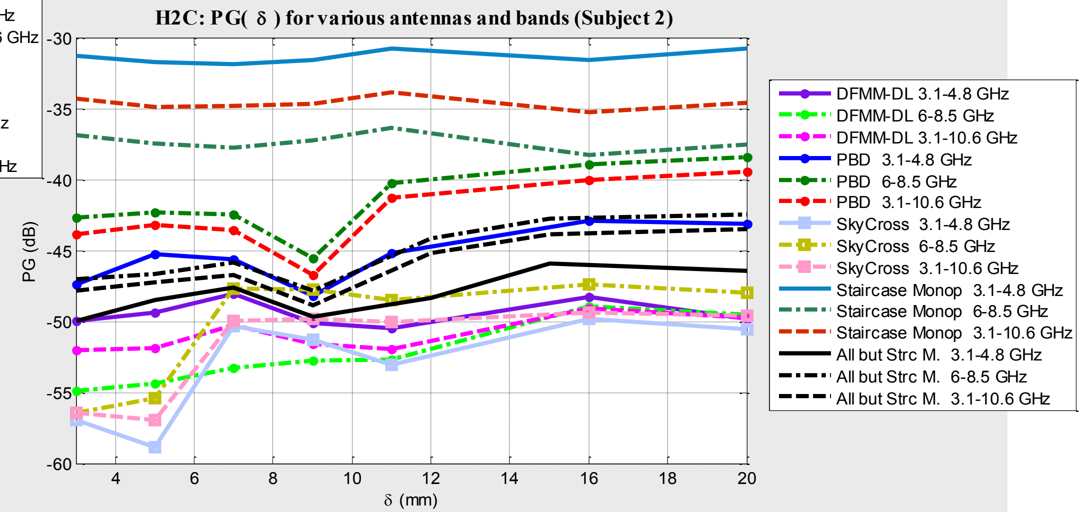


H2C: averaged PG for 2 human subjects $PG(\delta)$



General trend: $PG(\delta)$ ↗
Except for the Staircase Monopole...

Population is a strong source of variability (typically a few dB, but up to 15–20 dB for some cases)...



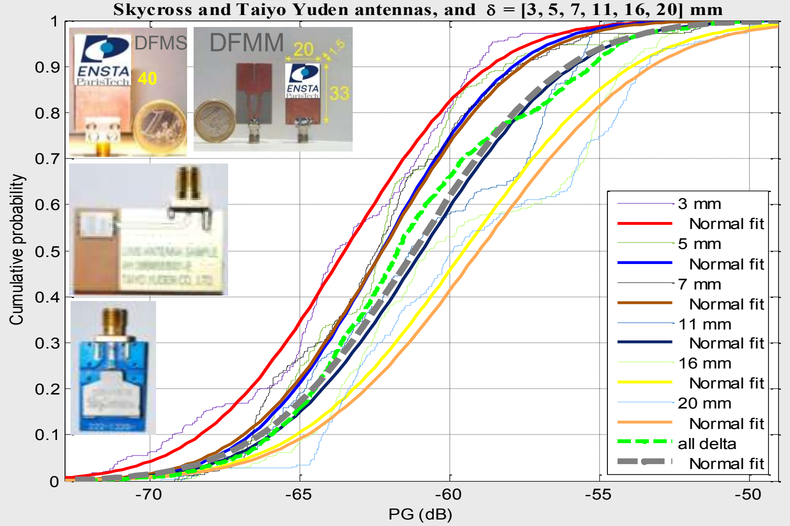
... **Antennas** as well, are even a stronger source of variability: up to more than 30 dB !...

The PL depends also significantly on the **frequency** (generally ↗)

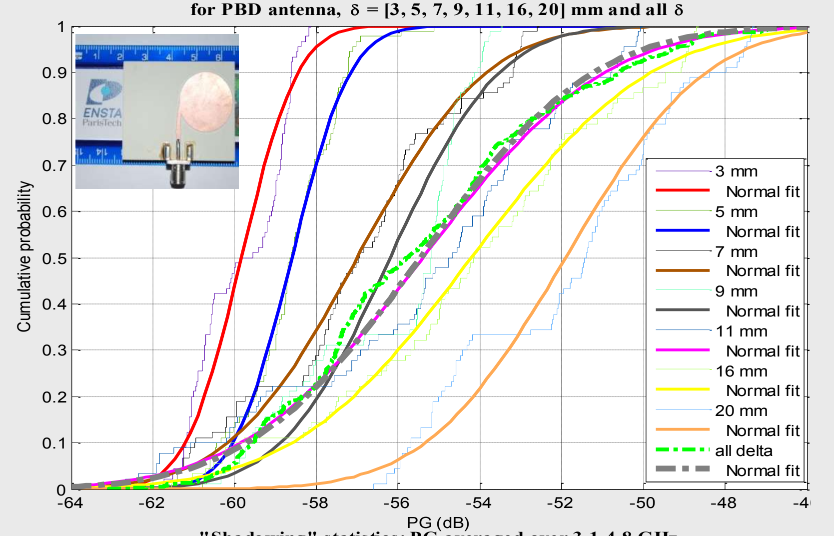
H2C: PG empirical statistics and models (3.1 – 4.8 GHz)

Tangent polarization

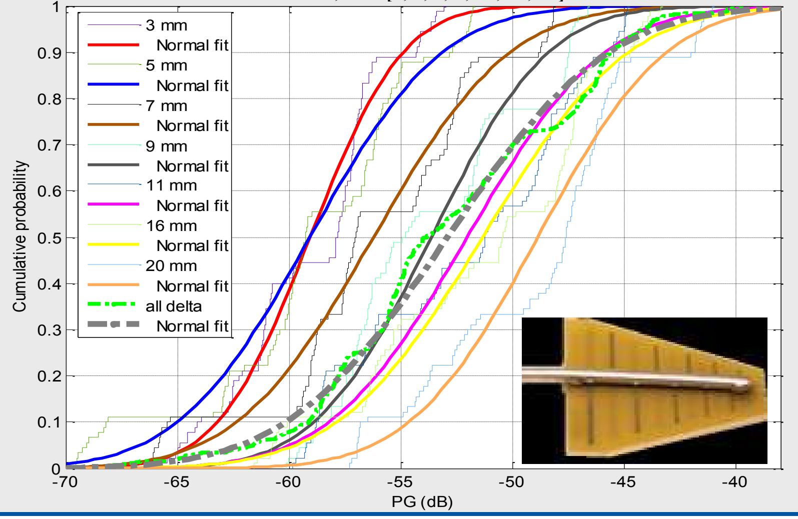
"Shadowing" statistics: PG averaged over 3.1-4.8 GHz, for DFMS, DFMM, Skycross and Taiyo Yuden antennas, and δ = [3, 5, 7, 11, 16, 20] mm



