

# Millimeter-Wave Technologies for Biomedical Electromagnetics



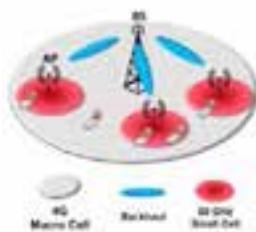
MAXIM ZHADOBOV

French National Center for Scientific Research



## OVERVIEW

### Dosimetry for 5G at mmW

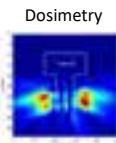
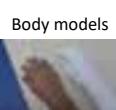
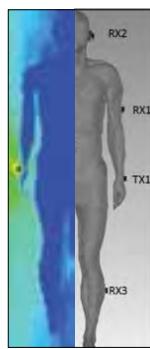


5G HetNet topology

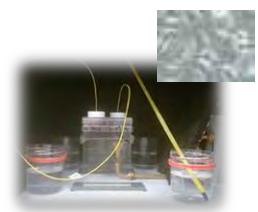


Representative use cases

### Body-centric wireless communications at mmW



### Exposure systems for *in vitro* and *in vivo* studies



*In vitro* exposure at 60 GHz



Reverberation chamber for  
*in vivo* exposure at mmW

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## DOSIMETRY FOR 5G AT MMW

The slide features the MiWaves logo on the left, which includes the text "MiWaves" and the website "www.miwaves.eu". To the right is a circular diagram of a cellular network. It shows three red dots representing users, each connected to a blue antenna. Below the users are labels: "4G Macro Cell", "SmallCell", and "5G D2D Small Cell". A legend at the bottom right identifies these symbols.

**User exposure at mmW**

The section is titled "User exposure at mmW" and contains three images with corresponding labels:

- Phone call**: A man talking on a mobile phone.
- Browsing**: A woman looking at her smartphone.
- Access point**: Two people standing near a yellow access point antenna labeled "AP".

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## USAGE SCENARIOS & MOBILE USER TERMINAL

The slide shows a diagram of a mobile user terminal (MUT) with various components labeled: PCB, Ground plane (PCB), Dielectric (PCB), and Vias. It also shows two head models representing "Front position" and "Edge position" for a "Phone call scenario".

