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FACULTY OF ENGINEERING AND ARCHITECTURE

Novel antenna design paradigms for the Internet of Things

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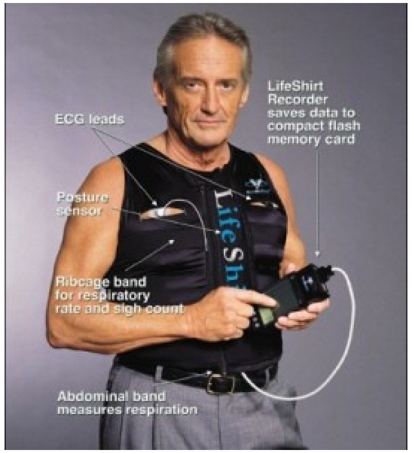
Outline

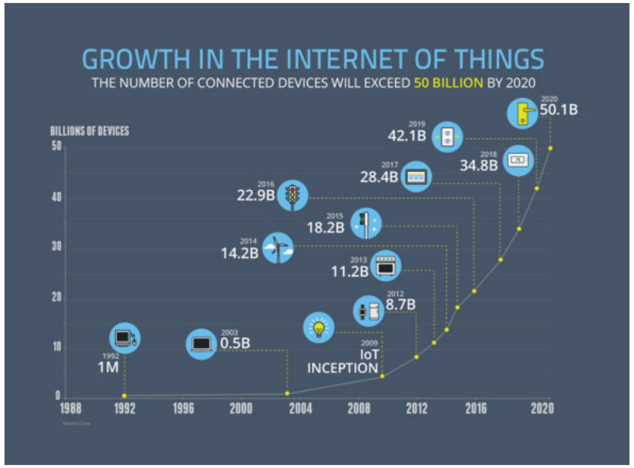
- **The Internet-of-Things**
  - **opportunities and design challenges**
- **Stochastic antenna design framework**
  - **Production uncertainties**
  - **Substrate compression**
  - **Substrate bending**
- **Some novel IoT antenna designs**
  - **Substrate-Integrated-Waveguide (SIW) Cavity-Backed Slot (CBS) topology**
  - **Three-element antenna array for integration into furniture**
  - **Half-mode SIW CBS antenna on cork substrate**
- **Conclusions**

The Internet-of-Things (IoT)

Invisibly integrated wireless communication systems

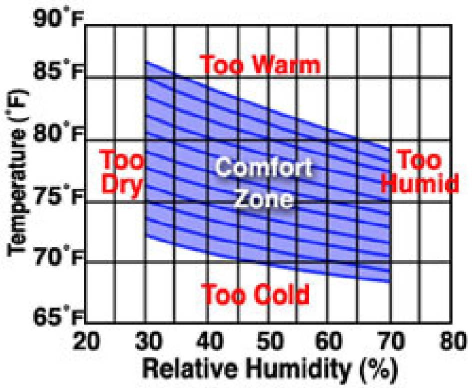


Increased Functionality



High data rates

IoT antenna design challenges

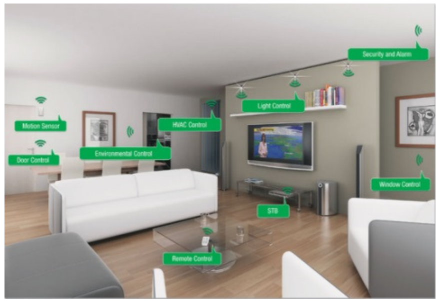


Stable antenna performance requires taking into account adverse conditions during design phase:

- effect of varying environmental conditions
- effect of fabrication tolerances
- effect of bending/compression/ layers covering antenna
- effect of equipment in near-field

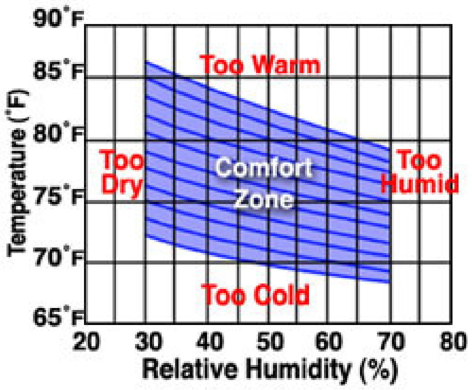
Antenna design constraints:

- Cost-effective, compact and low-profile for invisible integration
- wideband performance for high-datarate communication



→ a dedicated design strategy is needed!

IoT antenna design strategy



Stochastic design framework for random variations

- effect of varying environmental conditions
- effect of fabrication tolerances
- effect of bending/compression/ layers covering antenna

Antenna topology with high antenna/platform isolation

- effect of equipment in near-field

Antenna design constraints:

- Cost-effective, compact and low-profile for invisible integration
- wideband performance for high-datarate communication

→ a dedicated design strategy

Outline

- The Internet-of-Things
  - opportunities and design challenges
- Stochastic antenna design framework
  - Production uncertainties
  - Substrate compression
  - Substrate bending
- Some novel IoT antenna designs
  - Substrate-Integrated-Waveguide (SIW) Cavity-Backed Slot (CBS) topology
  - Three-element antenna array for integration into furniture
  - Half-mode SIW CBS antenna on cork substrate
- Conclusions

Design strategies accounting for randomness

1. **Overspecifying design requirements**

→ **enlarging bandwidth, applying stricter specs**

- ☒ out-of-band interference
- ☒ cost

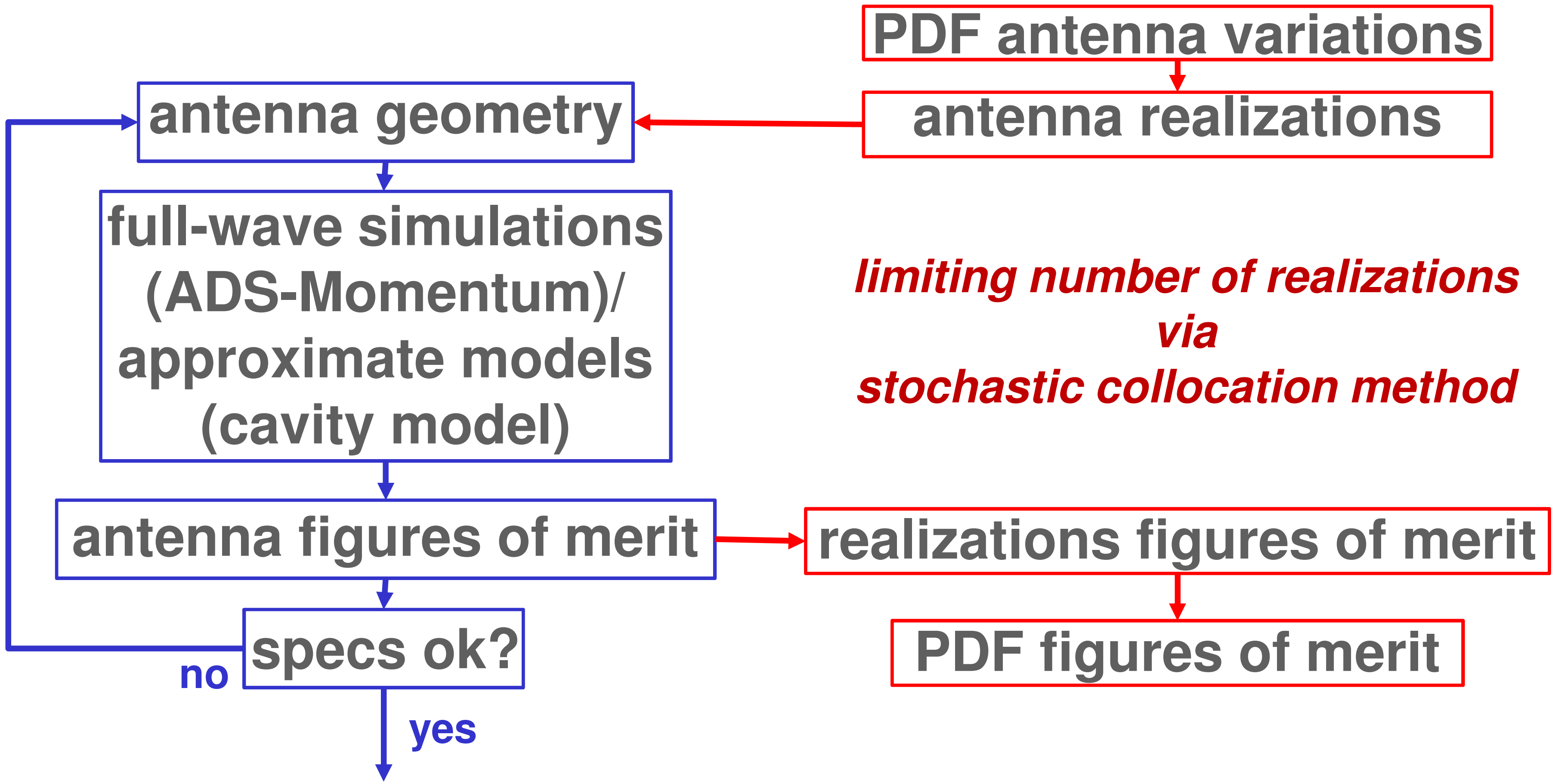
2. **Quantifying random effects on antenna performance**

→ **applying Monte Carlo analysis**

- ☑ very accurate
- ☒ time-consuming

→ **a more effective stochastic formalism is needed!**

Conventional design process / Stochastic design process



- **Polynomial chaos expansion** $\mathbb{P}(X_1, X_2, \dots, X_N)$
  - relates figures of merit $\boldsymbol{Z}$ to design parameters $\boldsymbol{X_1, X_2, \dots, X_N}$

$$Z \approx \mathbb{P}(X_1, X_2, \dots, X_N) = \sum_{k_1=0}^{P_1} \sum_{k_2=0}^{P_2} \dots \sum_{k_N=0}^{P_N} y_{k_1 k_2 \dots k_N} \phi_{k_1}^{X_1}(X_1) \phi_{k_2}^{X_2}(X_2) \dots \phi_{k_N}^{X_N}(X_N)$$

  - easy to find PDF figures of merit based on PDF design parameters
    - **analytically based on polynomial**
    - **Monte Carlo applied to polynomial**

Construction of $\mathbb{P}(X_1, X_2, \ldots, X_N)$

$$Z \approx \mathbb{P}(X_1, X_2, \ldots, X_N) = \sum_{k_1=0}^{P_1} \sum_{k_2=0}^{P_2} \ldots \sum_{k_N=0}^{P_N} y_{k_1 k_2 \ldots k_N} \phi_{k_1}^{X_1}(X_1) \phi_{k_2}^{X_2}(X_2) \ldots \phi_{k_N}^{X_N}(X_N)$$

- statistically independent $\boldsymbol{X_1, X_2, \ldots, X_N}$
  - **decorrelate random variables via Choleski decomposition**
- for each random variable
  - **basis function $\boldsymbol{\phi_{k_i}^{X_i}(X_i)}$ orthonormal to input PDF $\boldsymbol{P_{X_i}(X_i)}$**

$$< \phi_i^X(X), \phi_j^X(X) > = \int \phi_i^X(X) \phi_j^X(X) P_X(X) dX = \delta_{ij} = \begin{cases} 1 & if\ i = j \\ 0 & if\ i \neq j \end{cases}$$