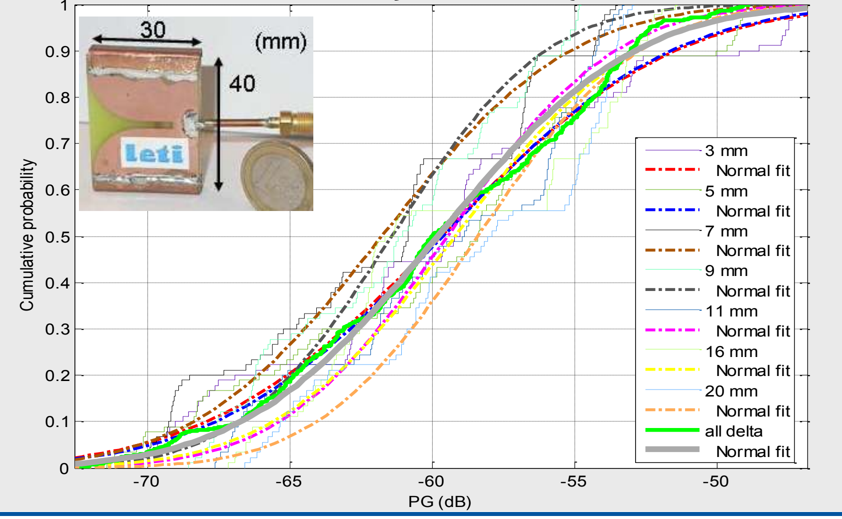
"Shadowing" statistics: PG averaged over 3.1-4.8 GHz, for PBD antenna, δ = [3, 5, 7, 9, 11, 16, 20] mm and all δ



"Shadowing" statistics: PG averaged over 3.1-4.8 GHz, for PLPDA antenna, δ = [3, 5, 7, 9, 11, 16, 20] mm and all δ

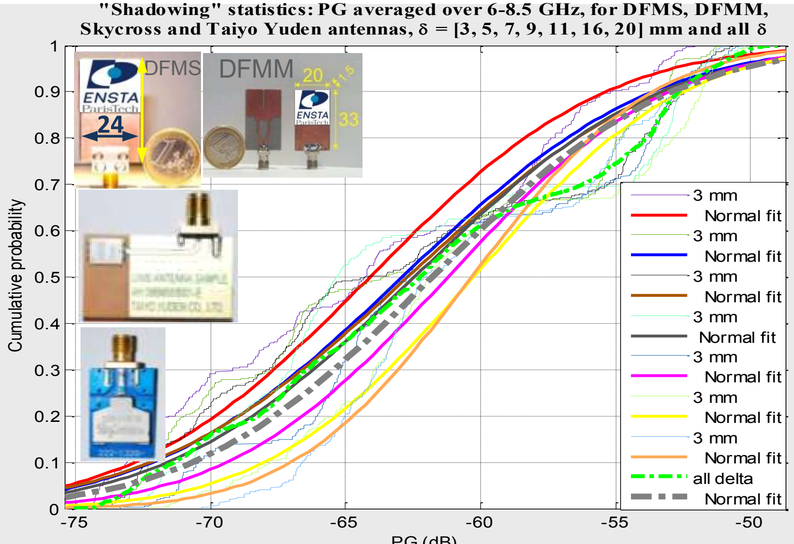


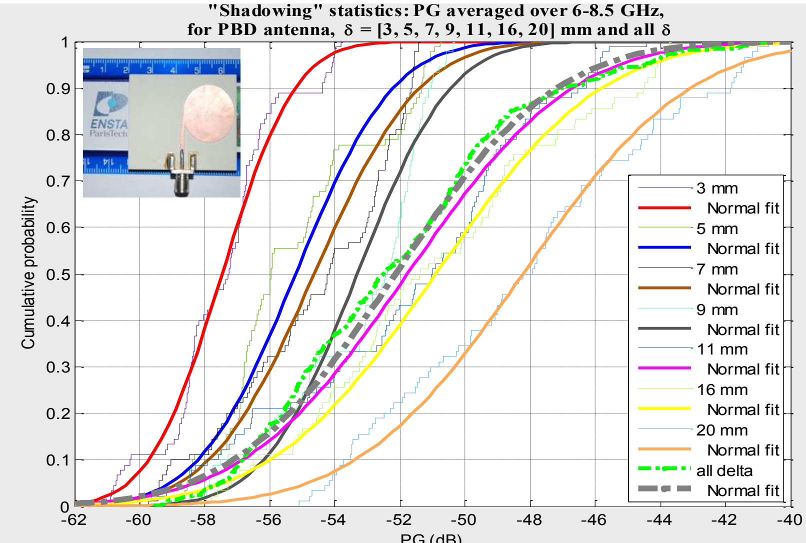
"Shadowing" statistics: PG averaged over 3.1-4.8 GHz, for ALVA antenna, δ = [3, 5, 7, 9, 11, 16, 20] mm and all δ

