Overcoming Regulatory Challenges for Efficient Laboratory Evaluation of Wireless Devices TCB Workshop, Oct 2024

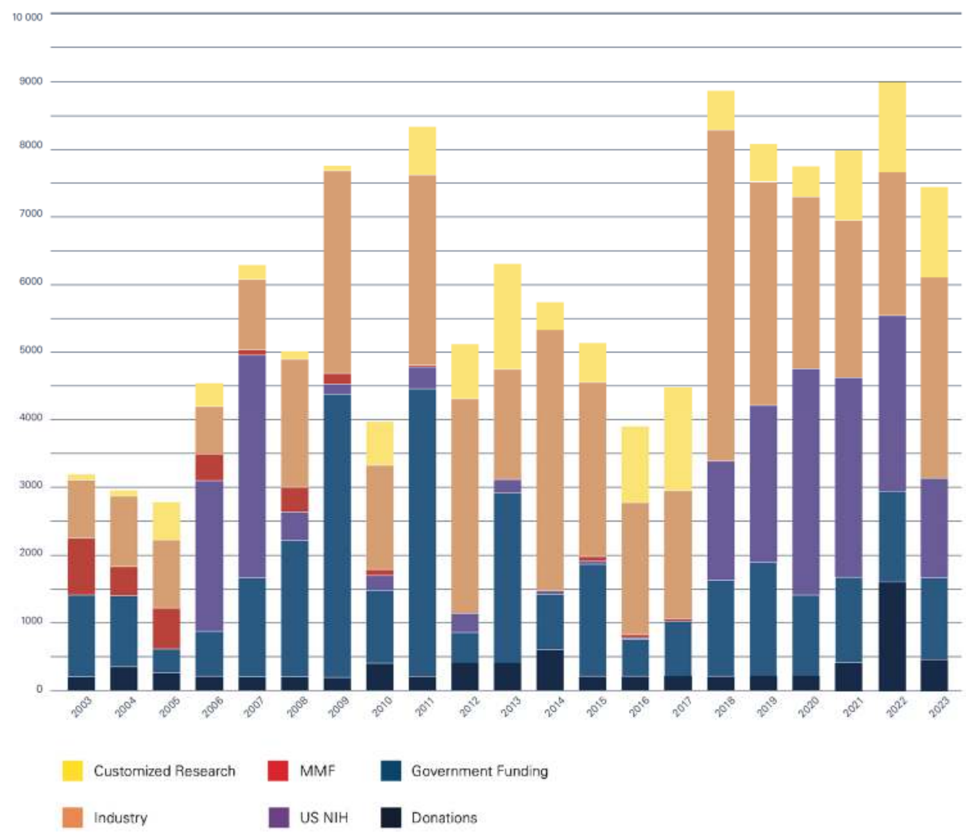
Niels Kuster, ETH Zurich & IT'IS Foundation

Outline

- Conflict of Interest
- Discussion of Scientific Challenges
  - 1: assessment of IPD in the reactive near-field
  - 2: surface conformal IPD
  - 3: assessment of APD
  - 4: comprehensive but agnostic validation systems
  - 5: evaluation of exposure mitigation features (TA, spatial diversity, proximity, motion, etc.)
- Status Summary of Scientific Challenges