- **Construction of $\mathbb{P}(X_1, X_2, \ldots, X_N)$**

$$Z \approx \mathbb{P}(X_1, X_2, \ldots, X_N) = \sum_{k_1=0}^{P_1} \sum_{k_2=0}^{P_2} \ldots \sum_{k_N=0}^{P_N} y_{k_1 k_2 \ldots k_N} \phi_{k_1}^{X_1}(X_1) \phi_{k_2}^{X_2}(X_2) \ldots \phi_{k_N}^{X_N}(X_N)$$

  - exploiting orthonormality to calculate coefficients $\boldsymbol{y_{k_1 k_2 \ldots k_N}}$ via $\boldsymbol{V_1} \times \boldsymbol{V_2} \times \ldots \times \boldsymbol{V_N}$-point Gaussian quadrature rule

$$y_{k_1 k_2 \ldots k_N} = \int \ldots \int_{\Gamma} \mathbb{F}(X_1, X_2, \ldots, X_N) \phi_{k_1}^{X_1} \phi_{k_2}^{X_2} \ldots \phi_{k_N}^{X_N} dP_{X_1, X_2, \ldots, X_N}$$

$$\approx \sum_{l_1=0}^{V_1} \sum_{l_2 0}^{V_2} \ldots \sum_{l_N=0}^{V_N} w_{l_1} w_{l_2} \ldots w_{l_N} \phi_{k_1}^{X_1}(x_{l_1}) \phi_{k_2}^{X_2}(x_{l_2}) \ldots \phi_{k_N}^{X_N}(x_{l_N}) \mathbb{F}(x_{l_1}', x_{l_2}', \ldots, x_{l_N}')$$

x_{l_i} **: zeros of** $\phi_{k_i}^{X_i}(X_i)$ **weights** w_{l_i} **correspond to** x_{l_i}

→ requires $V_1 \times V_2, \times \ldots \times V_N$ realizations $\mathbb{F}(x_{l_1}', x_{l_2}', \ldots, x_{l_N}')$

Alternative: Padé approximation

- Better for highly non-linear relationships: **rational function** $\boldsymbol{f(X_1, X_2, \ldots, X_N)}$ instead of polynomial

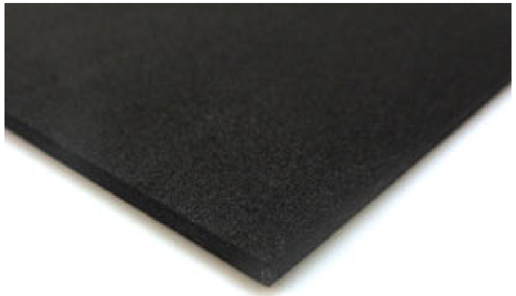
$$Z \approx f(X_1, X_2, \ldots, X_N) = \frac{P_M\ (X_1, X_2, \ldots, X_N)}{Q_L\ (X_1, X_2, \ldots, X_N)}$$

with polynomials $P_M(X_1, X_2, \ldots, X_N) = \sum_{j=0}^{c(M)} p_j\, \Phi_j$

$$Q_L(X_1, X_2, \ldots, X_N) = \sum_{j=0}^{c(L)} q_j\, \Phi_j \ , \qquad Q_L \neq 0\ in\ \Gamma$$

1. Production uncertainties

- non-uniformity in textile substrates



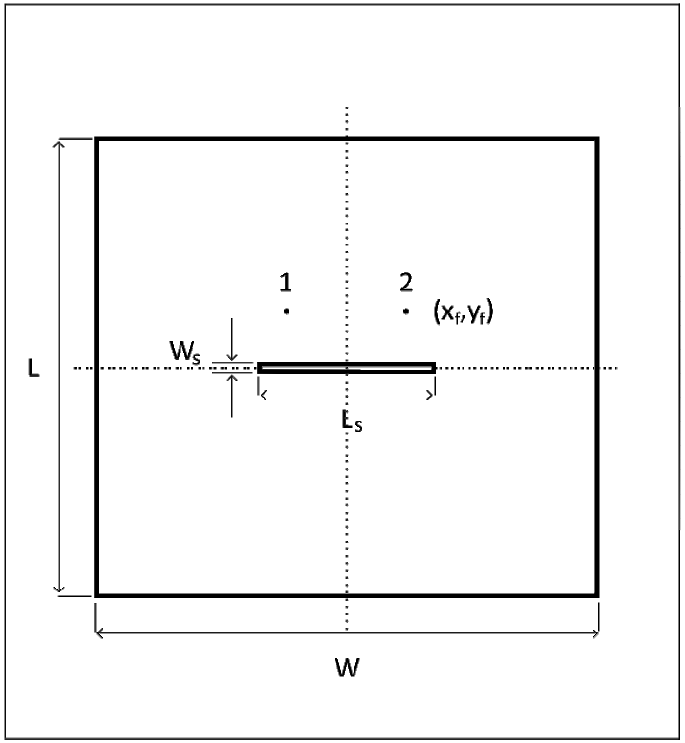
- variations in patch geometry

- feed misplacement

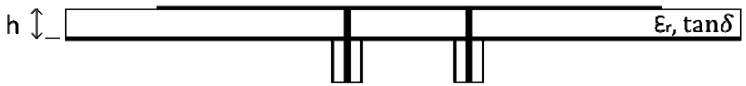
- **probe-fed 2.45GHz ISM-band patch antenna**
  - nominal input impedance

$$\boldsymbol{Z_{in}} = \mathbf{50}\ \boldsymbol{\Omega} \text{ at 2.45GHz}$$

W	44.46 mm
L	45.32 mm
(x_f,y_f)	(±5.7,5.7) mm
W_s	1 mm
L_s	14.88 mm

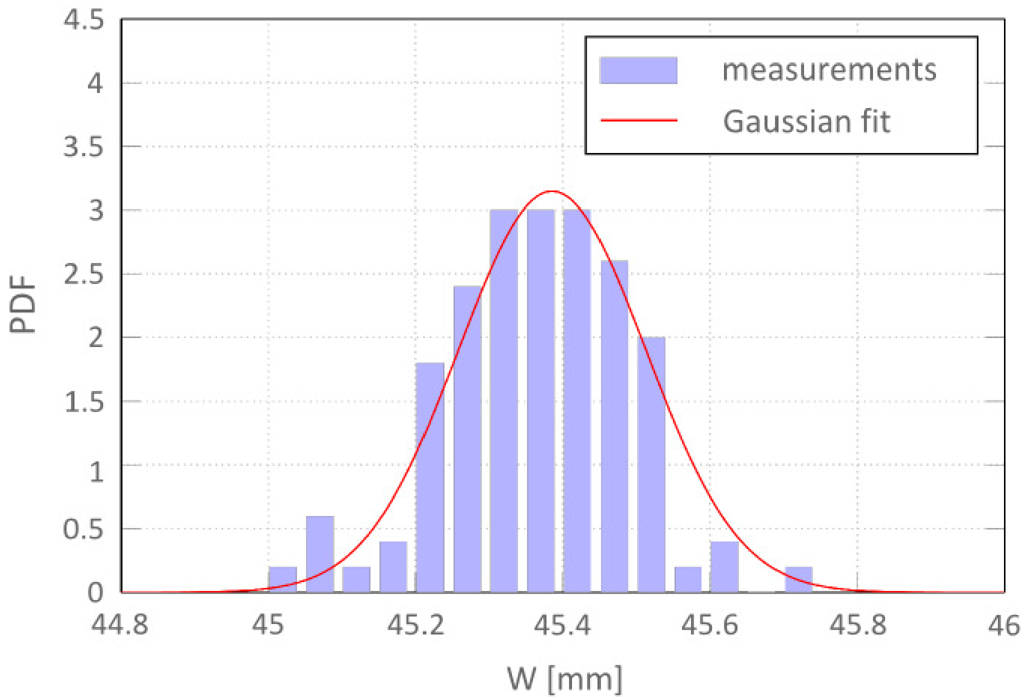


protective foam substrate (ε_r=1.53, h=3.94 mm)

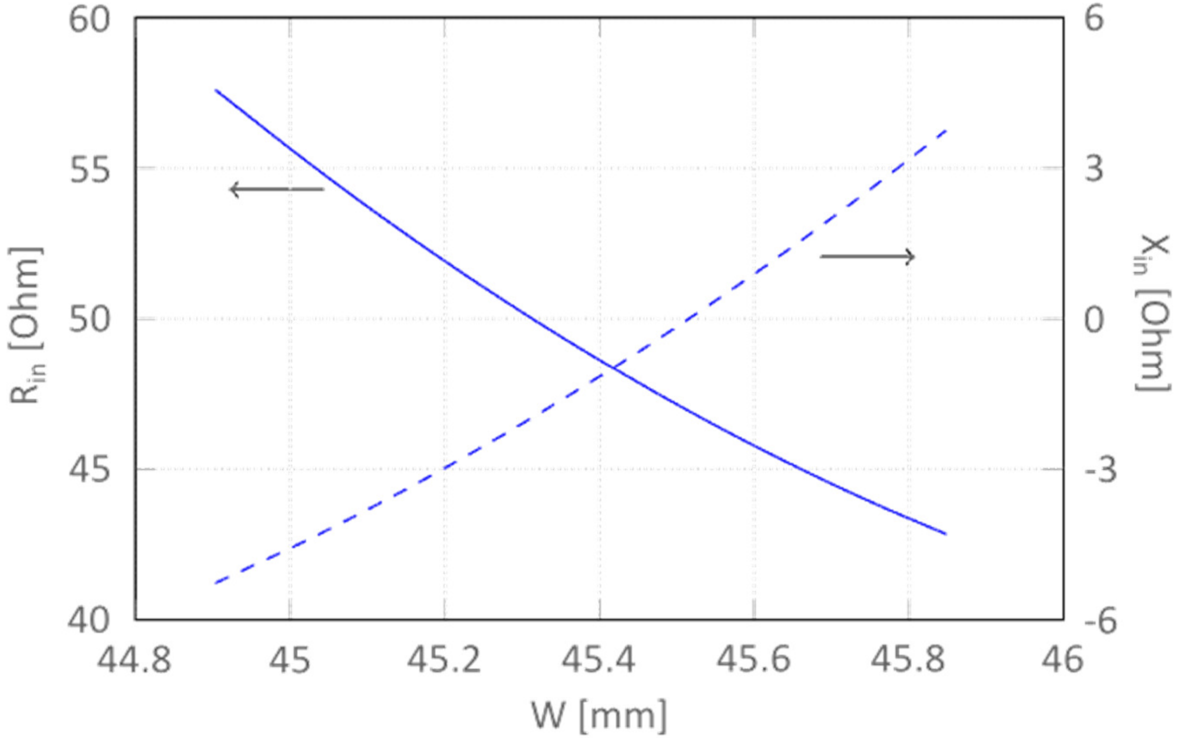


- **variations in patch width W: largest influence on Z_{in}**
  - measurements on 100 patches, manually cut

- **mean value**
  $\overline{W} = 45.385\ mm$
- **standard deviation**
  $\sigma = 0.127$
- **variation interval**
  $[44.9 - 45.9]\ mm$