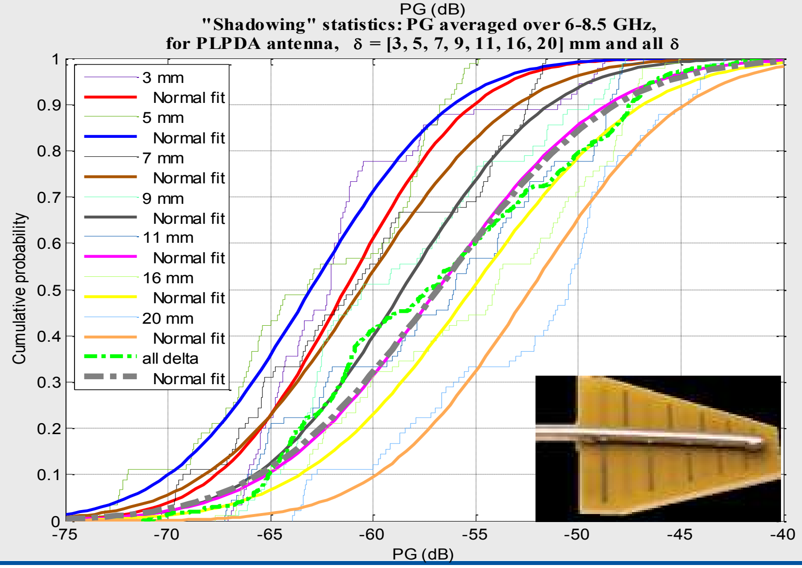


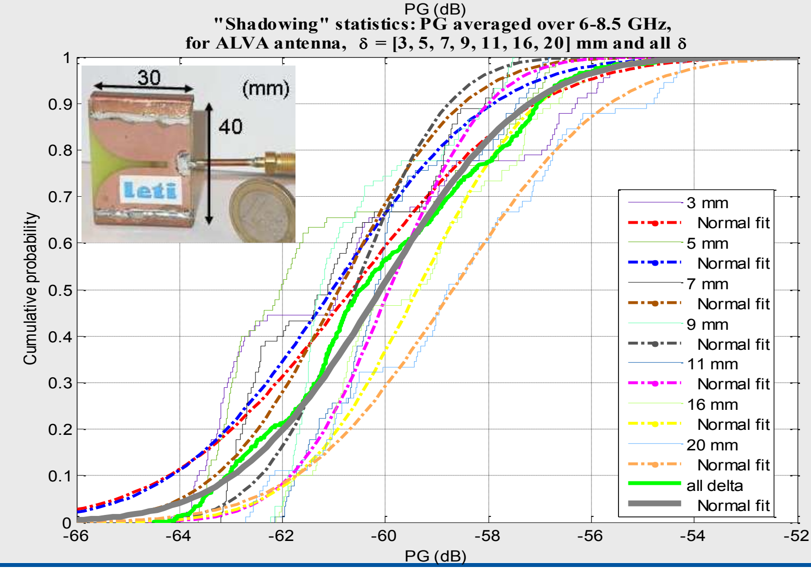
H2C: PG empirical statistics and models (6 – 8.5 GHz)

Tangent polarization



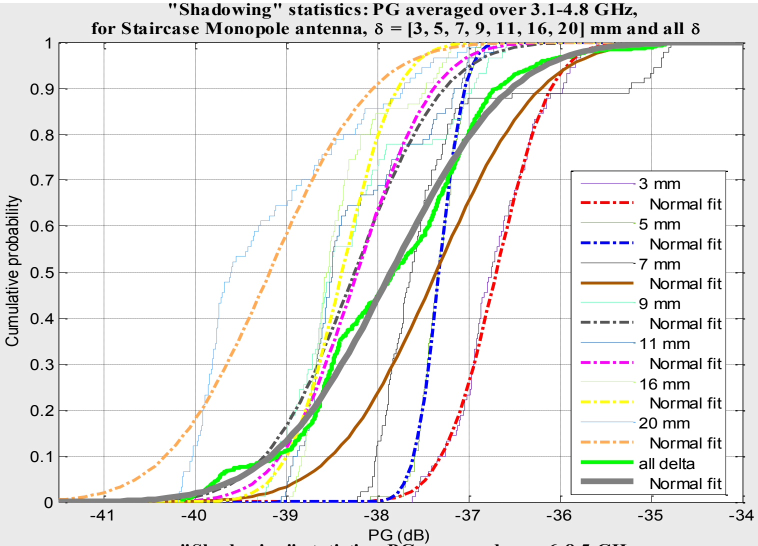


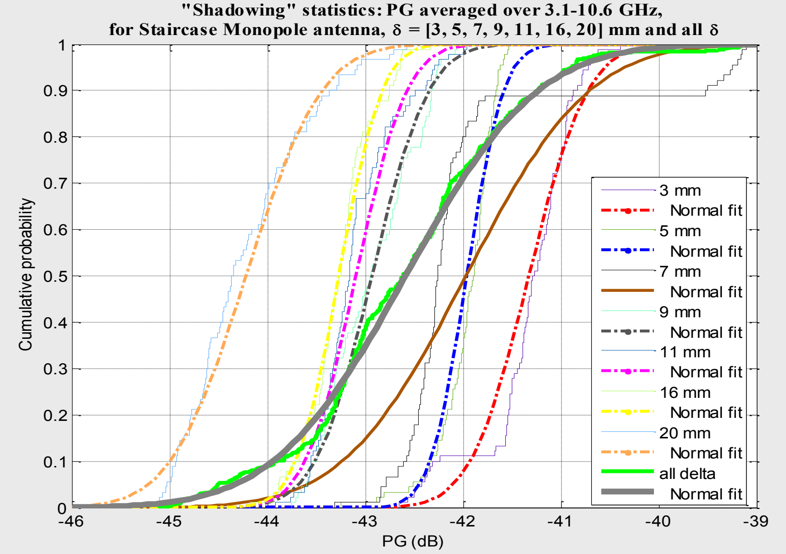


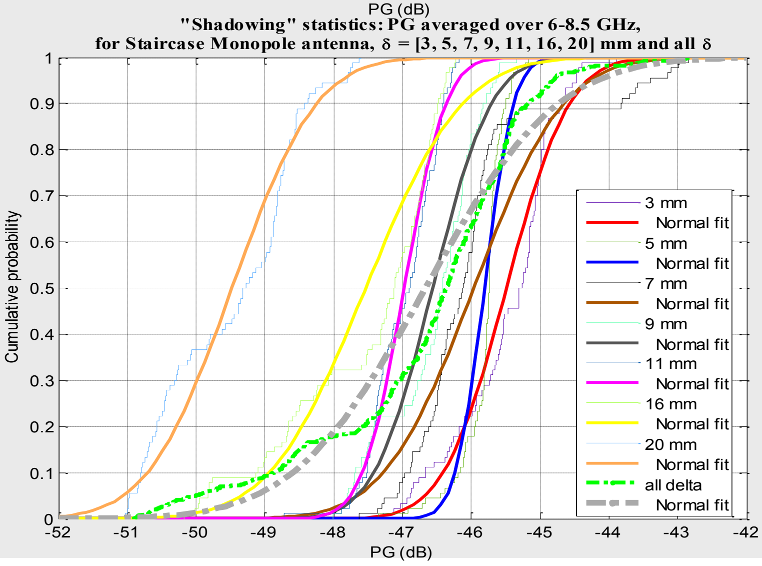


H2C: PG empirical statistics and models

Normal polarization







$PG(\delta)$ ↘ but almost constant and low σ

Screening effect of the ground plane...

→ Single model for all δ satisfying

H2C: PG empirical statistics and models

Hip-to-Chest ("Shadowing", Normal fits)