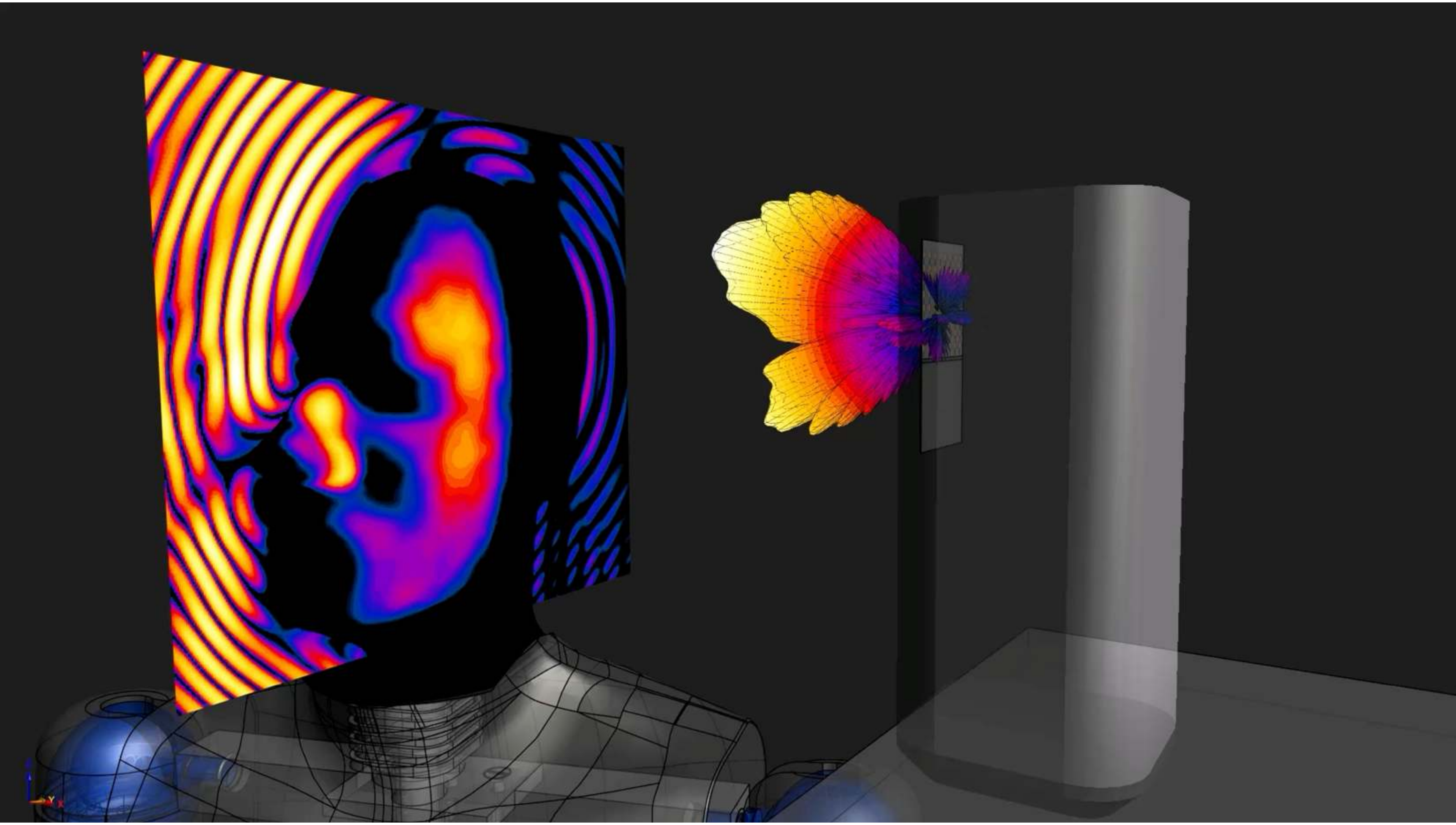
Conflict of Interest

- founder & director of the IT'IS Foundation
- founder, direct & indirect shareholder, president of NFT, SPEAG, ZMT, TI Solutions AG
- IT'IS received funds from various wireless and medical device companies
- collaborations with regulators, e.g., FCC, FDA, NIST, NICT, NIM, CTTL, RRA, etc.
- member of TC106/62209, IEC TC106/62253, ICES TC43/SC2, ICES TC28/SC1, SC2, SC3, SC4, CTIA ERP, ANSI 63.19, ITU SG1, WP-1B, IEC/62/MT40, ISO TS10974 JWG AMID, V&V40 (ASME), MDIC



Recap of
Science of mmWave Absorption

presented in detail last year



Bioelectromagnetics 41:348–359 (2020)

Limitations of Incident Power Density as a Proxy for Induced Electromagnetic Fields

Andreas Christ,[1]* **Theodoros Samaras**,[2] **Esra Neufeld**,[1] **and Niels Kuster**[1,3]

[1]*IT'IS Foundation, Zürich, Switzerland*
[2]*Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece*
[3]*Swiss Federal Institute of Technology, Zürich, Switzerland*

The most recent safety guidelines define basic restrictions for electromagnetic field exposure at frequencies more than 6 GHz in terms of spatial- and time-averaged transmitted power density inside the body. To enable easy-to-perform evaluations in situ, the reference levels for the incident power density were derived. In this study, we examined whether compliance with the reference levels always ensures compliance with basic restrictions. This was evaluated at several distances from different antennas (dipole, loop, slot, patch, and helix). Three power density definitions based on integration of the perpendicular real part of the Poynting vector, the real part of its three vector components, and its modulus were compared for averaging areas of $\lambda^2/16$, 4 cm^2 (below 30 GHz) and 1 cm^2 (30 GHz). In the reactive near-field ($d < \lambda/(2\pi)$), the transmitted power density can be underestimated if an antenna operates at the free space exposure limit. This underestimation may exceed 6 dB (4.0 times) and depends on the field source due to different coupling mechanisms. It is frequency-dependent for fixed-size averaging areas (4 and 1 cm^2). At larger distances, transmission can be larger than the theoretical plane-wave transmission coefficient due to backscattering between the body and field source. Using the modulus of the incident Poynting vector yields the smallest underestimation. Bioelectromagnetics. 2020;41:348-359. © 2020 Bioelectromagnetics Society.