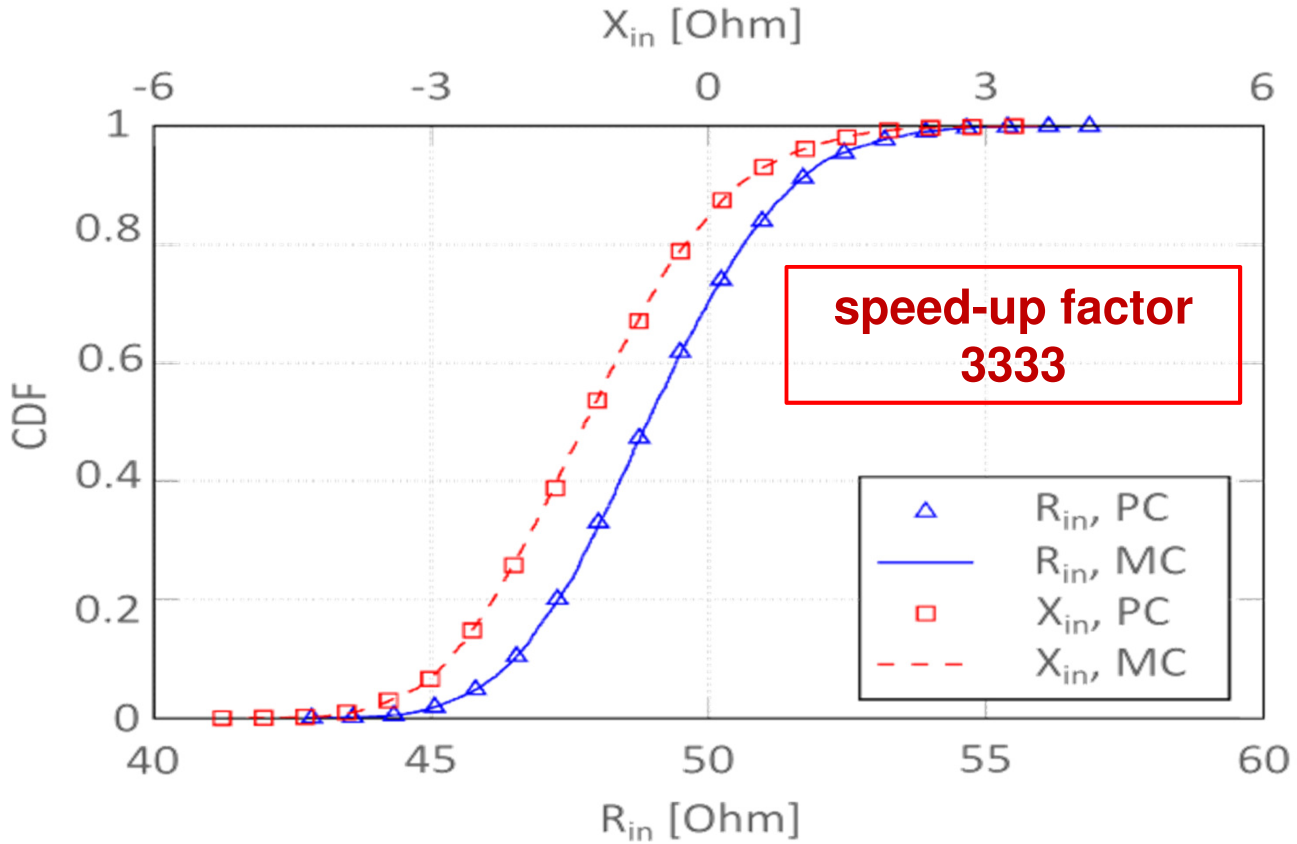


- **relates patch width W to Z_{in}**
  - convergence for polynomial order $P = 2$
  - $V = 3$ quadrature points



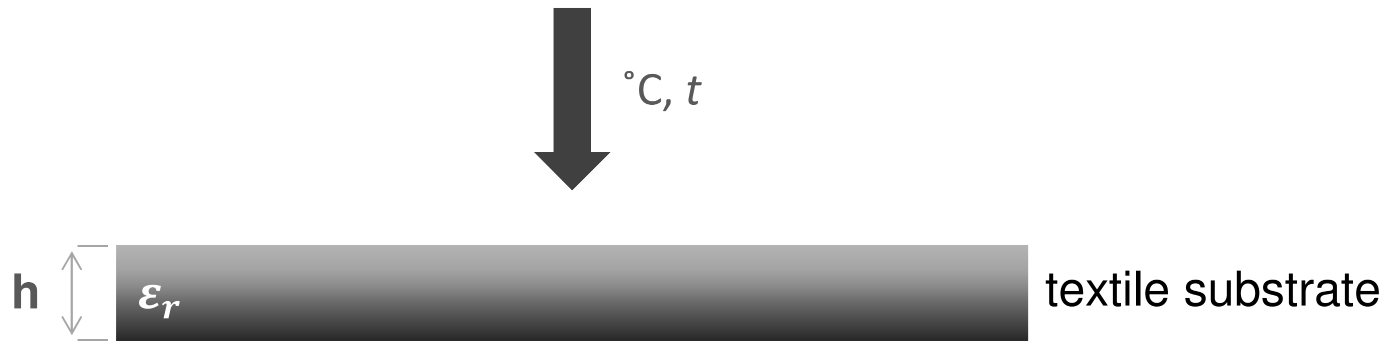
simulation time: **18** s (Intel Core i7-2600, 3.40 GHz, 16 GB RAM)

- **Output PDF of Z_{in} generated with 10000 realizations**
  - Monte-Carlo based on polynomial expansion (PC) (CPU-time 18s) versus based on full-wave simulations (MC) (CPU-time 16h 40min)



2. Substrate compression

- 2D stochastic model for correlated height and permittivity



(permanent) **substrate deformation**

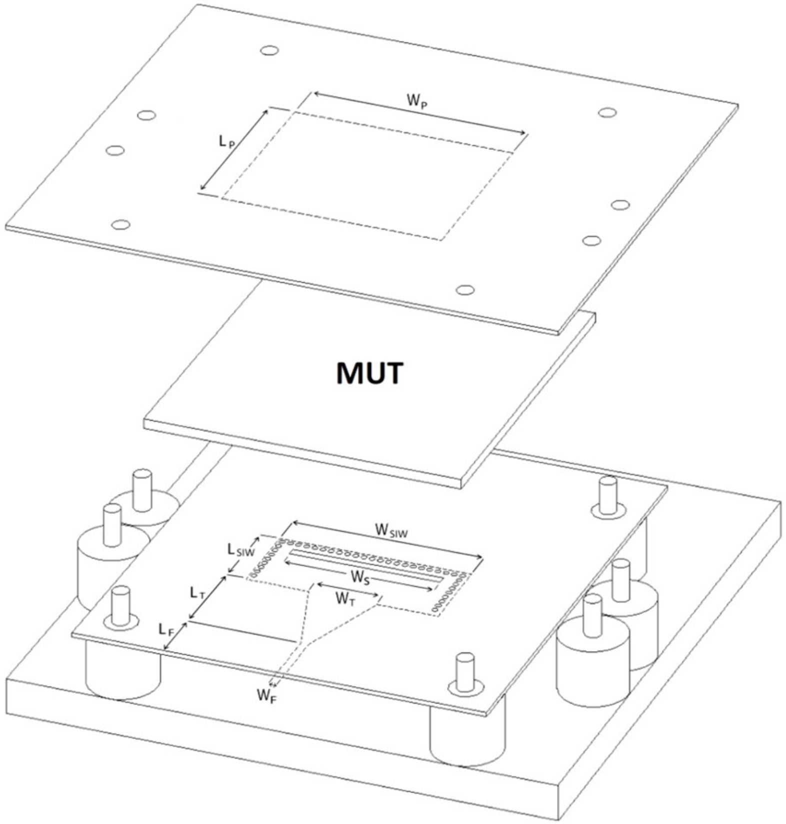
(compression set)

↑ **permittivity ε_r**

height h ↓

2. Substrate compression: permittivity measurement

- 2D model for correlated height and permittivity: input PDF



Resonance perturbation method based on aperture-coupled patch antenna:

- minimized interference and back radiation
- highest field strength confined in the material under test (MUT)
- fast replacement of MUT

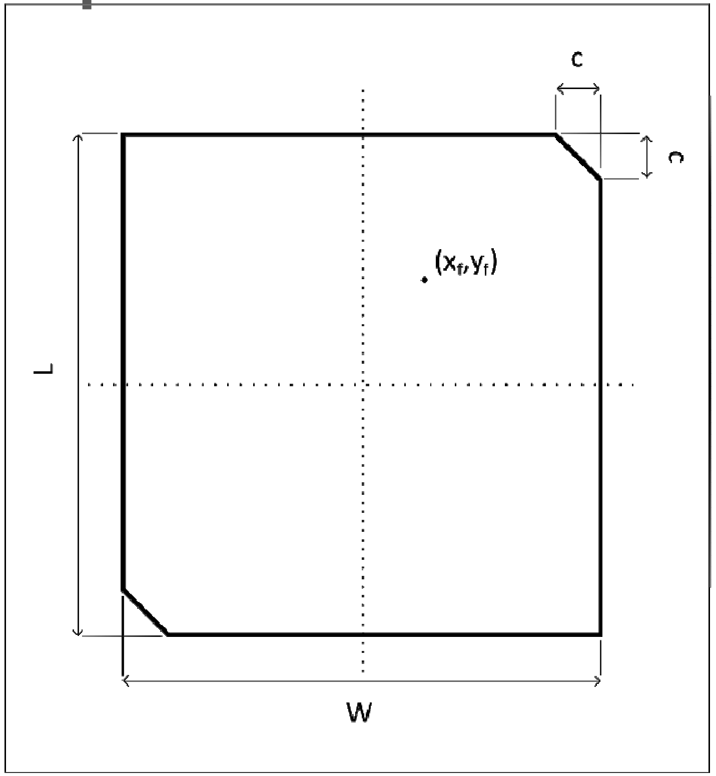
ε_r extracted by comparing measurements to CST Microwave Studio simulations