Subject1†		Monopole-like‡		PBD		ALVA		PLPDA		Staircase M.	
GHz	δ (mm)	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
3.1 - 4.8	3	-63.51	3.77	-59.83	1.08	-59.71	6.43	-59.05	3.25	-36.70	0.47
	5	-62.28	3.42	-58.60	1.12	-59.63	6.24	-59.07	4.64	-37.32	0.22
	7	-62.26	3.62	-57.00	2.47	-61.79	5.17	-56.22	4.79	-37.36	0.90
	9	-63.05	2.68	-56.20	2.09	-61.44	4.22	-53.64	4.10	-38.25	0.77
	11	-60.93	3.93	-55.39	3.48	-59.49	4.61	-52.03	4.83	-38.22	0.66
	16	-59.53	4.37	-54.20	3.44	-59.23	4.99	-51.34	5.10	-38.39	0.48
	20	-59.02	4.49	-51.90	2.69	-58.42	4.43	-48.87	4.50	-39.18	0.89
	all δ	**-61.21**	**4.02**	**-55.45**	**3.32**	**-59.82**	**5.40**	**-52.91**	**5.65**	**-37.85**	**1.03**
6 - 8.5	3	-64.10	6.81	-57.47	1.76	-60.65	2.78	-61.36	4.89	-45.49	0.72
	5	-62.90	7.23	-55.21	2.34	-61.03	2.44	-63.04	5.42	-45.81	0.34
	7	-62.70	7.44	-54.63	2.53	-60.90	1.88	-60.59	5.94	-45.97	1.02
	9	-62.46	7.12	-53.31	2.25	-60.60	1.43	-58.56	5.60	-46.56	0.67
	11	-61.22	6.39	-51.77	3.96	-59.92	1.50	-56.87	6.47	-46.98	0.47
	16	-60.26	6.05	-50.90	3.98	-59.38	1.84	-55.19	6.53	-47.54	1.10
	20	-60.33	5.22	-48.22	4.02	-58.69	2.38	-52.32	5.87	-49.48	0.96
	all δ	**-61.79**	**6.92**	**-52.14**	**3.87**	**-60.09**	**2.25**	**-56.86**	**6.79**	**-46.67**	**1.51**
3.1-10.6	3	-64.45	3.61	-59.57	1.42	-61.43	3.51	-60.32	4.17	-41.33	0.47
	5	-62.91	4.05	-57.46	1.74	-61.31	3.27	-60.78	5.11	-41.96	0.30
	7	-62.88	4.21	-56.69	2.57	-62.16	2.67	-58.17	5.36	-41.97	0.99
	9	-63.05	4.04	-55.45	2.01	-61.72	2.37	-56.46	4.72	-42.93	0.46
	11	-61.53	3.99	-53.69	3.85	-60.50	2.66	-54.81	5.56	-43.09	0.41
	16	-60.40	3.97	-52.82	3.79	-59.96	3.09	-53.69	5.71	-43.27	0.35
	20	-59.96	3.69	-50.11	3.50	-59.82	2.84	-51.08	5.17	-44.22	0.61
	all δ	**-61.91**	**4.25**	**-54.11**	**3.79**	**-60.91**	**3.07**	**-55.24**	**6.05**	**-42.59**	**1.06**

† Male: $h = 1.68$ m, $m = 65$ kg, $BMI = 23.03$ kg/m². ‡ "Monopole-like" = {DFMS, DFMM, Skycross, Taiyo Yuden}

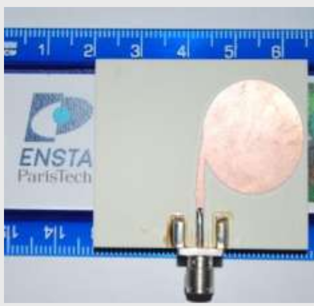
Good PG ↔ **Directivity** although badly matched

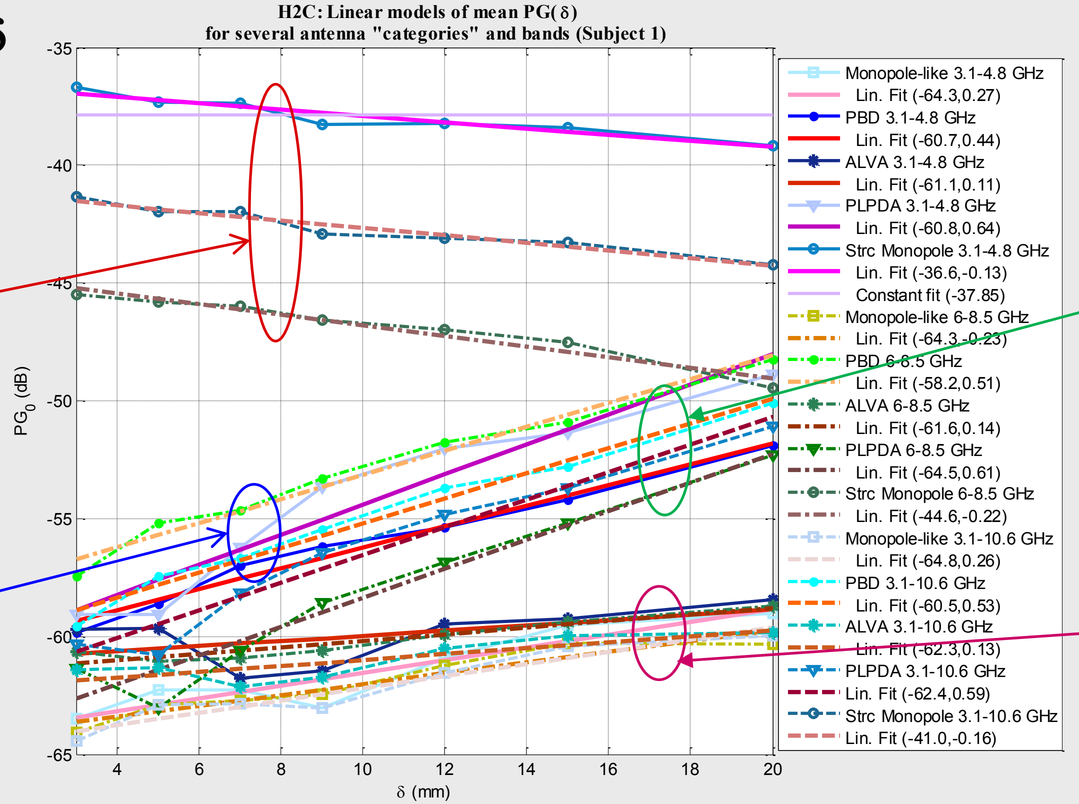
Almost constant PG ↔ **Ground plane screening** & correct PG ↔ balanced although poorly matched

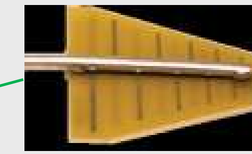
Good PG ↔ **balanced** (and well matched)