Keywords: millimeter wave exposure; incident power density; basic restrictions and reference levels; near-field coupling; compliance with exposure limits

Current Standards: IEC/IEEE 63195 Series of Standards

- IEC/IEEE 63195-2 definitions include surface-normal real components sPDn+, all real components sPDtot+ or the modulus of the Poynting vector sPDmod+

$$sPD(r_0)=\frac{1}{\hat{A}(r_0)}\int_{A(r_0)}\Re\{\boldsymbol{S}(\boldsymbol{r})\}\cdot\boldsymbol{n}_A(\boldsymbol{r})\cdot\Theta\left[\Re\{\boldsymbol{S}(\boldsymbol{r})\}\cdot\boldsymbol{n}_A(\boldsymbol{r})\right]d\hat{A}(\boldsymbol{r})$$

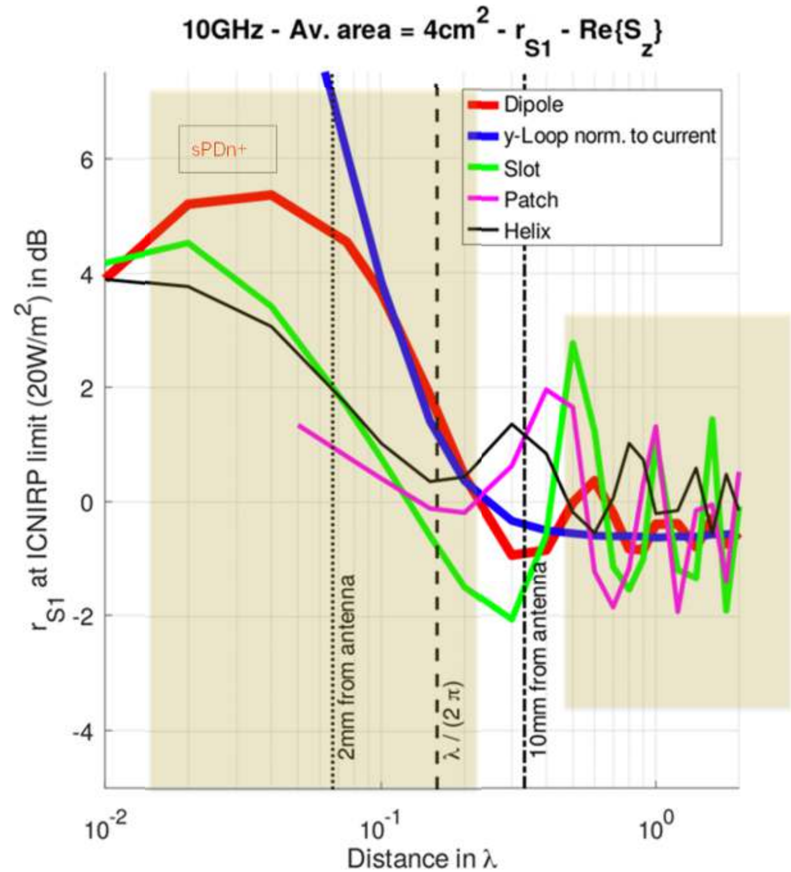
$$sPD(r_0)=\frac{1}{\hat{A}(r_0)}\int_{A(r_0)}\left\|\Re\{\boldsymbol{S}(\boldsymbol{r})\}\right\|\cdot\Xi\left\{\cos^{-1}\left[\boldsymbol{n}_R(\boldsymbol{r})\cdot\boldsymbol{n}_A(\boldsymbol{r})\right]\right\}d\hat{A}(\boldsymbol{r})$$

$$sPD(r_0)=\frac{1}{\hat{A}(r_0)}\int_{A(r_0)}\left[\left(\left\|\Re\{\boldsymbol{S}(\boldsymbol{r})\}\right\|\cdot\Xi\left\{\cos^{-1}\left[\boldsymbol{n}_R(\boldsymbol{r})\cdot\boldsymbol{n}_A(\boldsymbol{r})\right]\right\}\right)^2+\left(\left\|\Im\{\boldsymbol{S}(\boldsymbol{r})\}\right\|\right)^2\right]^{1/2}d\hat{A}(\boldsymbol{r})$$