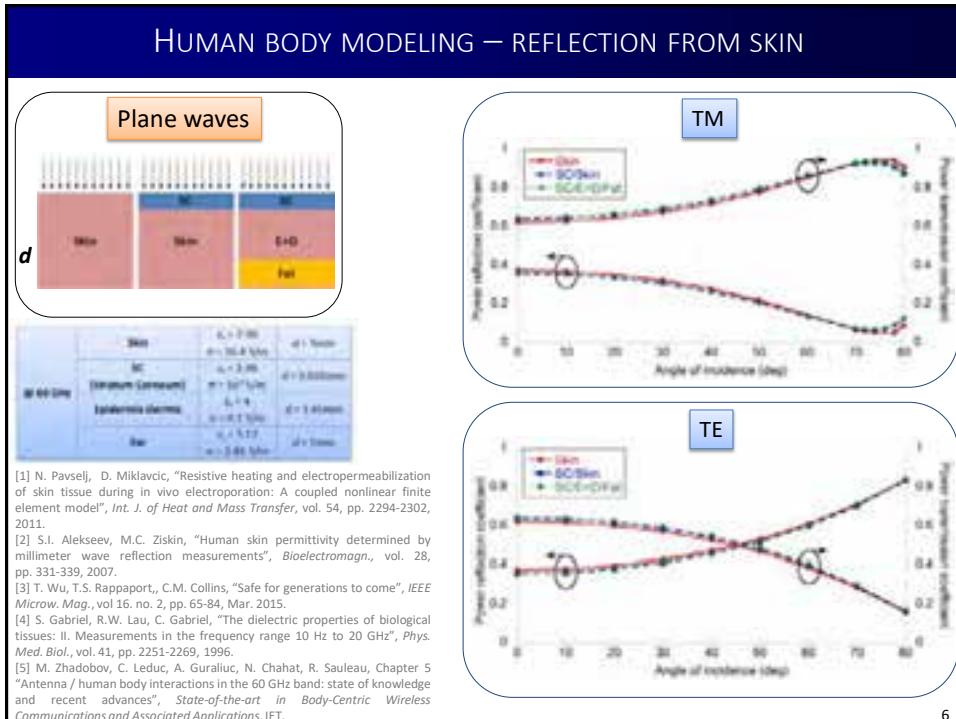
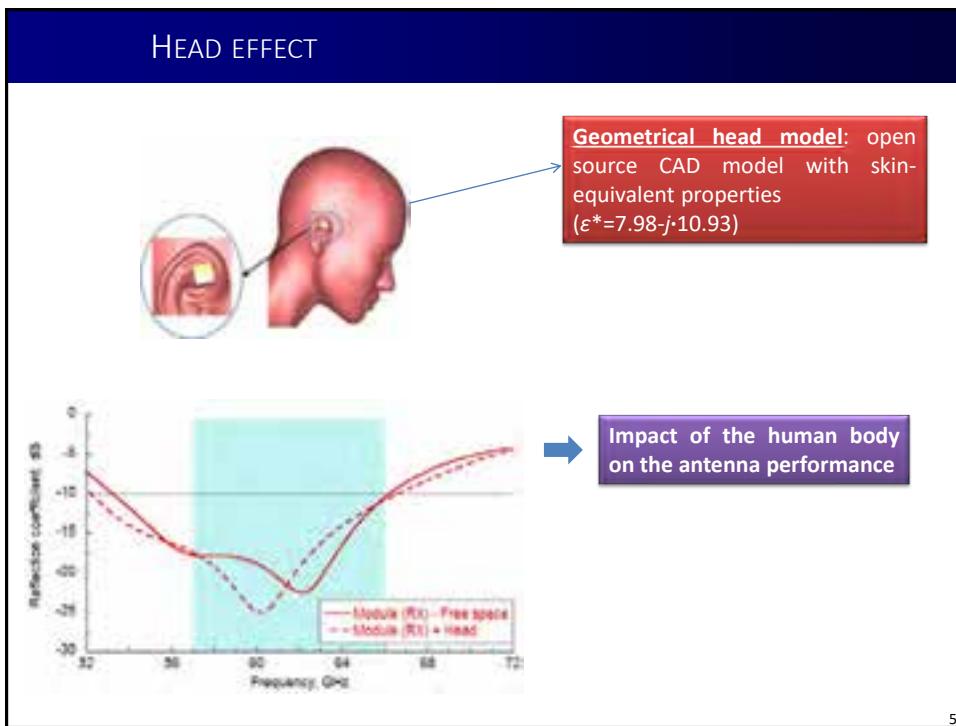
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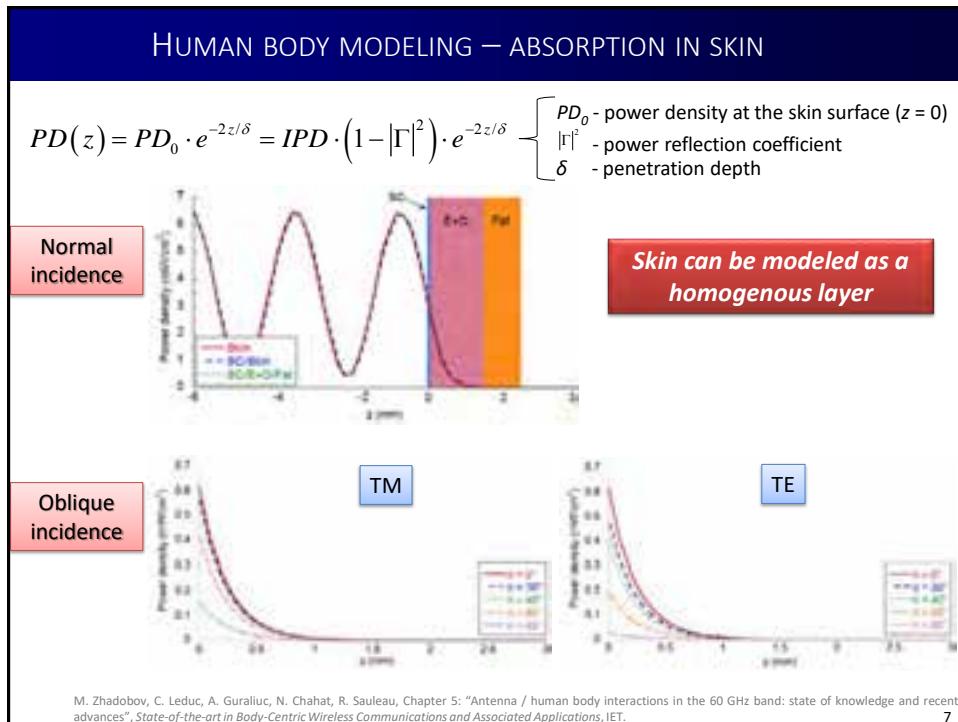
Below the diagram, there are two detailed views of the MUT's internal structure:

- Module "Front position"**: Shows a cross-section of the PCB with dimensions: 12mm width, 12mm height, and 1.6mm thickness. Labels include "Ground plane (PCB)", "Dielectric (PCB)", and "Vias".
- Module "Edge position"**: Shows a cross-section of the PCB with dimensions: 12mm width, 12mm height, and 1.6mm thickness. Labels include "Ground plane (PCB)", "Dielectric (PCB)", and "Vias".