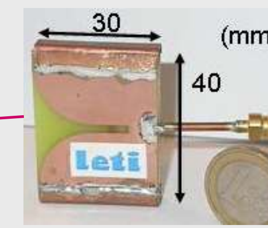
H2C: PG empirical statistics and models

- $PG_0(\delta) = PG_{00} + \kappa\delta$







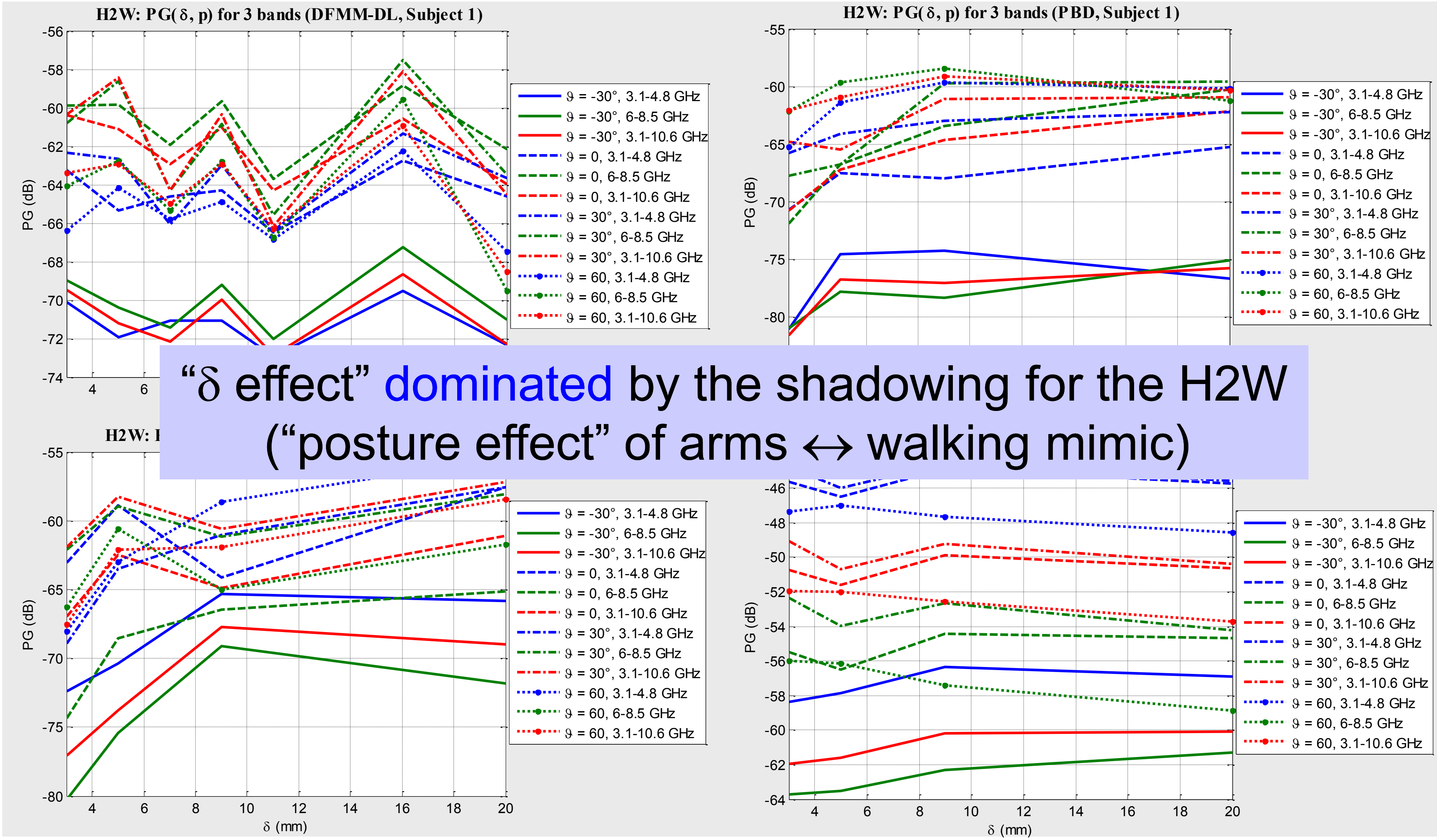


Hip-to-Chest: Mean Path Gain linear fits ($PG_0(\delta) = PG_{00} + \kappa\delta$)

Subject1†	Monopole-like‡		PBD		ALVA		PLPDA		Staircase M.	
Band (GHz)	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})	PG_{00}	κ (mm^{-1})
3.1 - 4.8	-64.26	0.2706	-60.66	0.4434	-61.08	0.1110	-60.79	0.6385	-36.56	-0.1339
6 - 8.5	-64.31	0.2288	-58.23	0.509	-61.58	0.1388	-64.49	0.6128	-44.56	-0.2238
3.1-10.6	-64.78	0.2577	-60.47	0.5280	-62.26	0.1259	-62.41	0.5859	-41.06	-0.1601

† Male: h = 1.68 m, m = 65 kg, BMI = 23.03 kg/m². ‡ "Monopole-like" = {DFMS, DFMM, Skycross, Taiyo Yuden}

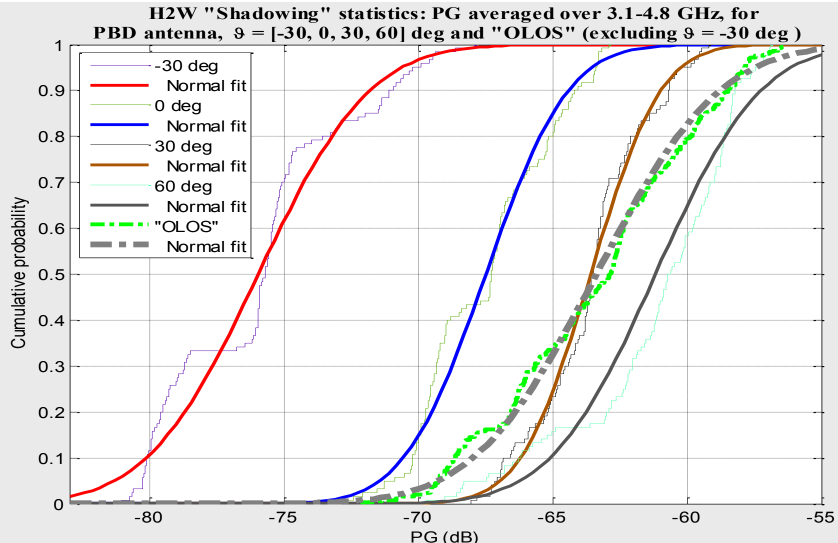
H2W: averaged PG for human subject 1 $PG(\delta,p)$