Case study: GPS antenna

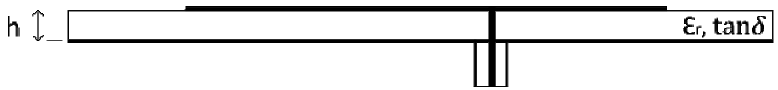
- **probe-fed microstrip GPS L1-band patch antenna**
  - requirements L1-band (1.57GHz):

$$|S11| \leq 0.316\ (-10dB)$$
$$AR \leq 1.41\ (3dB)$$ **(RHCP)**

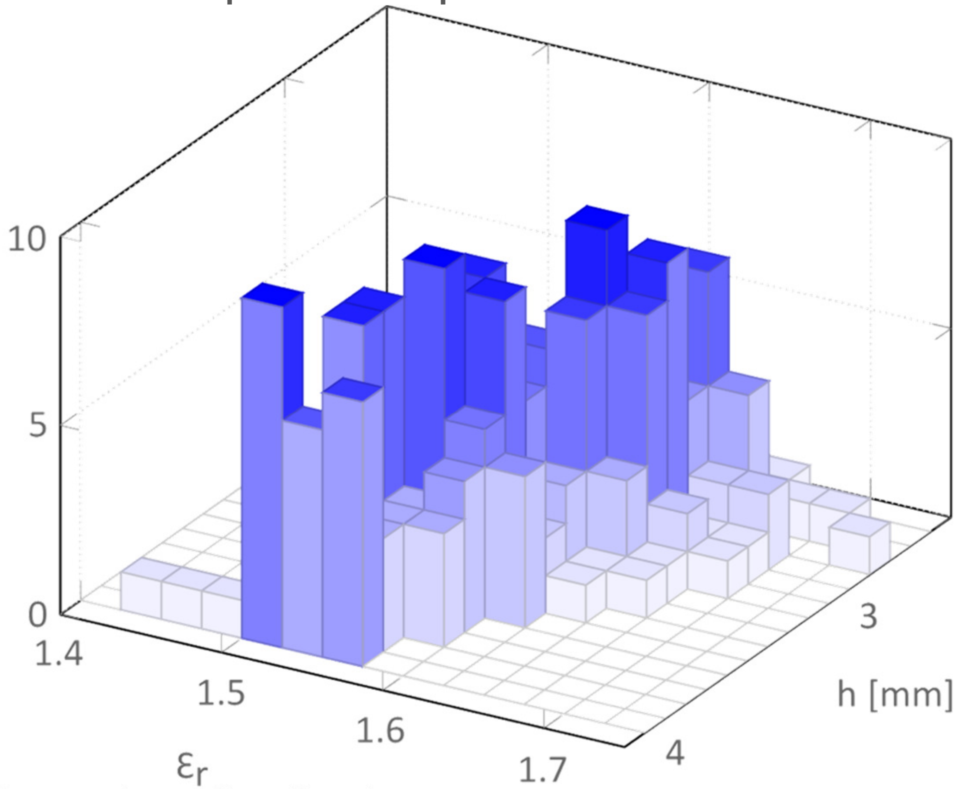
L	73.5 mm
W	69.5 mm
(x_f,y_f)	(8.5,14.5) mm
c	5 mm



protective foam substrate (ε_r=1.53, h=3.94 mm)



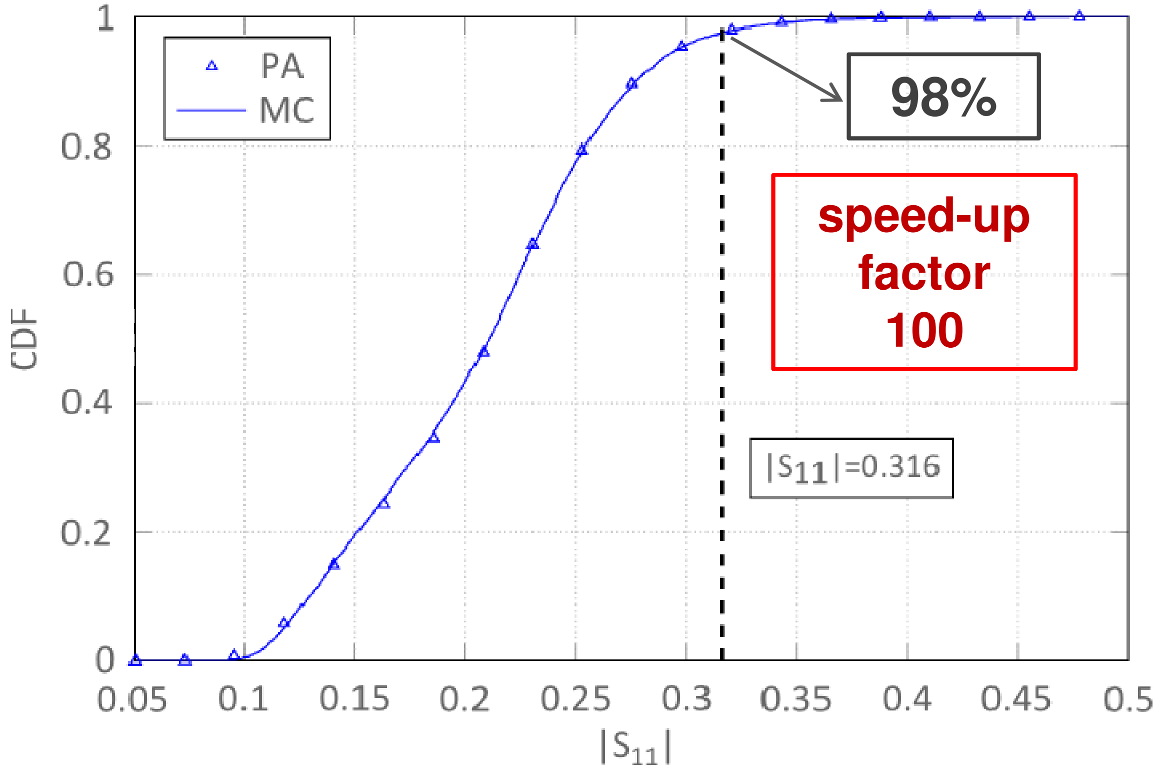
- **Input PDF**
  - 25 foam substrate samples compressed and measured 10 times



  - fit to bivariate Gaussian distribution
    - $\mu_h = 3.36\ mm,\ \mu_{\varepsilon_r} = 1.58,\ \sigma_h = 0.337,\ \sigma_{\varepsilon_r} = 0.049,$ **correlation** $\rho = -0.68$

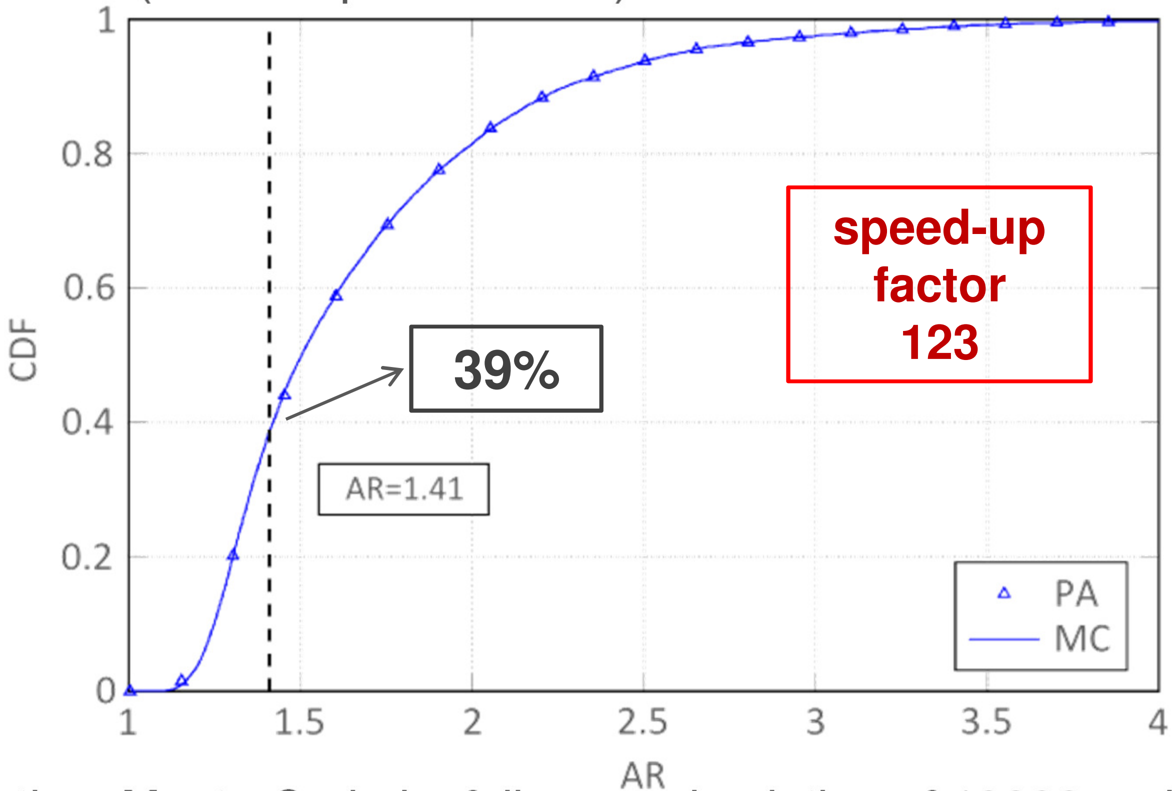
Output PDF constructed by Padé-chaos expansion

- antenna return loss at 1.57GHz



- validation: Monte-Carlo by full-wave simulation of 10000 realizations
  - **simulation time: 44 h 26 m**

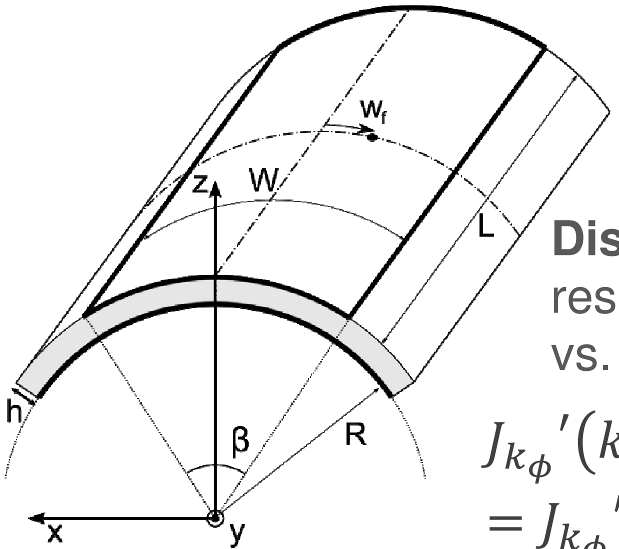
- **Output PDF constructed by Padé-chaos expansion**
  - axial ratio (circular polarization) at 1.57GHz



  - validation: Monte-Carlo by full-wave simulation of 10000 realizations
    - **simulation time: 44 h 26 m**

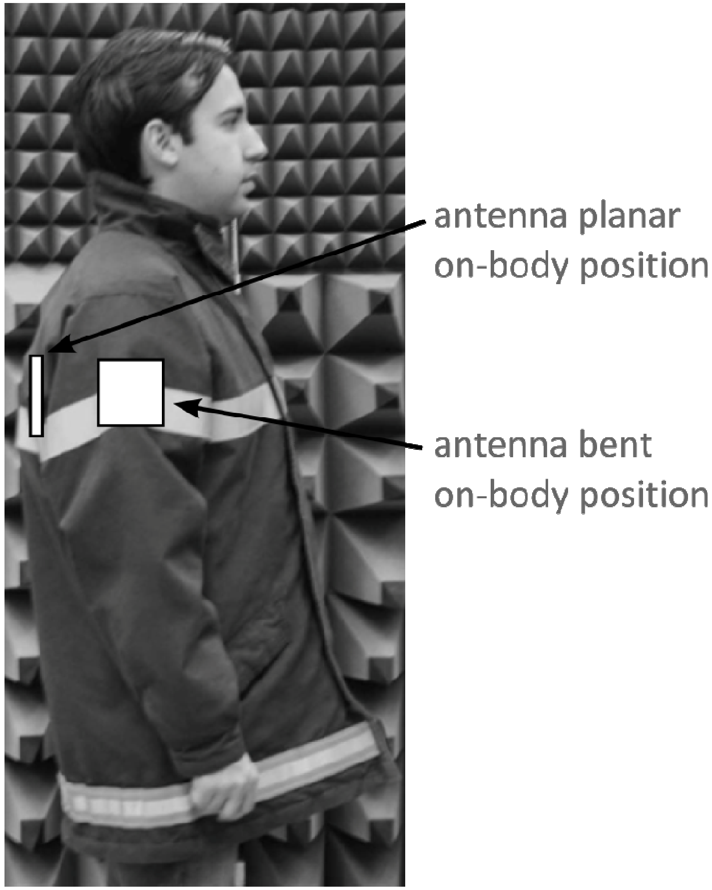
3. Substrate bending

- variations in antenna's curvature radius
  - **movements and activity of person wearing antenna**
  - **variations in body morphology over many different users**
  - **modeled by cavity model**