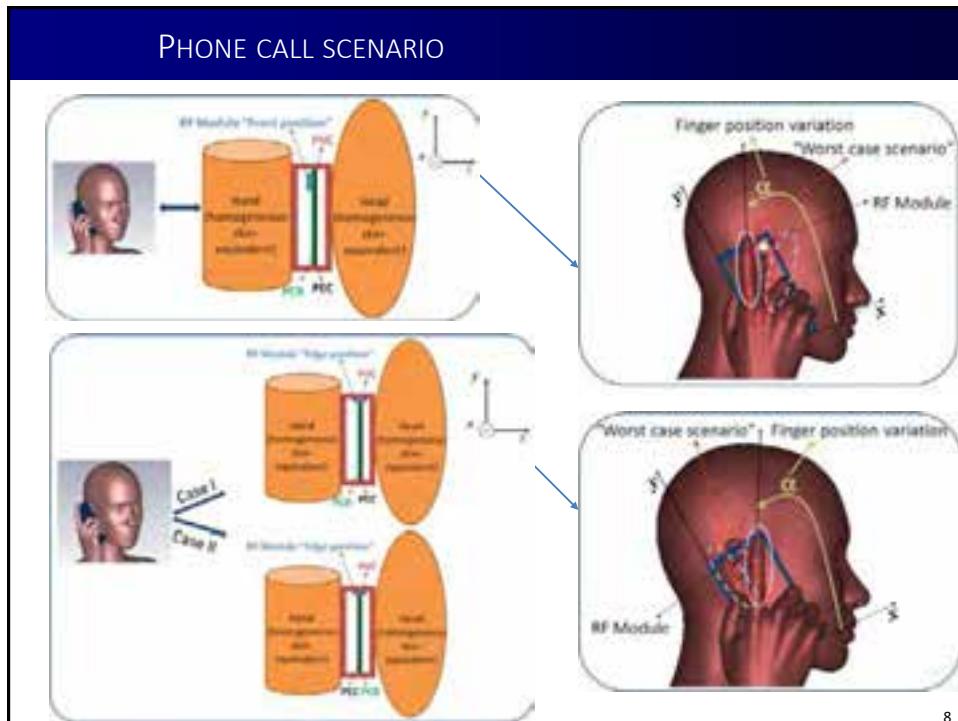
$P = 10 \text{ mW}$

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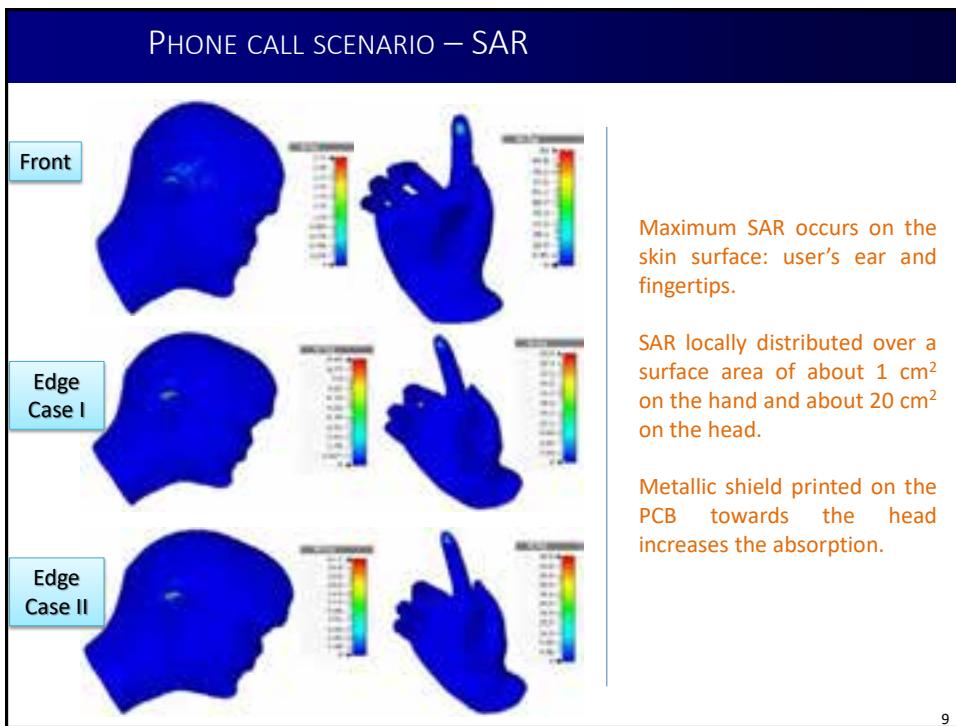




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### EXPOSURE GUIDELINES AND STANDARDS

Safety guidelines are set in terms of **Incident Power Density (IPD)**

	<b>Frequency (GHz)</b>	<b>Exposure type</b>	<b>IPD (mW/cm<sup>2</sup>)</b>	<b>Averaging</b>		<b>Safety factor</b>
				<b>Surface (cm<sup>2</sup>)</b>	<b>Time (min)</b>	
<b>ICNIRP [1] (and CENELEC [2])</b>	10-300	Occupational	5	20	68/f <sup>0.05</sup>	<b>Occupational</b>
			100	1		
		General	1	20		
			20	1		
<b>IEEE [3], [4]</b>	30 - 300	Occupational	10	100	2.524/f <sup>0.47</sup>	<b>F<sub>s</sub> = 5 or 10</b>
	3 - 96		200(f/3) <sup>0.2</sup>	1		
	> 96		400	1	25.24/f <sup>0.47</sup>	<b>General</b>
	30 - 100	General	1	100		
			20	1		
<i>f – frequency in GHz</i>						

[1] ICNIRP: "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Phys., vol. 74, no. 4, pp. 494-522, 1998.  
[2] EN 50413 – 2008, "Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)".  
[3] IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, ISBN 0-7381-4835-0 SS95389, Apr. 2006.  
[4] IEEE Standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 kHz to 300 GHz, ISBN 978-0-7381-6207-2 STD96039, Feb. 2010.