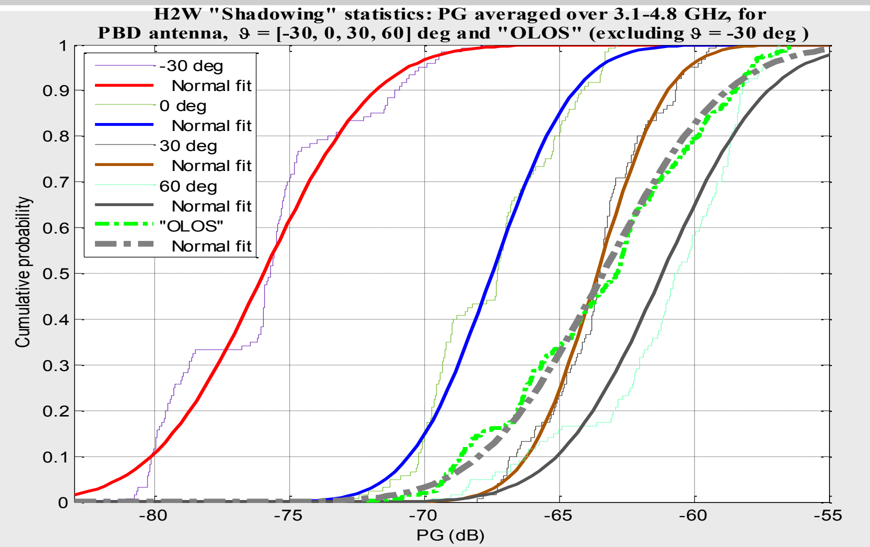


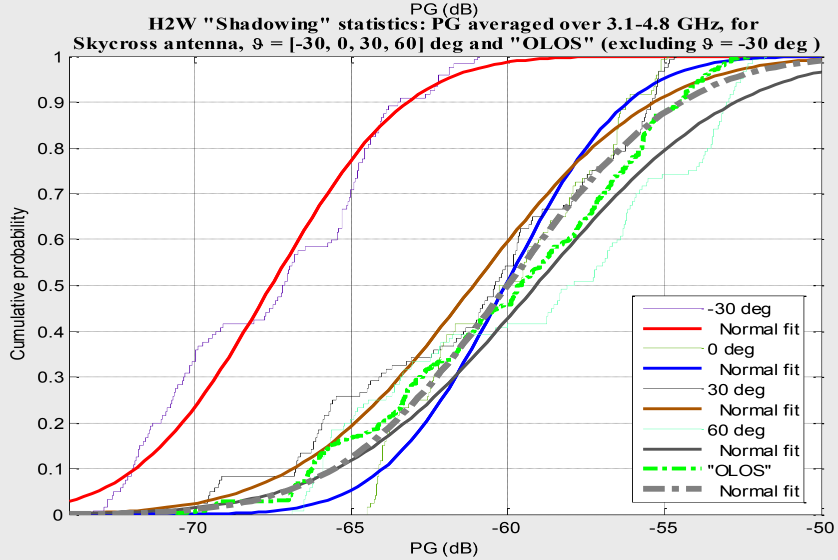
"δ effect" dominated by the shadowing for the H2W ("posture effect" of arms ↔ walking mimic)

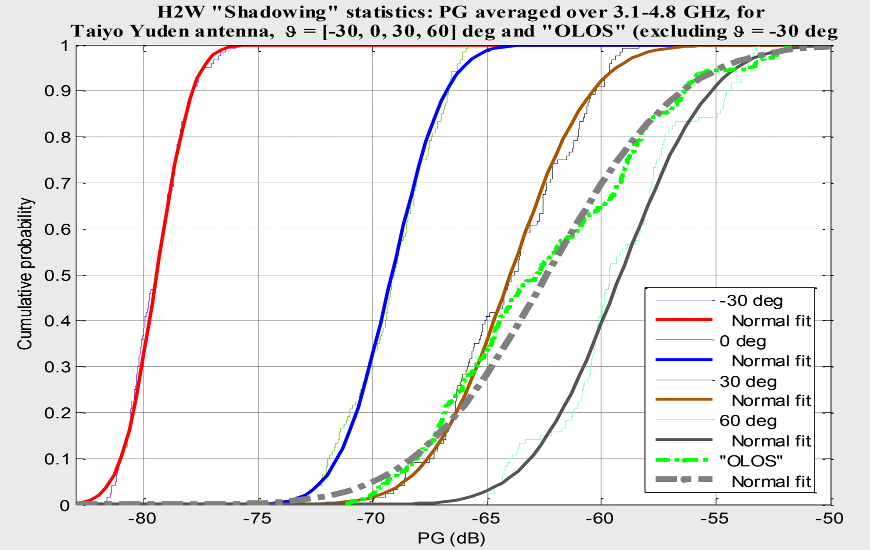
H2W: PG empirical statistics and models (3.1 – 4.8 GHz)

Tangent polarization



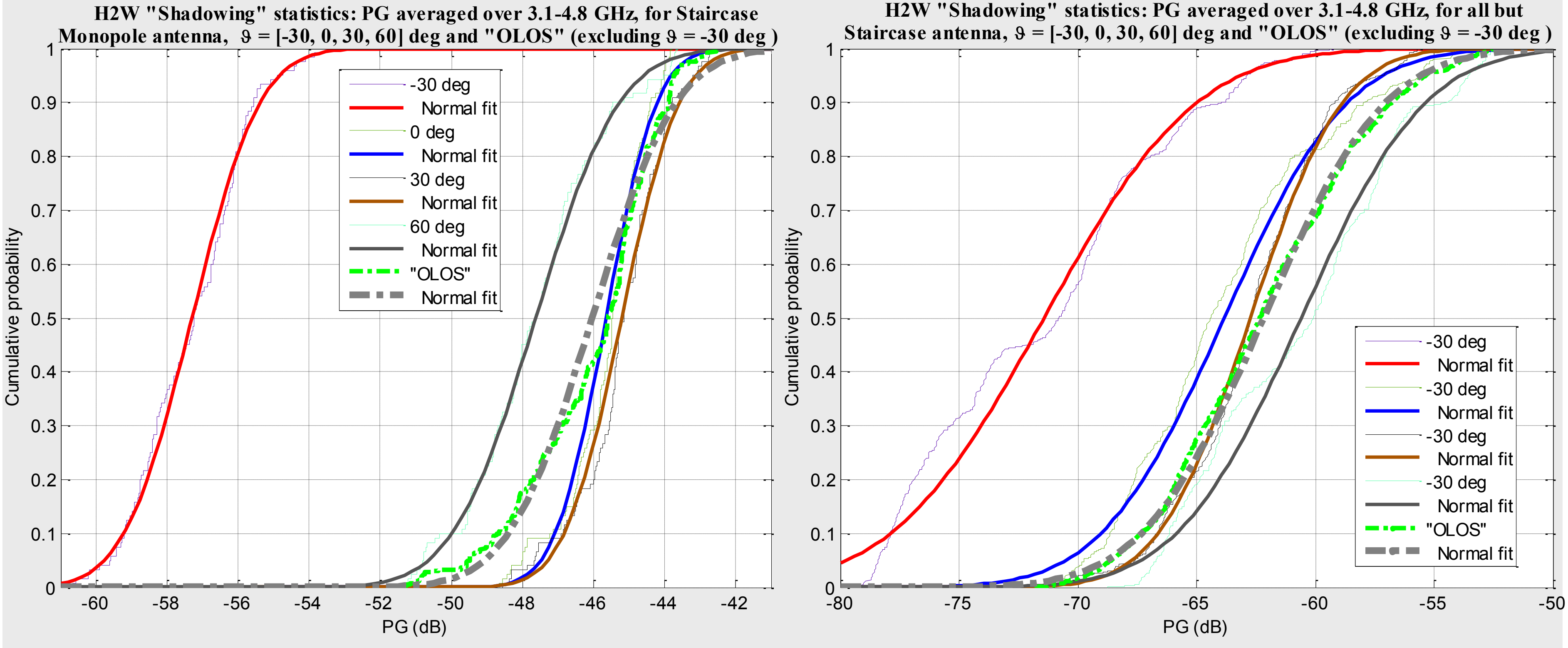






H2W: PG empirical statistics and models (3.1 – 4.8 GHz)