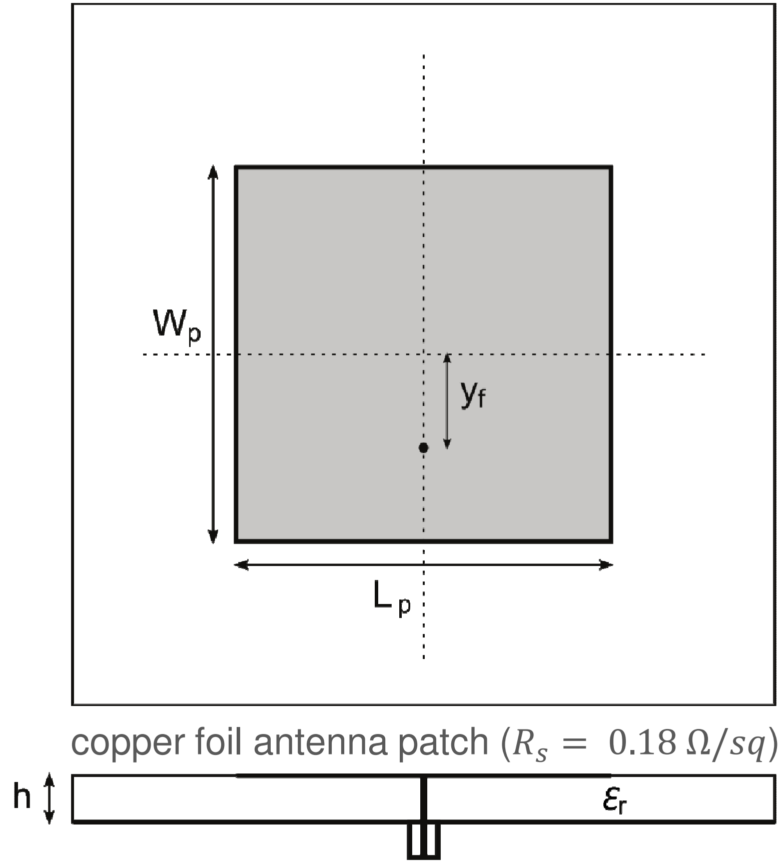
Dispersion relation:
resonance frequency f_r
vs. bending radius R

$$J_{k_\phi}{}'(k_p R) Y_{k_\phi}{}'(k_p(R+h)) = J_{k_\phi}{}'(k_p(R+h)) Y_{k_\phi}{}'(k_p R)$$



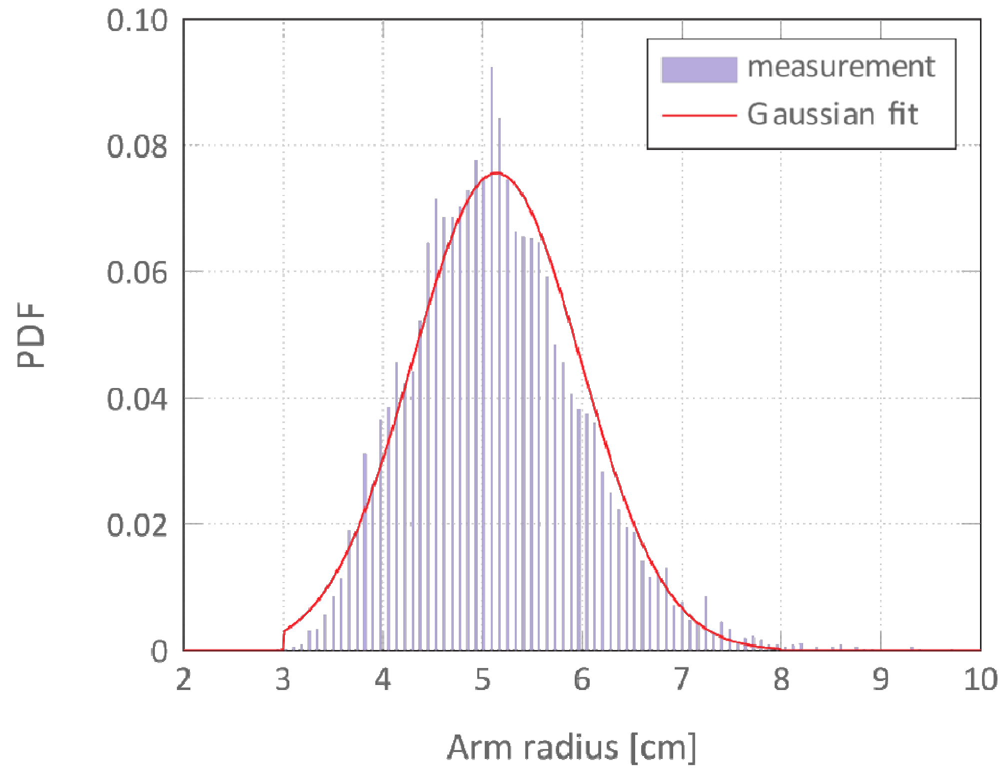
- **probe-fed microstrip GPS L1-band patch antenna**
  - Nominal resonance frequency f_r = 1.57GHz

W_p	69.25 mm
L_p	81.2 mm
y_f	16 mm



aramid fabric (ε_r=1.75, h=2 mm)

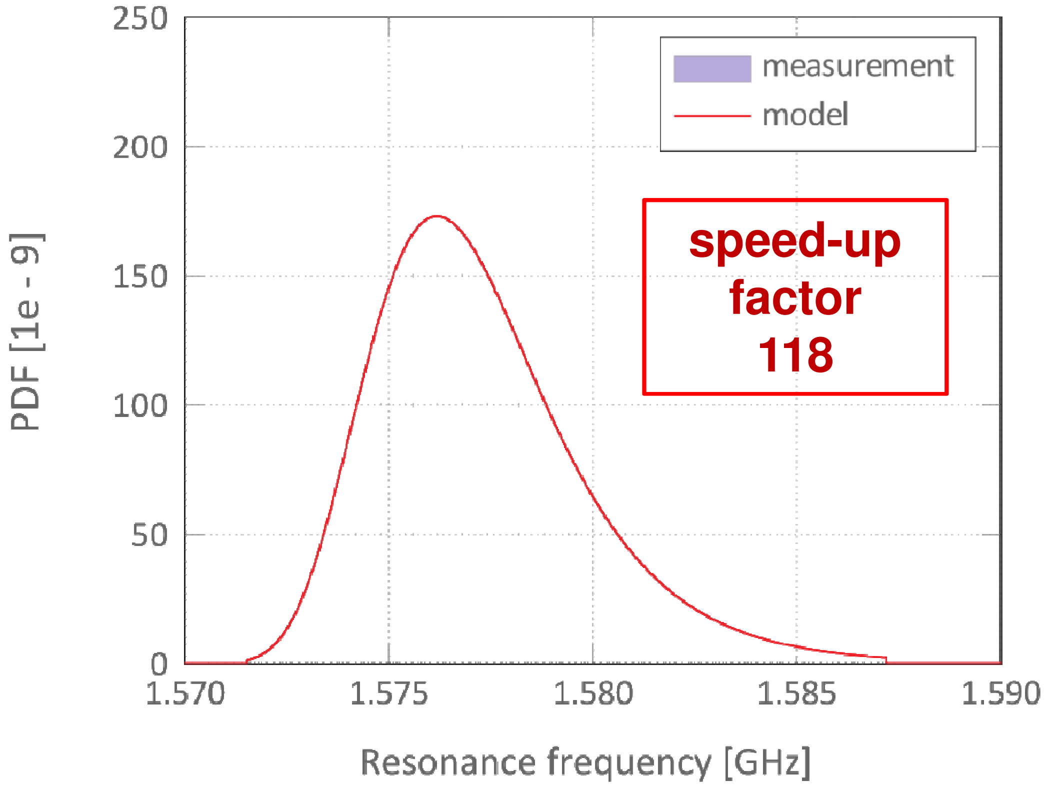
- **Input PDF arm radius R of human population**
  - from NHANES database



  - fit to truncated Gaussian distribution
    - $\bar{R} = 5.14\ cm$, $\sigma = 0.85$, **variation interval** $[3\text{–}8]\ cm$

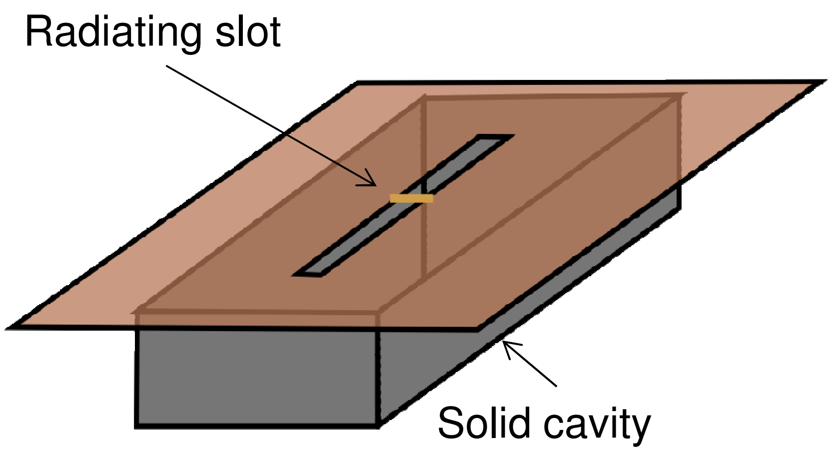
Output PDF by polynomial chaos expansion

- antenna resonance frequency

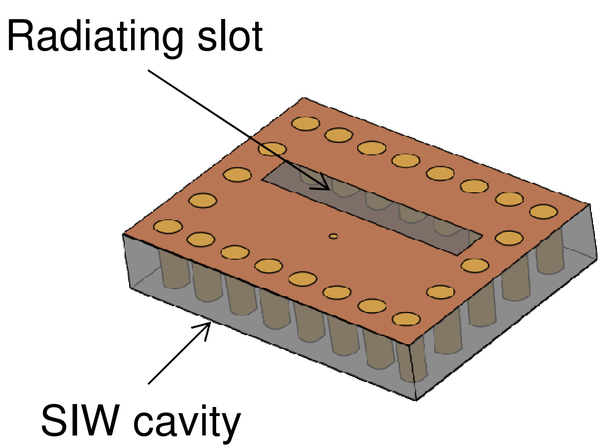


- validation: Monte-Carlo by full-wave simulation of 7056 realizations
  - **simulation time: 59s**

- The Internet-of-Things
  - opportunities and design challenges
- Stochastic antenna design framework
  - Production uncertainties
  - Substrate compression
  - Substrate bending
- Some novel IoT antenna designs
  - Substrate-Integrated-Waveguide (SIW) Cavity-Backed Slot (CBS) topology
  - Three-element antenna array for integration into furniture
  - Half-mode SIW CBS antenna on cork substrate
- Conclusions



Cavity-backed slot antenna topology
- High radiation efficiency
- High front-to-back ratio
- High isolation from its environment