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PHONE CALL SCENARIO – SUMMARY OF RESULTS									
Antenna position	Absorption region	Absorbed power, mW	Peak SAR, W/kg	Peak IPD <sub>eq</sub> , mW/cm <sup>2</sup>	Averaging			TRP, mW	Total efficiency, %
					SAR, W/kg	IPD, mW/cm <sup>2</sup>	Surface, cm <sup>2</sup>		
Front	Head	0.3	2.7	0.1	$2.7 \times 10^{-3}$	$0.1 \times 10^{-3}$	20	3.6	36
	Hand	4.1	93	3.9			1		
	Head (without the hand)	0.01	$3.8 \times 10^{-9}$	$1.6 \times 10^{-10}$			--		
Edge – Case I	Head	0.6	9.7	0.4	$0.9 \times 10^{-3}$	$4 \times 10^{-5}$	20	3.1	31
	Hand	5.3	33.3	1.4	$0.7 \times 10^{-3}$	$3 \times 10^{-5}$	1		
	Head (without the hand)	0.07	$5.4 \times 10^{-8}$	$2.4 \times 10^{-9}$	--	--	--		
Edge – Case II	Head	0.9	21.7	0.9	$1.6 \times 10^{-3}$	$7 \times 10^{-5}$	20	4.8	48
	Hand	3.4	55	2.3	$1.1 \times 10^{-3}$	$5 \times 10^{-5}$	1		
	Head (without the hand)	0.4	$1.3 \times 10^{-7}$	$0.6 \times 10^{-8}$	--	--	--		

- Exposure levels are lower compared to the limits  
- Presence of a hand increases the absorption in the head

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OPTIMAL POSITION OF THE ANTENNA MODULE									
<ul style="list-style-type: none"> <li>✓ Edge position is an appropriate choice providing acceptable antenna performance and reduced user exposure.</li> </ul>									
<ul style="list-style-type: none"> <li>✓ As far as the metallic shield printed on the PCB, both positions towards head or hand, can be chosen:</li> </ul>									
<ul style="list-style-type: none"> <li>➤ <u>PEC towards head</u> – lower exposure (<math>IPD_{eq\_head} = 0.4 \text{ mW/cm}^2</math>, <math>IPD_{eq\_hand} = 1.4 \text{ mW/cm}^2</math>) lower antenna efficiency (31%)</li> <li>➤ <u>PEC towards hand</u> – higher exposure (<math>IPD_{eq\_head} = 0.9 \text{ mW/cm}^2</math>, <math>IPD_{eq\_hand} = 2.3 \text{ mW/cm}^2</math>) higher antenna efficiency (48%)</li> </ul>									
<p style="text-align: center;">A. Guraliuc, M. Zhadobov, R. Sauleau, L. Marnat, L. Dussopt. Near-field user exposure in forthcoming 5G scenarios in the 60-GHz band. <i>IEEE Transactions on Antennas and Propagation</i>, 65(12), pp. 6606-6615, Dec. 2017.</p>									

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## BODY-CENTRIC WIRELESS COMMUNICATIONS

Wireless networking between sensors and communicating devices placed on, off, or implanted in human body  
healthcare, sports, smart home, entertainment, military

**E-health monitoring**  
Smart wireless sensors

**Smart clothing**  
Connected textiles for sports

**Positioning & gesture recognition**  
Touchless interactions

**5G and IoT**  
Millimeter-wave communications

**Person-to-person wireless communications**

**Wireless implants**  
Powering through the body

Base station

off-body

on-body

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## ON-BODY MILLIMETER-WAVE ANTENNAS

First mmW antennas for body-centric communications

**On the classical substrate**  
(127 or 254  $\mu\text{m}$  RT Duroid 5880;  $\epsilon_r = 2.2$ ;  $\tan\delta = 0.003$ )

Antenna for off-body communications  
(broadside, 57-65 GHz, gain 12 dBi)  
N. Chahat, M. Zhadobov et al. IEEE AP, 60(12), 2012.

Antenna for on-body communications  
(end-fire, 55-65 GHz, gain 12 dBi)  
A. Guraliuc, N. Chahat, C. Leduc, M. Zhadobov et al. Electronics, 60(12), 2012.

**Textile antennas**  
(200  $\mu\text{m}$  cotton;  $\epsilon_r = 1.5$ ;  $\tan\delta = 0.016$ )

57-65 GHz, gain 8 dBi  
N. Chahat, M. Zhadobov et al. IEEE AP, 61(4), 2013.