Normal polarization (and comparison with others)



H2W: PG empirical statistics and models

Hip-to-Wrist ("Shadowing", Normal fits)

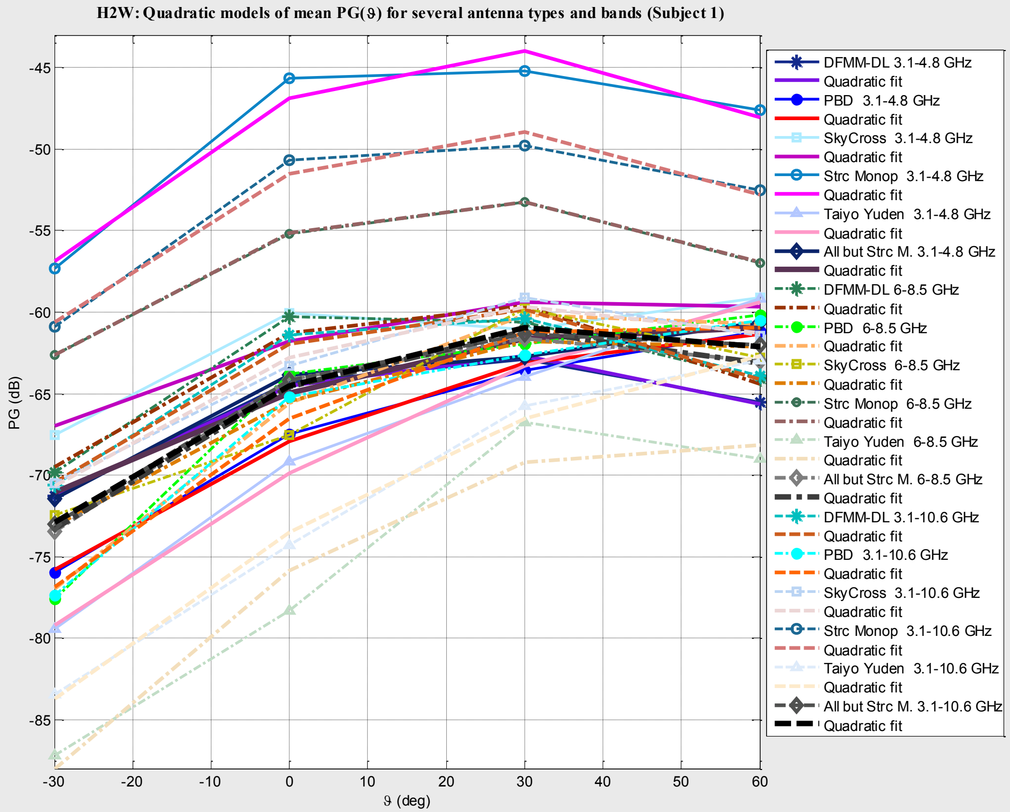
Subject 1†		DFMM-DL		PBD		Skycross		Taiyo Yuden		All but StrcM.		Staircase M.	
GHz	ϑ (deg)	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ	Mean	σ
3.1 - 4.8	–30	-71.26	1.79	-75.97	3.25	-67.53	3.39	-79.45	1.23	-71.43	5.04	-57.30	1.50
	0	-64.31	2.18	-67.49	2.40	-60.06	3.05	-69.17	1.86	-63.83	4.06	-45.65	1.12
	30	-62.89	1.59	-63.59	2.04	-61.09	4.49	-63.99	2.81	-62.74	3.03	-45.20	1.27
	60	-65.54	2.10	-61.17	3.07	-59.09	4.97	-59.18	3.09	-60.60	4.10	-47.62	1.84
	OLOS	**-64.17**	**2.45**	**-63.37**	**3.59**	**-60.00**	**4.32**	**-62.39**	**4.62**	**-62.18**	**4.02**	**-46.04**	**1.85**
	all ϑ	**-65.09**	**3.68**	**-64.55**	**6.45**	**-61.00**	**5.09**	**-63.61**	**7.57**	**-63.26**	**6.19**	**-47.18**	**5.15**
6 - 8.5	–30	-69.81	1.58	-77.59	3.37	-72.45	4.85	-87.21	1.53	-73.45	7.09	-62.60	1.48
	0	-60.26	2.03	-63.80	4.87	-67.52	3.81	-78.32	2.36	-64.12	7.46	-55.19	1.46
	30	-60.62	2.71	-61.98	4.83	-59.77	2.69	-66.75	3.96	-61.60	4.73	-53.23	1.72
	60	-64.10	3.56	-60.15	2.15	-62.80	2.83	-68.98	1.79	-62.99	4.13	-56.97	2.06
	OLOS	**-61.35**	**3.48**	**-61.72**	**4.73**	**-62.33**	**4.65**	**-69.30**	**5.58**	**-62.78**	**6.03**	**-54.87**	**2.38**
	all ϑ	**-62.40**	**4.53**	**-62.93**	**7.90**	**-63.44**	**6.56**	**-70.53**	**8.23**	**-63.91**	**8.21**	**-55.88**	**3.87**
3.1-10.6	–30	-70.60	1.69	-77.34	3.07	-70.49	4.18	-83.46	0.98	-73.02	5.76	-60.89	1.20
	0	-61.42	2.13	-65.17	3.48	-63.31	2.42	-74.27	1.73	-64.18	5.43	-50.67	1.18
	30	-60.40	2.73	-62.62	2.68	-59.10	2.58	-65.76	2.85	-61.32	3.73	-49.79	1.20
	60	-63.93	2.95	-60.49	1.82	-61.45	3.44	-62.94	2.71	-62.00	3.17	-52.50	1.78
	OLOS	**-61.68**	**3.06**	**-62.35**	**3.59**	**-60.95**	**3.32**	**-65.68**	**5.20**	**-62.34**	**4.59**	**-50.85**	**1.87**
	all ϑ	**-62.75**	**4.53**	**-63.56**	**7.28**	**-62.04**	**5.65**	**-66.90**	**7.99**	**-63.46**	**7.18**	**-51.95**	**4.60**

† Male: $h = 1.83$ m, $m = 83$ kg, $BMI = 24.77$ kg/m².

"**OLOS**" ⇔ $\vartheta \in \{0,30,60\}$

Remains the winner!