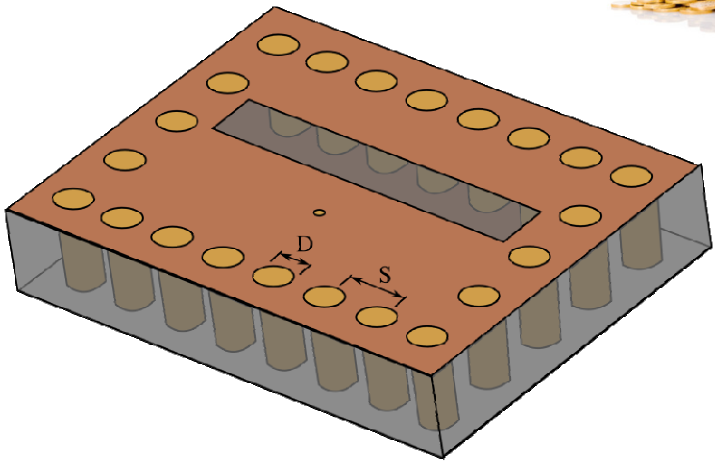


Substrate Integrated Waveguide (SIW) technology
- low-profile
- cost-effective
- simple implementation
- easy integration with planar circuitry

Antenna materials

Application-specific antenna substrate

- Stable, high-performance
- Green, recyclable design
- Reuse object's material if possible
- Significant cost and area reduction
- Reliable material characterization necessary



Copper-plated tafetta

- Conductive layers
- Rs = 0.18 Ω/sq

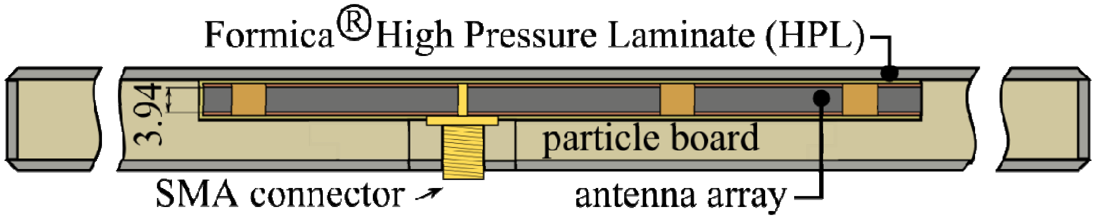
Brass tubular eyelets

- Effective electric walls
- Closely spaced to minimize radiation loss ($S/D < 2.5$)

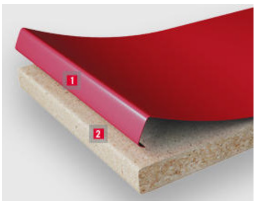
Goal

- Ultra-wideband three-element SIW CBS antenna array
- Invisible integration into furniture (desks, worktop kitchen, …)

Integration procedure

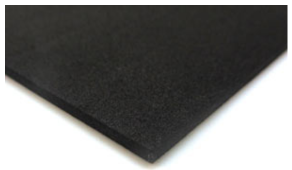


Integration platform



- Common material for furniture
- 38 mm-thick particle board
- 1 mm-thick High Pressure Laminate (HPL)
- ε_r = 2.7 – 3.07 [1]
- tanδ = 0.07 – 0.09 [1]

Antenna substrate

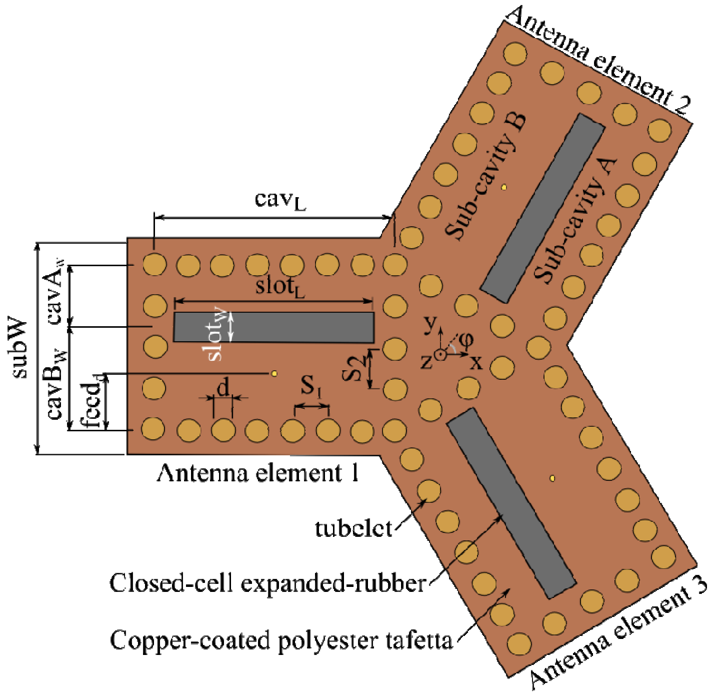


- 3.94 mm-thick closed-cell expanded-rubber
- Low losses
- Low moisture regain
- ε_r = 1.495 @ 5.50 GHz [2]
- tanδ = 0.016 @ 5.50 GHz [2]

[1] G. I. Torgovnikov, Dielectric Properties of Wood and Wood-based Materials, Springer-Verlag, Berlin, 1993
[2] F. Declercq, H. Rogier, and C. Hertleer, "Permittivity and Loss Tangent Characterization for Garment Antennas Based on a New Matrix-Pencil Two-Line Method," IEEE Trans. Antennas Propagat., vol. 56, no. 8, pp. 2548–2554, Aug 2008.

Design requirements

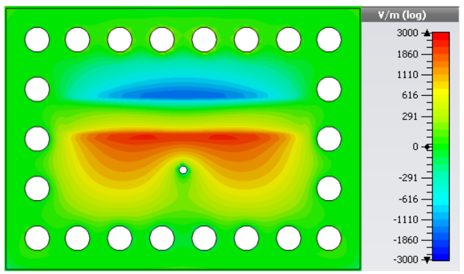
- 5 GHz Wi-Fi band [5.15-5.85] GHz , with 250 MHz margins
    - Return loss > 10 dB, [4.90-6.10] GHz
    - Isolation > 25 dB, [4.90-6.10] GHz



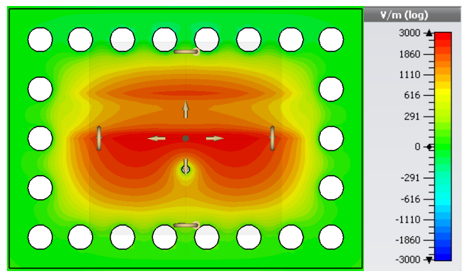
Single element design

- Coaxial feed
- Linearly-polarized
- Multi-moded bandwidth enhancement technique [3]

Field distribution



lowest resonance frequency



highest resonance frequency

[3] G. Q. Luo, Z. F. Hu, W. J. Li, X. H. Zhang, L. L. Sun, and J. F. Zheng, “Bandwidth-Enhanced Low-Profile Cavity-Backed Slot Antenna by Using Hybrid SIW Cavity Modes,” IEEE Trans. Antennas Propagat., vol. 60, no. 4, pp. 1698–1704, Apr. 2012.

Three-element SIW CBS antenna array

Design requirements

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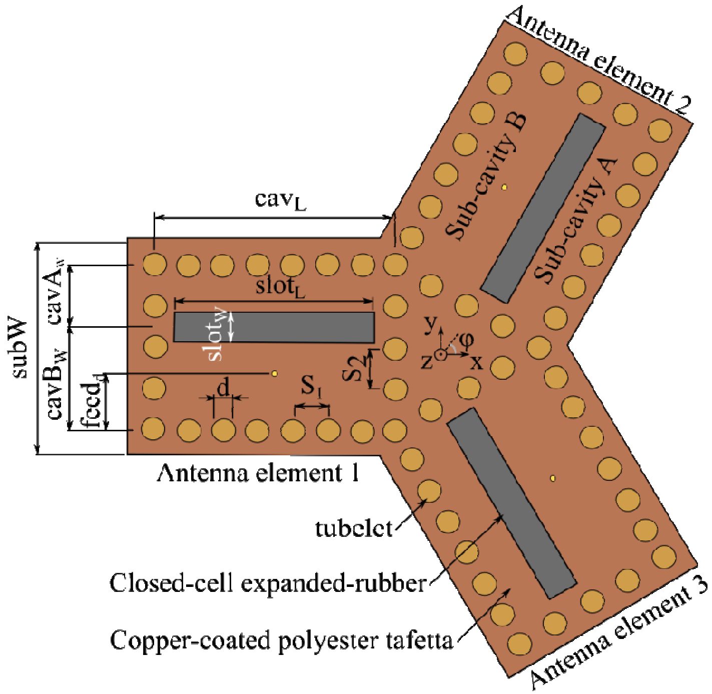
    - Isolation > 25 dB, [4.90-6.10] GHz



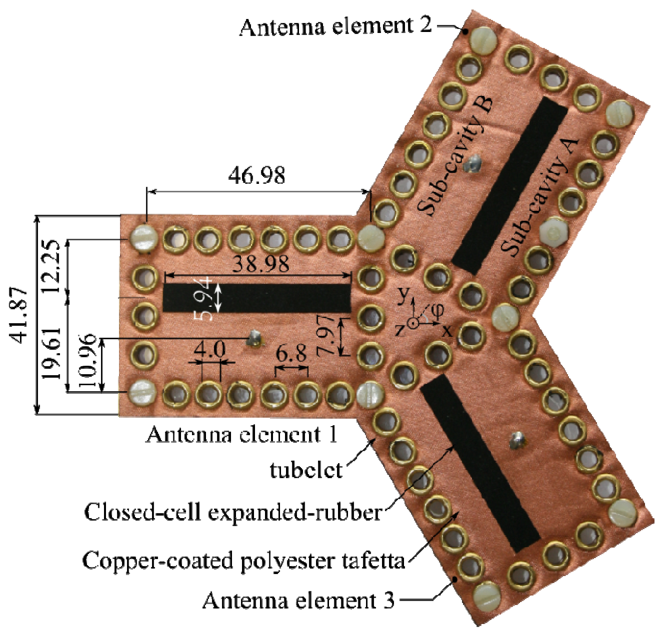
Array design

- Three identical antenna elements
- Threefold rotational symmetry
- Polarization diversity
- Spatial diversity

→ High MIMO/diversity gain

Three-element SIW CBS antenna array

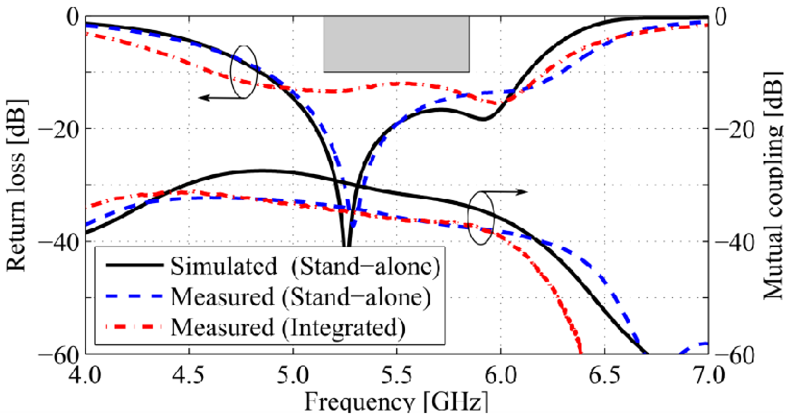
Prototype



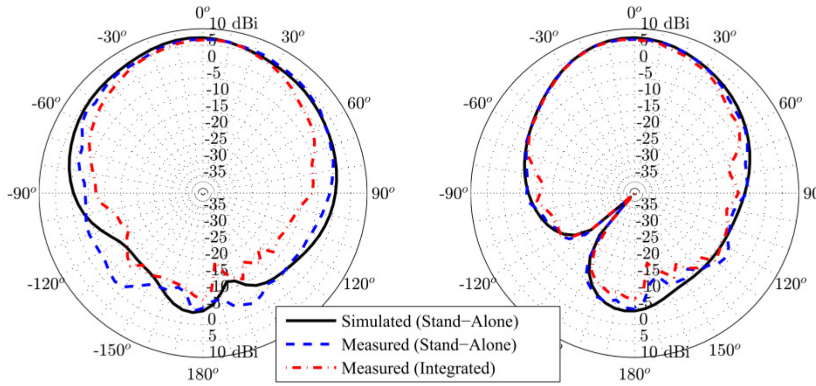
Invisible integration in conference table