- uncertainties arise due to evaluation of the incident field in free-space, i.e., due to the absence of the dielectric loading of the DUT by the body of the exposed subject

Normal Component is Poor Proxy of Exposure

- ratio of the transmitted to the incident psPD in homogeneous skin vs. free space calculated
- confinement of EM energy between the antenna and the exposed body leads to increased or lower exposure



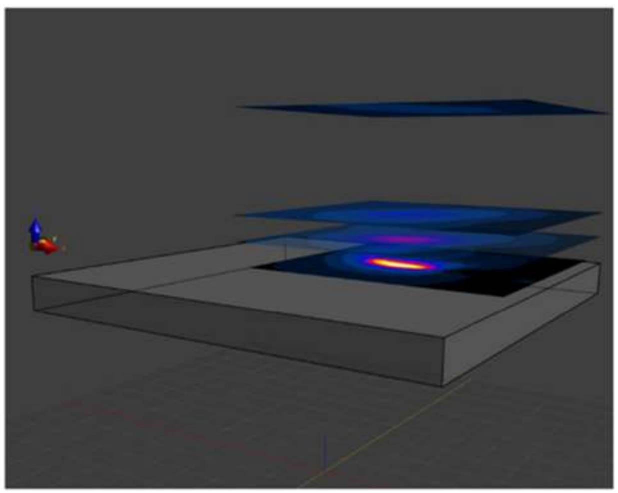
ITIS FOUNDATION

Challenge 1:
IPD in the Reactive Near-Field

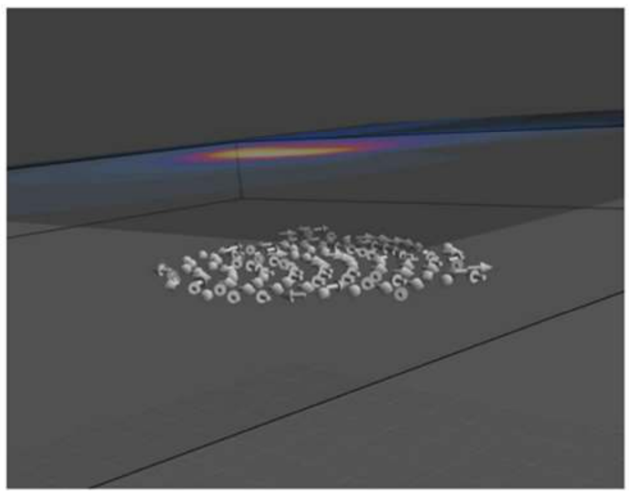
Equivalent Source Reconstruction (ESR) Algorithm

- Implementation V3.x
  - based on distinct dipole sources
  - dipoles distributed in DUT based on field distribution and noise level
  - implemented in Python.
- Implementation V4.x
  - based on continuous dipole distribution
  - represented in a FEM mesh
  - refines mesh from corse parametrisation
  - implemented fully in C++

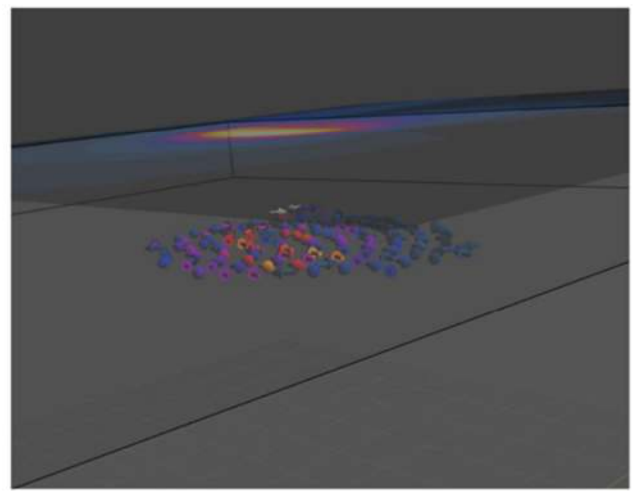
Measured E-field amplitudes ($|\boldsymbol{E}_{pol}|$)