H2W: PG empirical statistics and models



$$PG_0(\vartheta) = PG_{00} + \zeta_1\vartheta + \zeta_2\vartheta^2$$

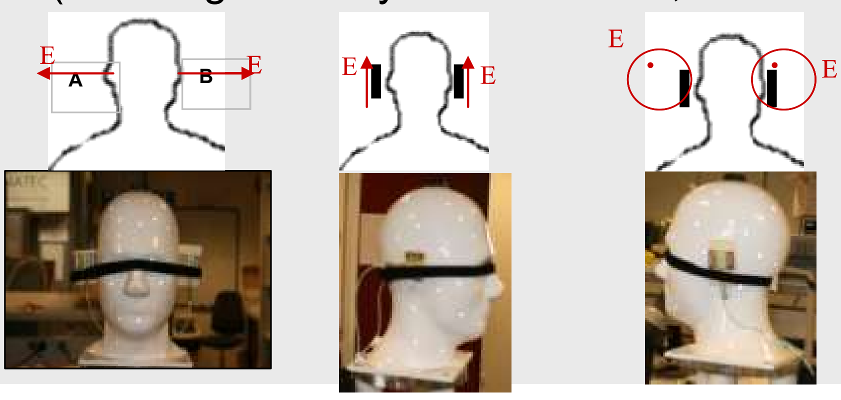
Hip-to-Wrist: Mean Path Gain quadratic fits ($PG_0(\vartheta) = PG_{00} + \zeta_1\vartheta + \zeta_2\vartheta^2$)

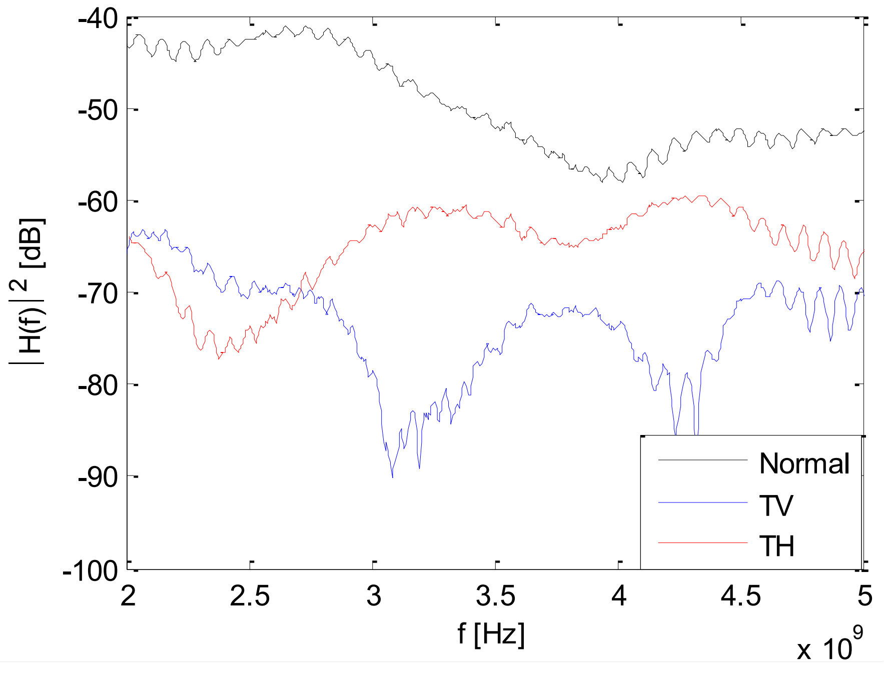
Subject 1†	DFMM-DL			PBD			Skycross			Taiyo Yuden			All but Staircase M.			Staircase M.		
Band (GHz)	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})	PG_{00}	ζ_1 (deg^{-1})	ζ_2 (deg^{-2})
3.1 - 4.8	-64.53	0.1420	-0.0027	-67.95	0.2115	-0.0017	-61.79	0.1266	-0.0015	-69.88	0.2657	-0.0015	-64.96	0.1574	-0.0015	-46.90	0.2156	-0.0039
6 - 8.5	-61.28	0.1644	-0.0036	-65.60	0.2801	-0.003	-65.48	0.1886	-0.002	-75.85	0.3134	-0.003	-64.55	0.2023	-0.003	-55.16	0.1557	-0.003
3.1-10.6	-61.96	0.1759	-0.0035	-66.55	0.2607	-0.0028	-62.77	0.1839	-0.0026	-73.52	0.2866	-0.0018	-64.54	0.1992	-0.0026	-51.53	0.1945	-0.0036

† Male: h = 1.83 m, m = 83 kg, BMI = 24.77 kg/m².

Conclusions: Antenna design objectives

- **Economic and/or acceptability constraints**
  - Small size, integrated/integrable, chip → (quasi-)planar or low profile
  - Maybe flexible (fabric antennas...)
- **Electromagnetic and/or system constraints**
  - Polarization “matched” to propagation modes (e.g. Creeping waves → TE)
  - *On-on*: “end-fire” pattern (along the body)
  - *On-off*: boresight pattern (off the body)
  - Low sensitivity to body proximity (detuning – mainly narrowband –, efficiency)





Conclusion et perspectives

- **Les caractéristiques du canal WBAN *on-on* sont essentiellement liées :**
  - Au type de lien radio (Hip to Chest, etc.)
  - Aux effets de masquage
  - Au mouvement (et à la posture)
  - Aux nombreuses sources de variabilité
    - Morphologiques (Taille, corpulence, âge, proportions des tissus de surface)
    - Des antennes (types, distance ua corps, polarisation, orientation, résilience/sensibilité aux effet de proximité
    - De l'environnement (extérieur, intérieur – types de pièces, volume, réverbération, etc.)
  - A un spectre Doppler centré en 0 ($\Delta\nu$ ~ 15 Hz)
- **Les modèles doivent rendre compte de la statistique…**
  - De l'atténuation moyenne
  - Des évanouissement lents
  - Des évanouissements rapides
- **… Mais aussi des nombreuses sources de variabilité**

Conclusion et perspectives

- **Les (« bons ») modèles disponibles doivent être généralisés, étendus:**
  - Pour mieux rendre compte de la dispersion de population
  - En intégrant des modèles caractérisant la variabilité d'antenne
  - En modélisant réellement les effet de l'environnement, intérieur notamment
    - → « Room electromagnetics »…
  - Globalement, ils devraient être moins « environnement dépendants » c'est-à-dire plus aspécifiques, donc plus « paramétriques »
    - Statistique de population insuffisante : nombre de sujets faible et non nécessairement représentatifs
    - Modèles fondés sur des mesures avec en général un seul type d'antenne
    - Dans un environnement donné
- **Les modèles doivent rendre compte des corrélations spatiales**
  - Pour les systèmes multi-antennes (« colocalisées »)
  - Pour les techniques d'accès et réseau alternatives et innovantes
    - Techniques de relayage, multi-sauts, etc.
  - Travaux menés en ce sens (corrélations), mais le développement des modèles reste inachevé…
- **Antennes résilientes → techniques de désensibilisation**

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Ultra wide…
… thanks for your attention!