Three-element SIW CBS antenna array

S-parameters



Radiation (far-field) performance



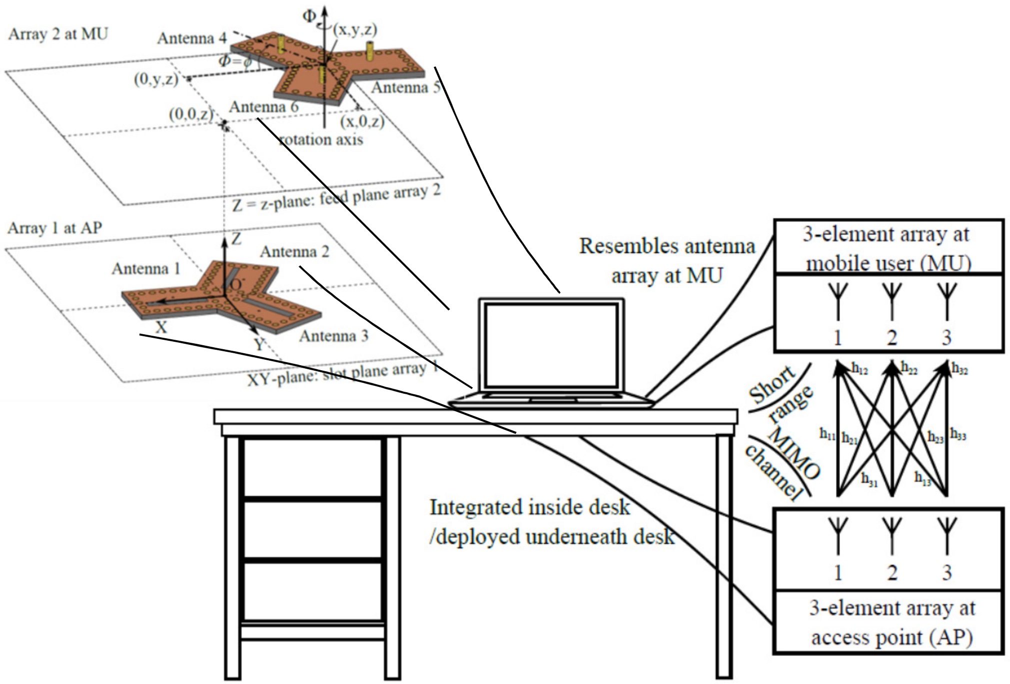
E-plane H-plane

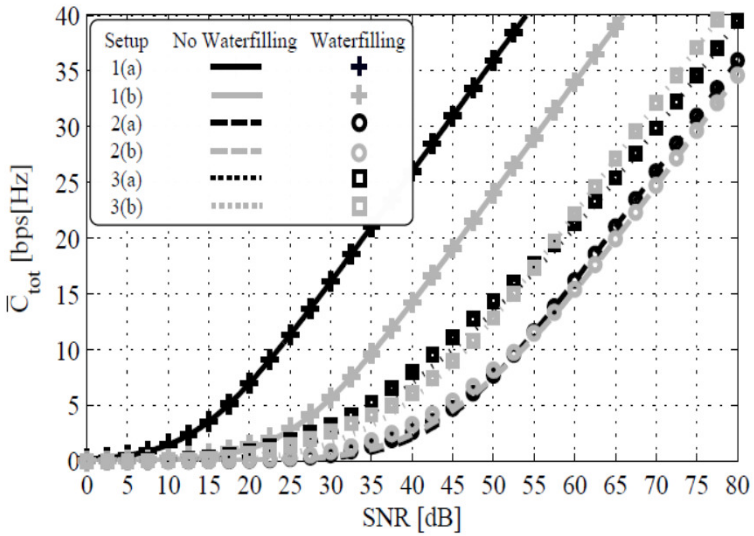
Summary

	Simulated (Stand-Alone)	Measured (Stand-Alone)	Measured (Integrated)
Impedance bandwidth [MHz]	1296	1433	1652
η_{rad} at 5.5 GHz [%]	91	84	78
$Gain_{max}$ at 5.5 GHz [dBi]	6.45	5.9	5.8
FTBR at 5.5 GHz [dB]	13.2	10.9	13.2

▪ ultra-high datarate short-distance channel

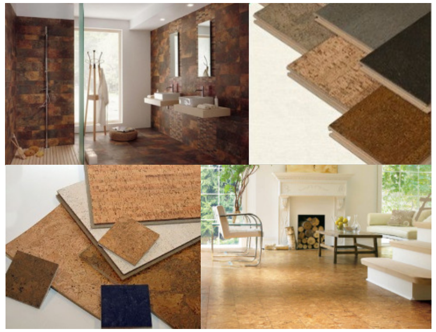
- 3x3 spatial multiplexing 802.11ac link
- wideband antenna array in desk and laptop





- up to 4.2 Gbps at 40dB SNR in 160MHz bandwidth
- up to 18.2 Gbps at 40dB SNR in 700MHz bandwidth

Half-mode SIW CBS antenna



Goal

- Miniaturized, wideband single-element SIW CBS antenna
- Invisible integration into cork floor and wall tiles

Antenna substrate

- 3 mm-thick cork substrate by Amorim Cork Composites S.A.
- Cork granules, bound by polyurethane
- Invisible integration: similar substrate as superstrate
- Low losses, low moisture regain
- Characterized at 5.50 GHz using resonator technique [5]

Antenna design

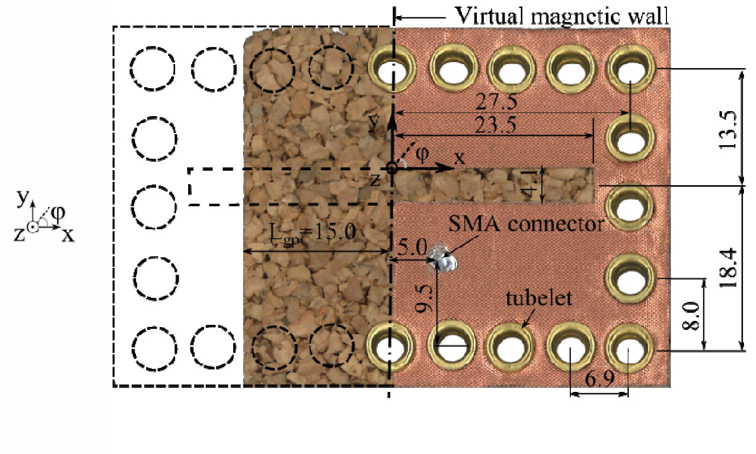
- Based on average parameters (ε_r , tan_d) = (1.22, 0.0363)
- Retain 300 MHz impedance bandwidth margins
- Allow for slight variation in cork material properties

➡ Return loss > 10 dB, [4.85-6.15] GHz

Resonator	(ε_r, tan_d)
1	(1.20, 0.0306)
2	(1.17, 0.0244)
3	(1.25, 0.0481)
4	(1.26, 0.0421)

[5] O. Caytan, S. Lemey, S. Agneessens, D. Vande Ginste, P. Demeester, C. Loss, R. Salvado, and H. Rogier, “Half-mode substrate-integrated-waveguide cavity-backed slot antenna on cork substrate,” Antennas Wirel. Propag. Lett., vol. PP, no. 99, 2015.

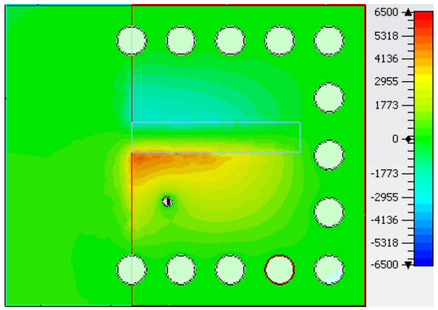
Half-mode SIW CBS antenna



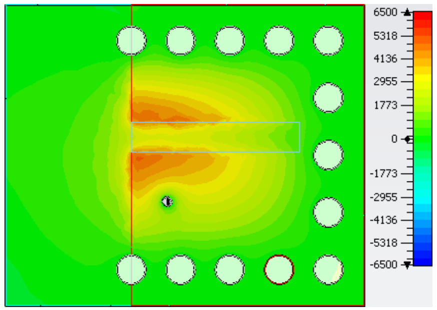
Half-mode SIW CBS Antenna

- Return loss > 10 dB, [4.85-6.15] GHz
- Multi-moded bandwidth enhancement technique
- Half-mode SIW miniaturization technique