Generate a distribution of point-sources



Optimize (complex) amplitudes



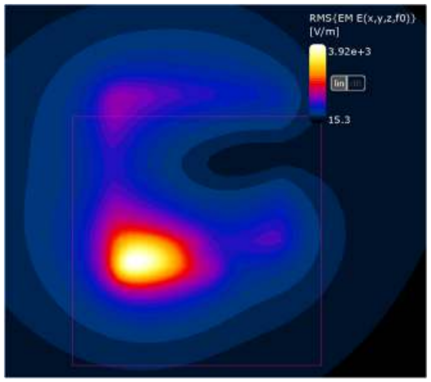
IT'IS FOUNDATION

ESR V4.0

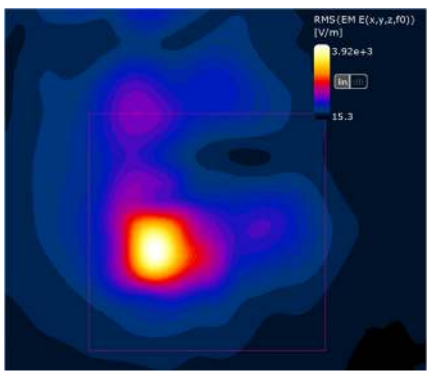
- Continuous dipole distribution represented by FEM mesh
- Starts with a corse parametrisation (corse and regular FEM mesh)
- Iterative approach:
  - Optimise parameters of mesh (same optimiser as ESR V1.x)
  - Refine FEM mesh (refinement techniques: Kelly, etc)
  - Use refined FEM mesh parameters as starting point for next optimisation
- No penalty in optimiser-cost-function for points below noise-threshold
- Solution can be propagated anywhere the FEM mesh surface.

IFA Antenna 6 GHz (2 min vs > 15 min)

2 mm from DUT



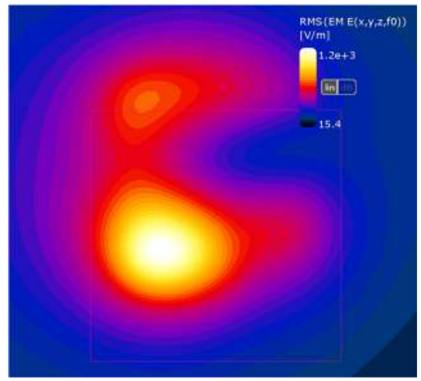
Target
psPDn+: 934 W/m2/W



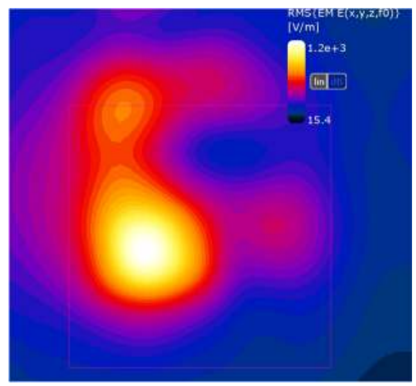
Measured
psPDn+: 1053.8 W/m2/W

Difference: 0.50 dB

5 mm from DUT



Target
psPDn+: 672.5 W/m2/W



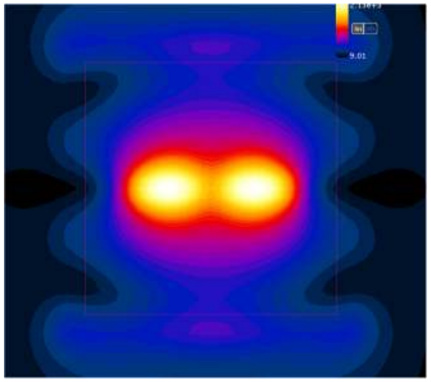
Measured
psPDn+: 599.1 W/m2/W

Difference: -0.50 dB

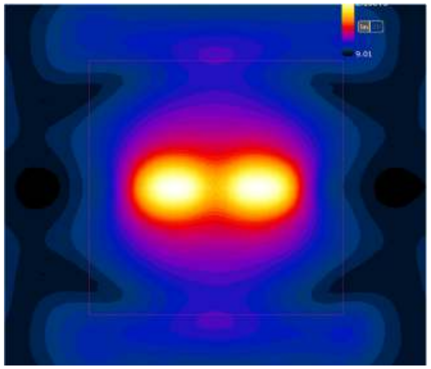
IT'IS FOUNDATION

Slot Antenna 10GHz (4:25min vs > 15min)