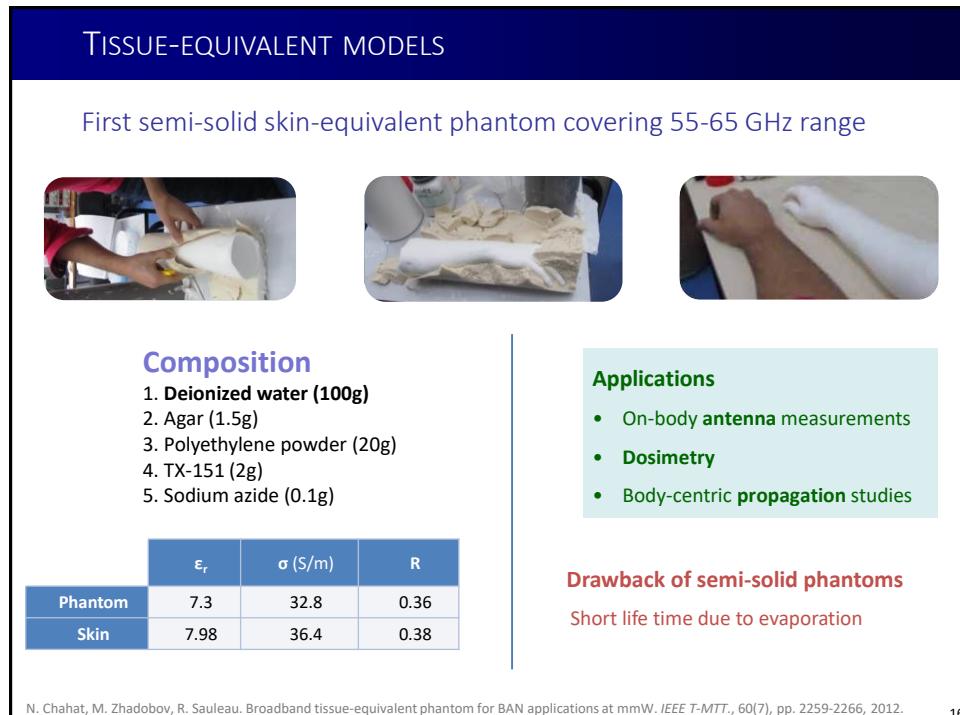
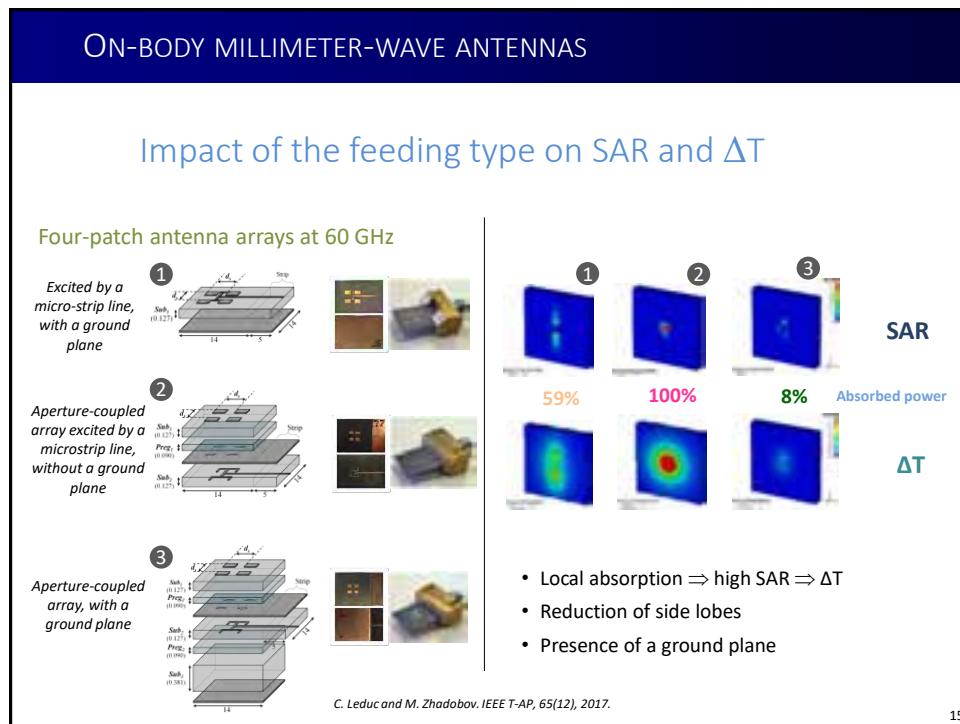
55-67 GHz, gain 11.9 dBi  
N. Chahat, M. Zhadobov et al. IEEE AWPL, 11, 2012.

Textile antenna fabrication using laser ablations (ProtoLaser S)

Fabrication precision  
 $< 10 \mu\text{m}$

0.66 mm

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## SOLID SKIN-EQUIVALENT PHANTOM AT 60 GHz



**Fabrication**

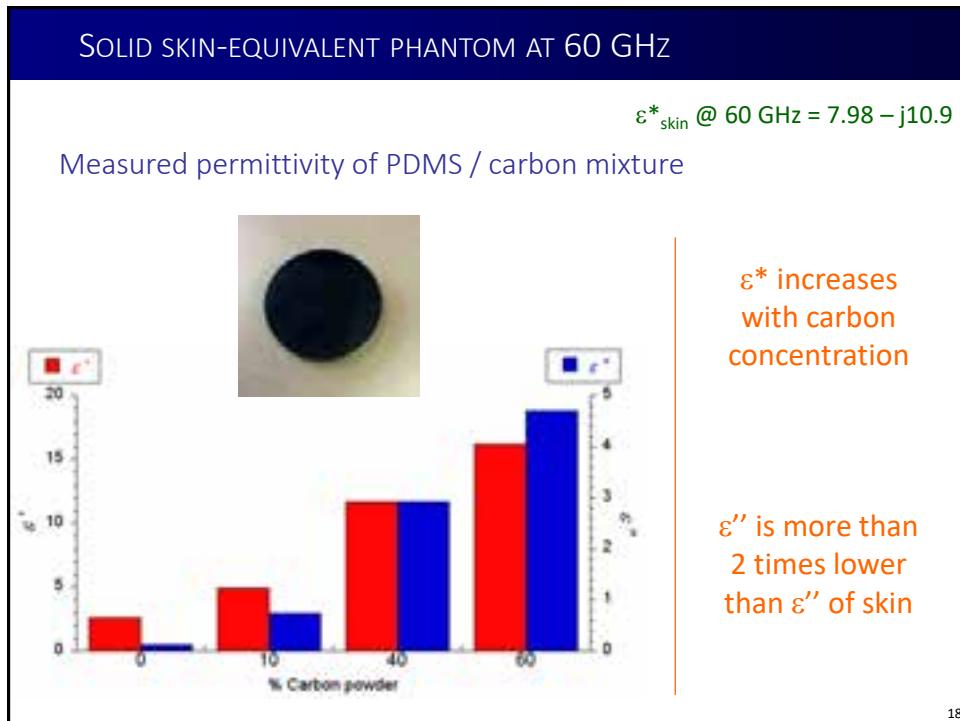
1. PDMS - 10 (silicone gel) : 1 (curing agent)
2. Degas PDMS
3. Mix PDMS with Carbon powder
4. Degas dielectric composite (carbon-PDMS)
5. Dry dielectric composite
6. Deposit metallic backing