Field distribution

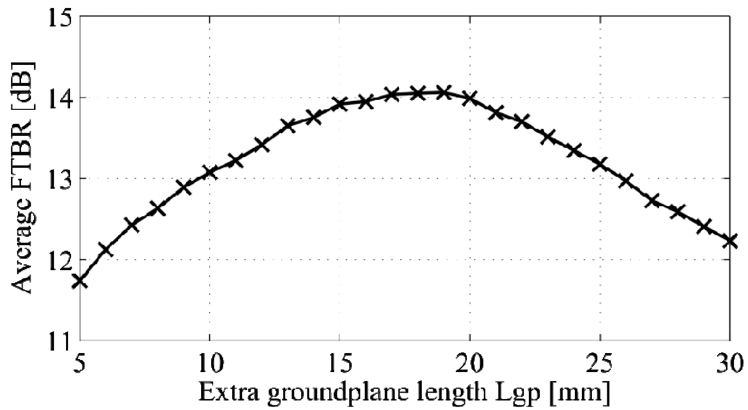


lowest resonance frequency

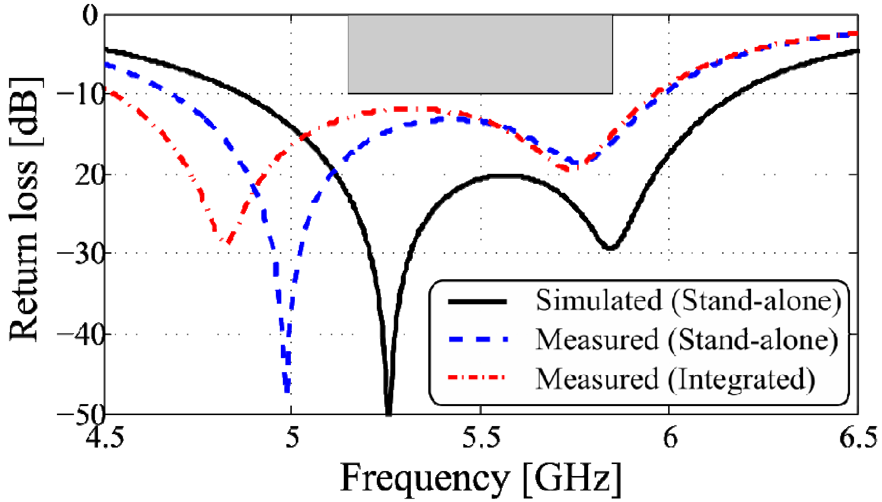


highest resonance frequency

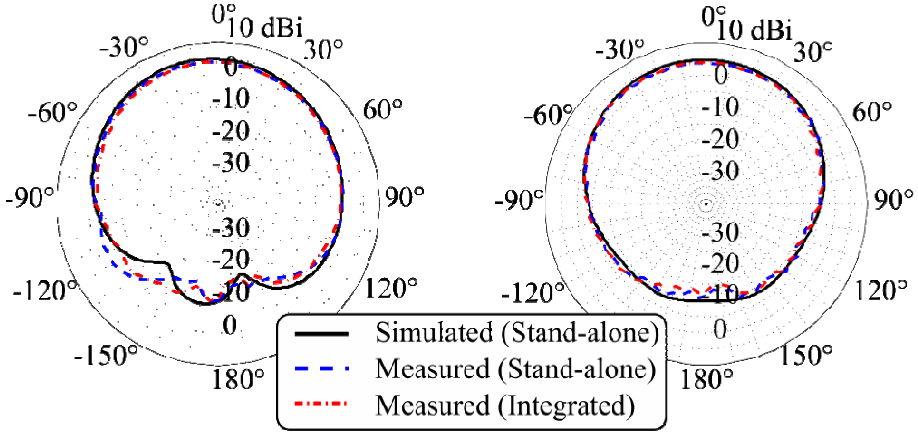
Optimal Front-to-back ratio (FTBR)



Return loss



Radiation performance at 5.5 GHz



E-plane

H-plane

Summary

	Simulated (Stand-Alone)	Measured (Stand-Alone)	Measured (Integrated)
Impedance bandwidth [MHz]	1317	1312	1436
η_{rad} at 5.5 GHz [%]	83	85	80
$Gain_{max}$ at 5.5 GHz [dBi]	5.0	4.3	4.2
FTBR at 5.5 GHz [dB]	14.5	15.0	16.8

Outline

- The Internet-of-Things
  - opportunities and design challenges
- Stochastic antenna design framework
  - Production uncertainties
  - Substrate compression
  - Substrate bending
- Some novel IoT antenna designs
  - Substrate-Integrated-Waveguide (SIW) Cavity-Backed Slot (CBS) topology
  - Three-element antenna array for integration into furniture
  - Half-mode SIW CBS antenna on cork substrate
- Conclusions

Conclusions

- **Accounting for random variations in IoT antennas**
  - in antenna geometry
  - In deployment conditions

→ **Stochastic antenna design framework**
  - → quantify statistics of antenna's figures of merit

- **Better isolation between antenna and IoT platform**

→ **Dedicated antenna topology**
  - → Cavity-backed slot antenna in SIW technology

- **Design examples**
  - three-element UWB antenna array for integration into furniture
  - miniature HMSIW antenna for integration in cork floors and walls

Further reading

1. C. Hertleer, H. Rogier, L. Vallozzi, and L. Van Langenhove, “A Textile Antenna for Off-Body Communication Integrated into Protective Clothing for Firefighters”, IEEE Trans. on Antennas Propag., vol. 57, no. 4, pp. 919–925, Apr. 2009.
2. C. Hertleer, A. Van Laere, H. Rogier, L. Van Langenhove, “Influence of Relative Humidity on Textile Antenna Performance.,” Textile Research Journal, vol. 80, no. 2, pp. 177–183, Jan. 2010.
3. P. Van Torre, L. Vallozzi, H. Rogier, M. Moeneclaey, C. Hertleer, J. Verhaevert, “Indoor off-body wireless MIMO communication with dual polarized textile antennas.”, IEEE Trans. on Antennas Propag. (IF 2.151, ranking 11/78, Q1, 13 citations), vol. 59, no. 2, pp. 631–642, Feb. 2011.
4. M. Scarpello, D. Kurup, H. Rogier, D. Vande Ginste, F. Axisa, J. Vanfleteren, W. Joseph, L. Martens, G. Vermeeren, “Design of an Implantable Slot Dipole Conformal Flexible Antenna for Biomedical Applications”, IEEE Trans. on Antennas Propag., vol. 59, no. 10, pp. 3556–3564, Oct. 2011.
5. F. Boeykens, L. Vallozzi, and H. Rogier, “Cylindrical bending of deformable textile rectangular-patch antennas,” International Journal of Antennas and Propagation, Article ID 170420, 11 pages, doi:10.1155/2012/170420, 2012
6. M. L. Scarpello, I. Kazani, C. Hertleer, H. Rogier and D. Vande Ginste, “Stability and Efficiency of Screen-Printed Wearable and Washable Antennas”, IEEE Antennas and Wireless Propagation Letters, vol. 11, pp. 838–841, 2012.
7. P. Van Torre, L. Vallozzi, L. Jacobs, H. Rogier, M. Moeneclaey and J. Verhaevert, “Characterization of measured indoor off-body MIMO channels with correlated fading, correlated shadowing and constant path loss,” IEEE Trans. on Wireless Communications, vol. 11, no. 2, pp. 712-721, Feb. 2012.
8. R. Moro, S. Agneessens, H. Rogier, and M. Bozzi, "Wearable Textile Antenna in Substrate Integrated Waveguide Technology," IET Electronics Letters, vol. 48, no. 16, pp. 985–987, Aug. 2012.
9. F. Declercq, I. Couckuyt, H. Rogier, and T. Dhaene, “Environmental High Frequency Characterization of Fabrics based on a Novel Surrogate Modelling Antenna Technique”, IEEE Trans. on Antennas Propag., vol. 61, no. 10, pp. 5200–5213, Oct. 2013.
10. S. Lemey, F. Declercq and H. Rogier, “Dual-band Substrate Integrated Waveguide Textile Antenna with Integrated Solar Harvester”, IEEE Antennas and Wireless Propagation Letters, vol. 13, Digital Object Identifier: 10.1109/LAWP.2014.2303573, pp. 269–272, 2014.
11. F. Boeykens, H. Rogier, and L. Vallozzi, “An efficient technique based on polynomial chaos to model the uncertainty in the resonance frequency of textile antennas due to bending”, IEEE Trans. on Antennas Propag, vol. 62, no. 3, pp. 1253–1260, Mar. 2014.
12. N. Carvalho, A. Georgiadis, A. Costanzo, H. Rogier, A. Collado, J. A. García, S. Lucyszyn, P. Mezzanotte, J. Kracek, D. Masotti, A. Boaventura, M. Nieves Ruíz, M. Pinuela, D. Yates, P. Mitcheson, M. Mazanek, and V. Pankrac, “Wireless Power Transmission: R&D Activities within Europe”, IEEE Trans. Microwave Theory Tech., vol. 62, no. 4, pp. 1031–1045, Apr. 2014.

Further reading

13. S. Agneessens, and H. Rogier, "Compact Half Diamond Dual-Band Textile HMSIW On body Antenna", IEEE Trans. on Antennas Propag., vol. 62, no. 4, pp. 2374–2381, May 2014.
14. S. Lemey, F. Declercq, and H. Rogier, "Textile antennas as hybrid energy harvesting platforms", Proceedings of the IEEE, vol. 102, no. 11, pp. 1833–1857, Nov. 2014.
15. M. Rossi, A. Dierck, H. Rogier, and D. Vande Ginste, "A Stochastic Framework for the Variability Analysis of Textile Antennas", IEEE Trans. on Antennas Propag., vol. 62, no. 12, pp. 6510-6514, Dec. 2014.
16. S. Agneessens, S.Lemey, T. Vervust, and H. Rogier, "Wearable, small, and robust: the circular Quarter-Mode Textile Antenna", IEEE Antennas and Wireless Propagation Letters, vol. 14, Digital Object Identifier: 10.1109/LAWP.2014.2368597, pp. 1482–1485, 2015.
17. R. Moro, S. Agneessens, H. Rogier, A. Dierck, and Maurizio Bozzi, "Textile Microwave Components in Substrate Integrated Waveguide Technology", IEEE Trans. Microwave Theory Tech. (IF 2.243, ranking 46/249, Q1, 3 citations), vol. 63, no. 2, pp. 422–432, Feb. 2015.
18. M. Marinova, A. Thielens, E. Tanghe, L. Vallozzi, G. Vermeeren, W. Joseph, H. Rogier, L. Martens, "Diversity Performance of Off-body MB-OFDM UWB-MIMO", IEEE Trans. on Antennas Propag., vol. 63, no. 7, pp. 3187–3197, Mar. 2015.
19. P. Vanveerdeghem, P. Van Torre, A. Thielens, J. Knockaert, W. Joseph, and Hendrik Rogier, "Compact Personal Distributed Wearable Exposimeter", IEEE Sensors Journal, vol. 15, no. 8, pp. 4393–4401, Aug. 2015.
20. P. Nepa, and H. Rogier, "Wearable Antennas for Off-Body Radio Links at VHF and UHF bands (below 1 GHz): Challenges, State-of-the-Art and Future Trends", IEEE Antennas and Propagation Magazine, vol. 57, no. 5, Digital Object Identifier: 10.1109/MAP.2015.2472374, pp. 30–52, Oct. 2015.
21. O. Caytan, S. Lemey, S. Agneessens, D. Vande Ginste, P. Demeester, C. Loss, R. Salvado, and H. Rogier, "Half-Mode Substrate-Integrated-Waveguide Cavity-Backed Slot Antenna on Cork Substrate", IEEE Antennas and Wireless Propagation Letters, vol. 15, Digital Object Identifier: 10.1109/LAWP.2015.2435891, pp. 162–165, 2015.
22. O. Caytan, S. Lemey, S. Agneessens, and H. Rogier, "SIW Antennas as Hybrid Energy Harvesting and Power Management Platforms for the Internet of Things", Int. Journal of Microwave and Wireless Technologies, doi:10.1017/S1759078716000325, in press, Feb. 2016.
23. S. Lemey, T. Castel, P. Van Torre, T. Vervust,J. Vanfleteren, P. Demeester, D. Vande Ginste, and Hendrik Rogier, "Threefold Rotationally Symmetric SIW Antenna Array for Ultra-Short-Range MIMO Communication", IEEE Trans. on Antennas Propag., vol. , no. , pp. –, in press, Feb. 2016.
24. T. Castel, P. Van Torre, L. Vallozzi, M. Marinova, S. Lemey, W. Joseph, C. Oestges, and H. Rogier, "Capacity of Broadband Body-to-Body Channels between Firefighters wearing Textile SIW Antennas", IEEE Trans. on Antennas Propag. (IF 2.181, ranking 10/77, Q1), vol. , no. , pp. –, in press, Feb. 2016.
25. M. Rossi, S. Agneessens, H. Rogier, and D. Vande Ginste, "Stochastic Analysis of the Impact of Substrate Compression on the Performance of Textile Antennas", IEEE Trans. on Antennas Propag., vol. , no. , pp. –, in press, Mar. 2016.