2 mm from DUT



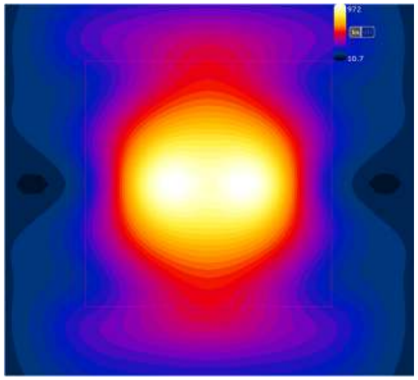
Target
psPDn+: 1028 W/m2/W



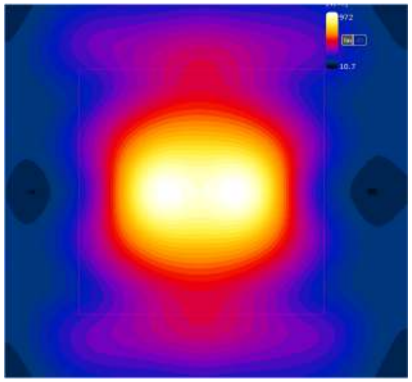
Measured
psPDn+: 981 W/m2/W

Difference: -0.20 dB

5 mm from DUT



Target
psPDn+: 762.2 W/m2/W



Measured
psPDn+: 543.2 W/m2

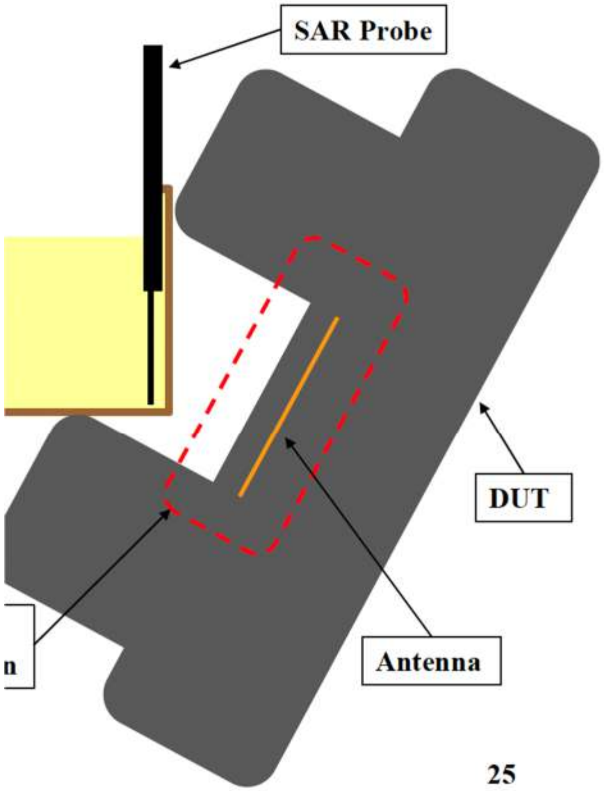
Difference: -1.4 dB

IT'IS FOUNDATION