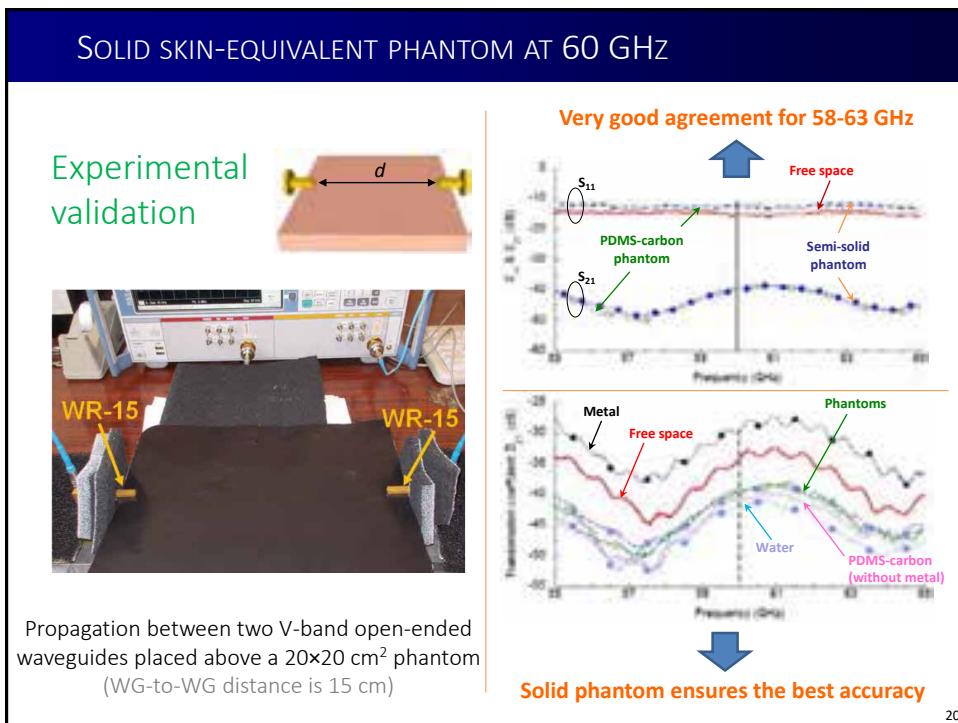
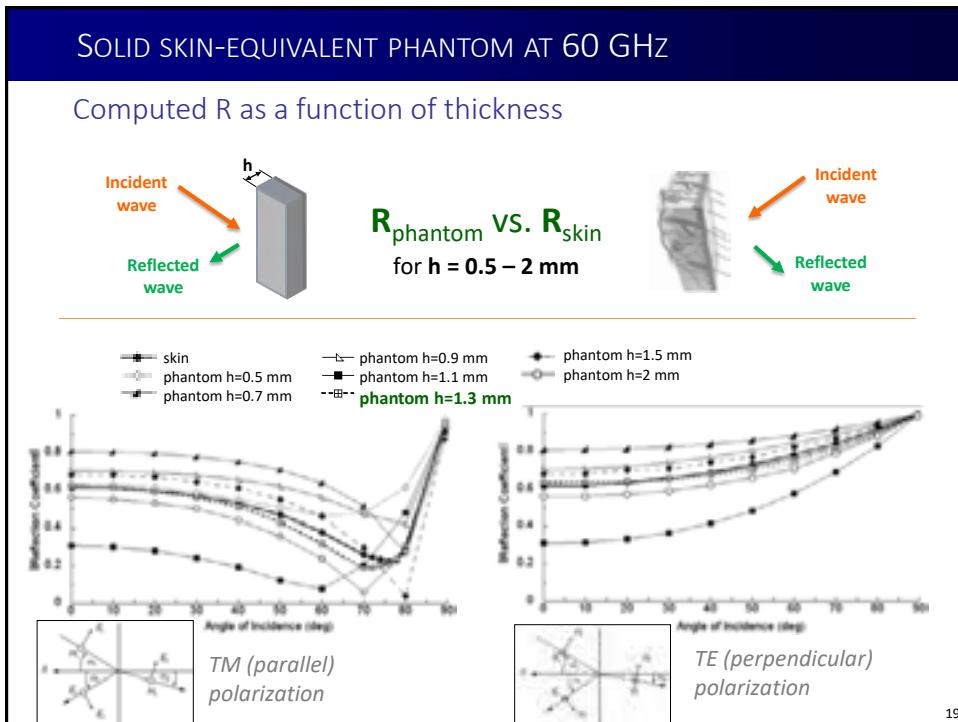
**Composition**



- PDMS
- Carbon powder
- Metallic backing

A. R. Guraliuc, M. Zhadobov, O. De Sagazan, R. Sauvageau IEEE  
*Transactions on Microwave Theory and Techniques*, 62(6), 2014.  
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## DOSIMETRY METHOD BASED ON IR THERMOMETRY