Challenge 2:
Device Conformal SAR, IPD

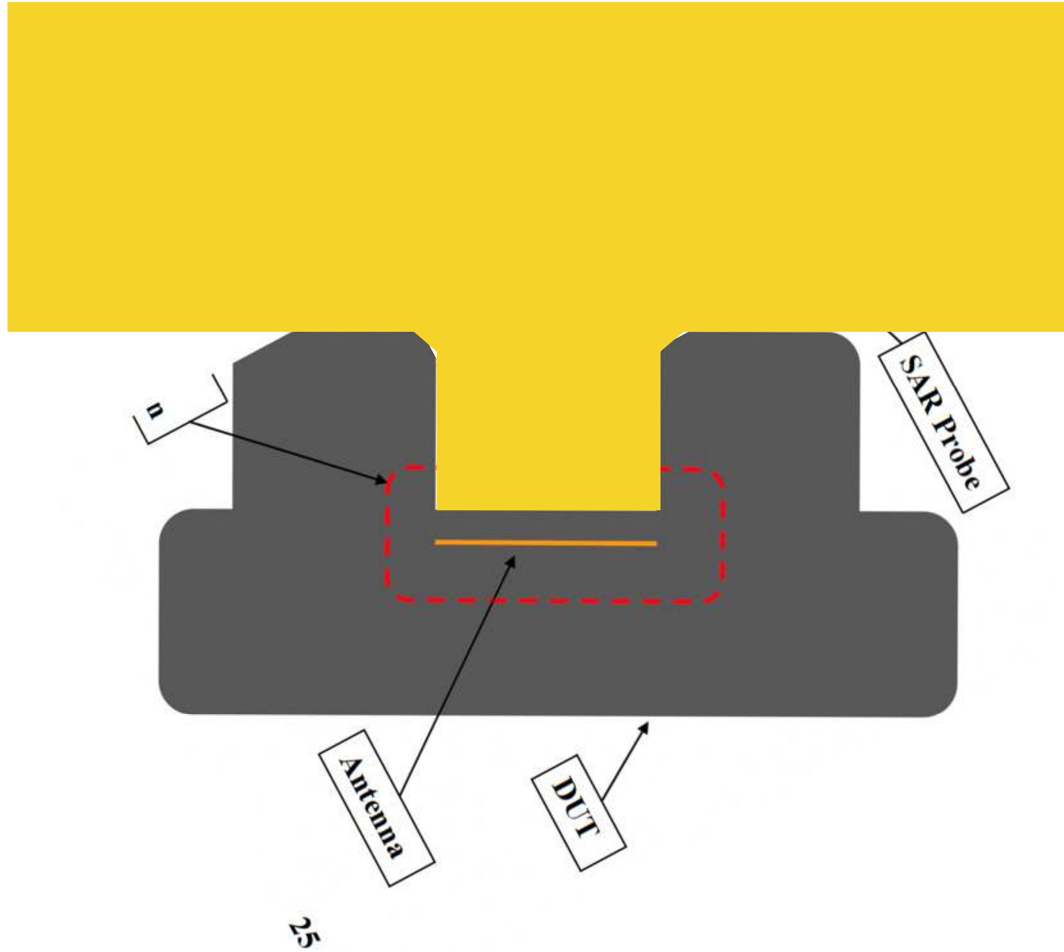
Challenge 2: Description

- SAR phantom does not conform with device form factor



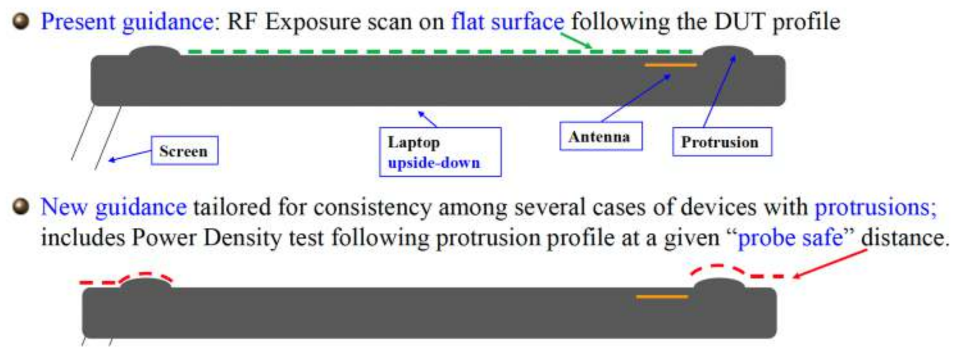
Specific Phantoms

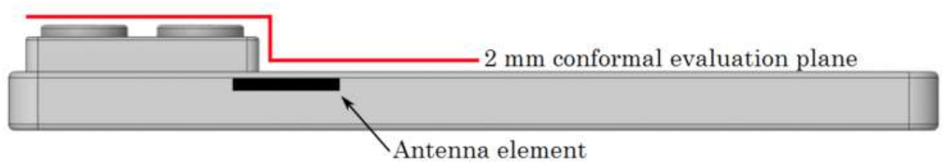
- IEC/IEEE 62209-1528
- validation procedure is also defined