**Determining  $T(r,t) \Rightarrow SAR(r) \Rightarrow IPD_{eq}(r)$  in the near field**

**Antenna on a phantom**

**Absorption in the body**

**SAR and IPD distributions**

**Simulations**

**Measurements**

**Compact anechoic chamber**  
(measurement using a high-resolution IR camera)

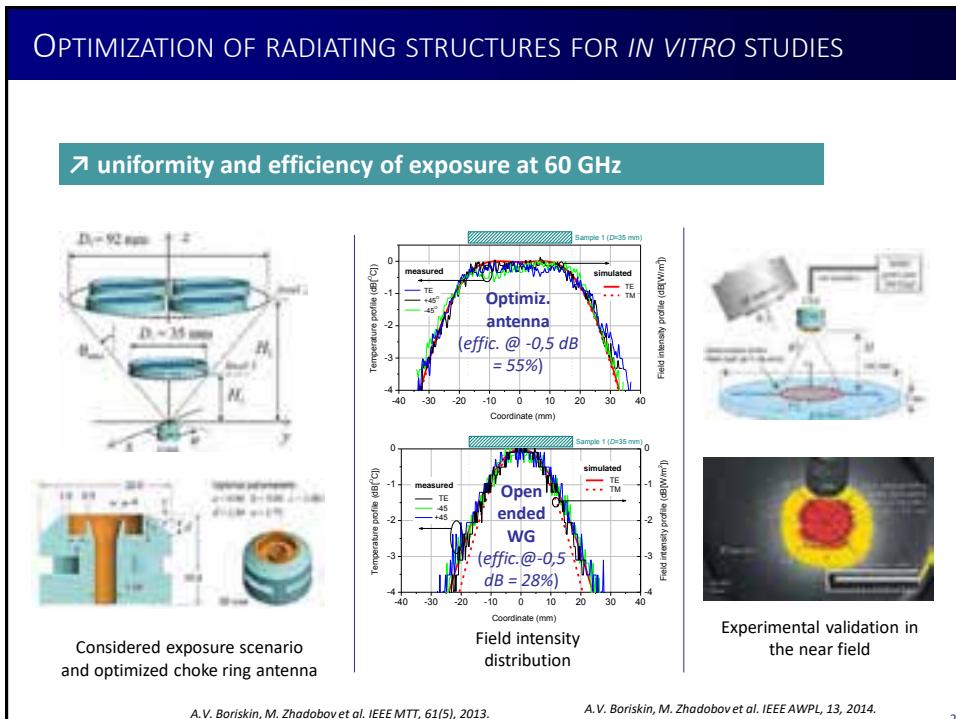
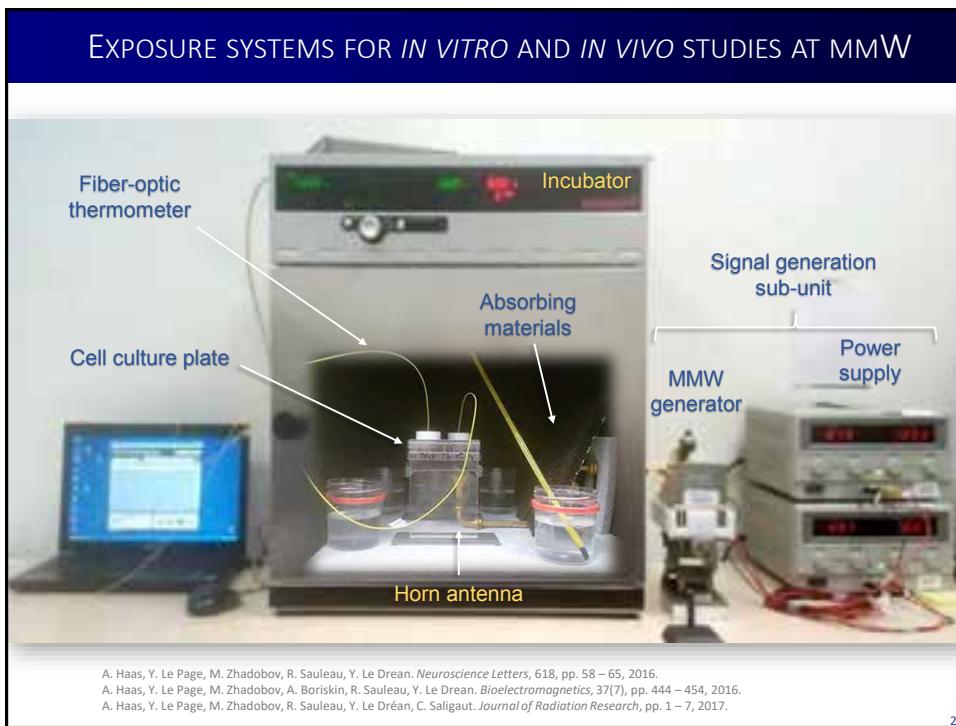
N. Chahat, M. Zhadobov et al. IEEE AP, 60(12), 2012.

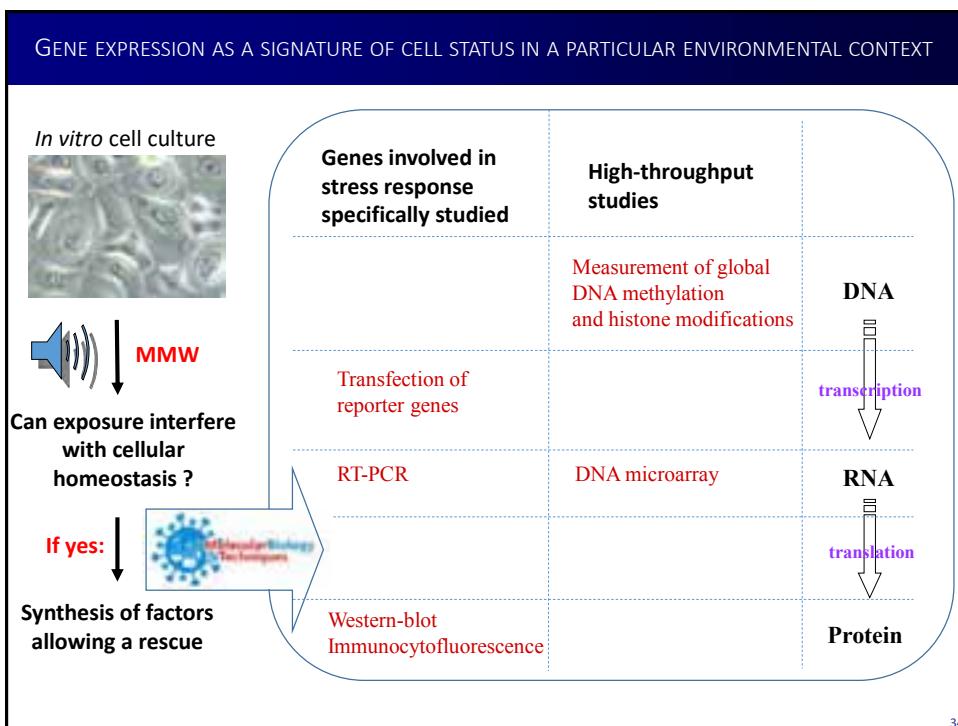
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**M. Zhadobov, C. Leduc, A. Guraliuc, N. Chahat, R. Sauvage. Antenna / human body interactions in the 60 GHz band: state of knowledge and recent advances, pp. 97-142, 2016.**

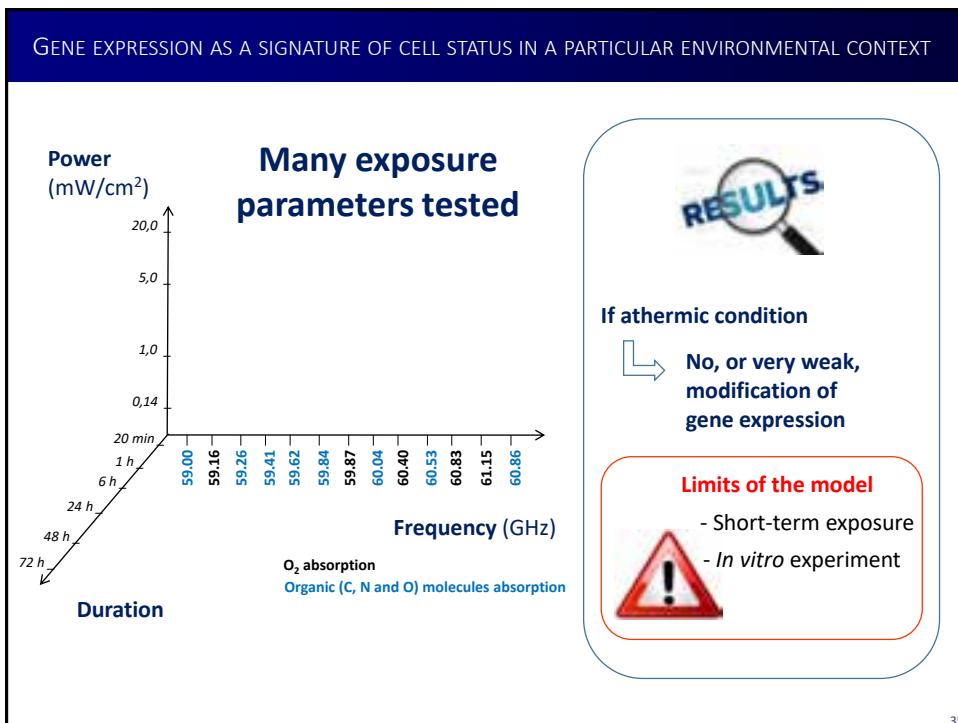
**N. Chahat, A. Tang, A. Guraliuc, M. Zhadobov, R. Sauvage, G. Valerio. Antennas, phantoms, and body-centric propagation at millimetre waves, 2016.**

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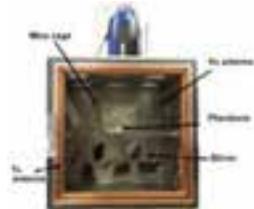
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## FIRST REVERBERATION CHAMBER AT MMW

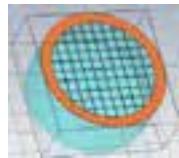
### Application to *in vivo* studies (isotropic exposure)



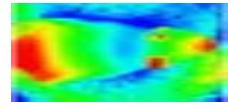
Reverberation chamber for  
*in vivo* exposure at mmW



Internal view of the chamber



Interface for dosimetry  
(transparent at IR and  
opaque at mmW)



Example of results obtained  
using IR camera and skin-  
equivalent phantom

A. K. Fall, M. Zhadobov et al. Submitted to Bioelectromagnetics Journal (2019).

A. K. Fall, P. Besnier, C. Lemoine, M. Zhadobov et al. IEEE EMC, 75(1), 2015.

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