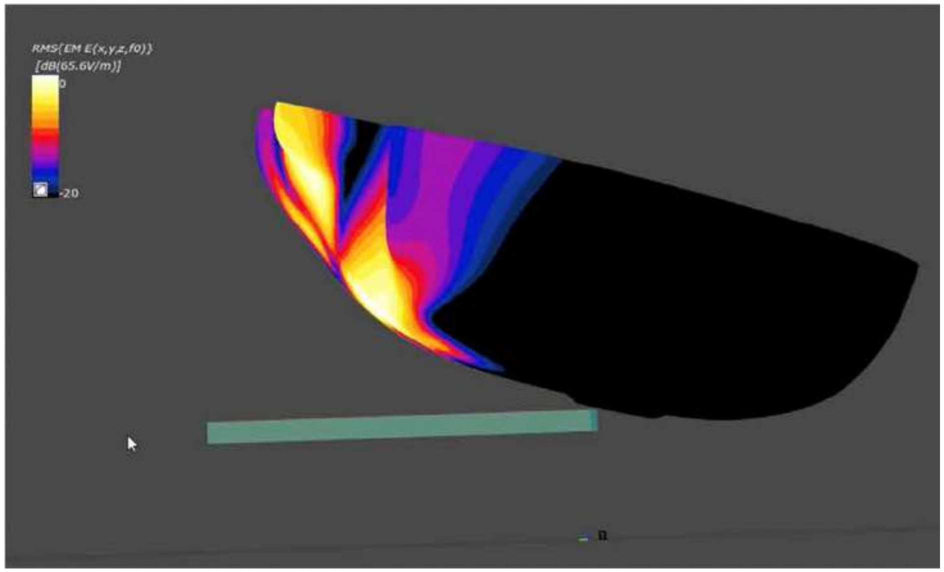


Challenge 2: Description

- evaluation of IPD in 2 mm distance from the device
- evaluation on the location of the phantom
- device surface is generally not a plane, e.g., camera module
- none-flat phantoms, e.g., SAM phantom

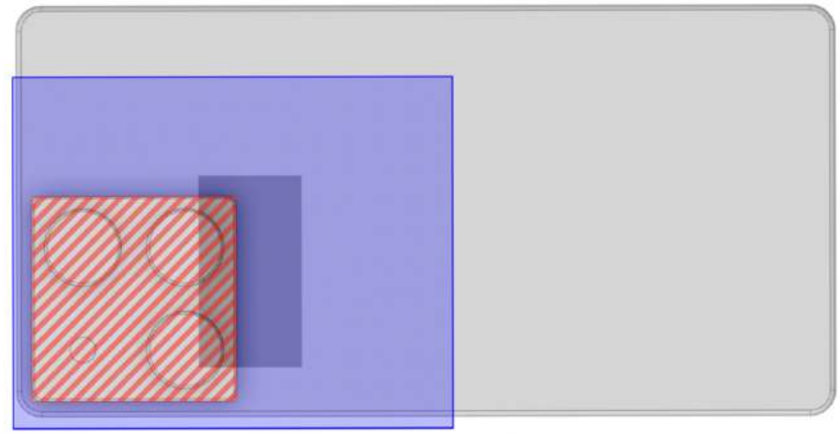


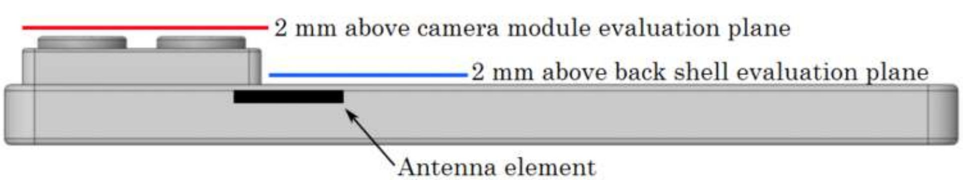


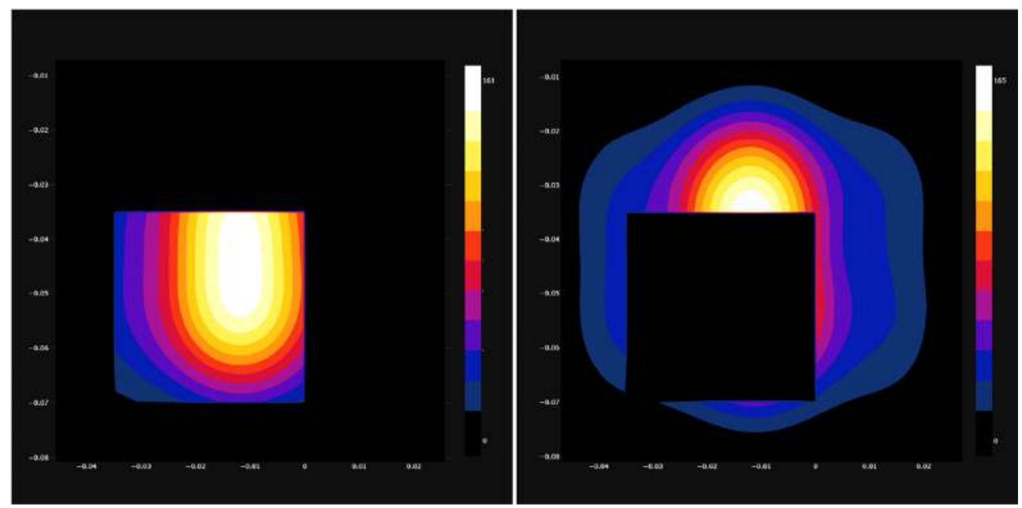


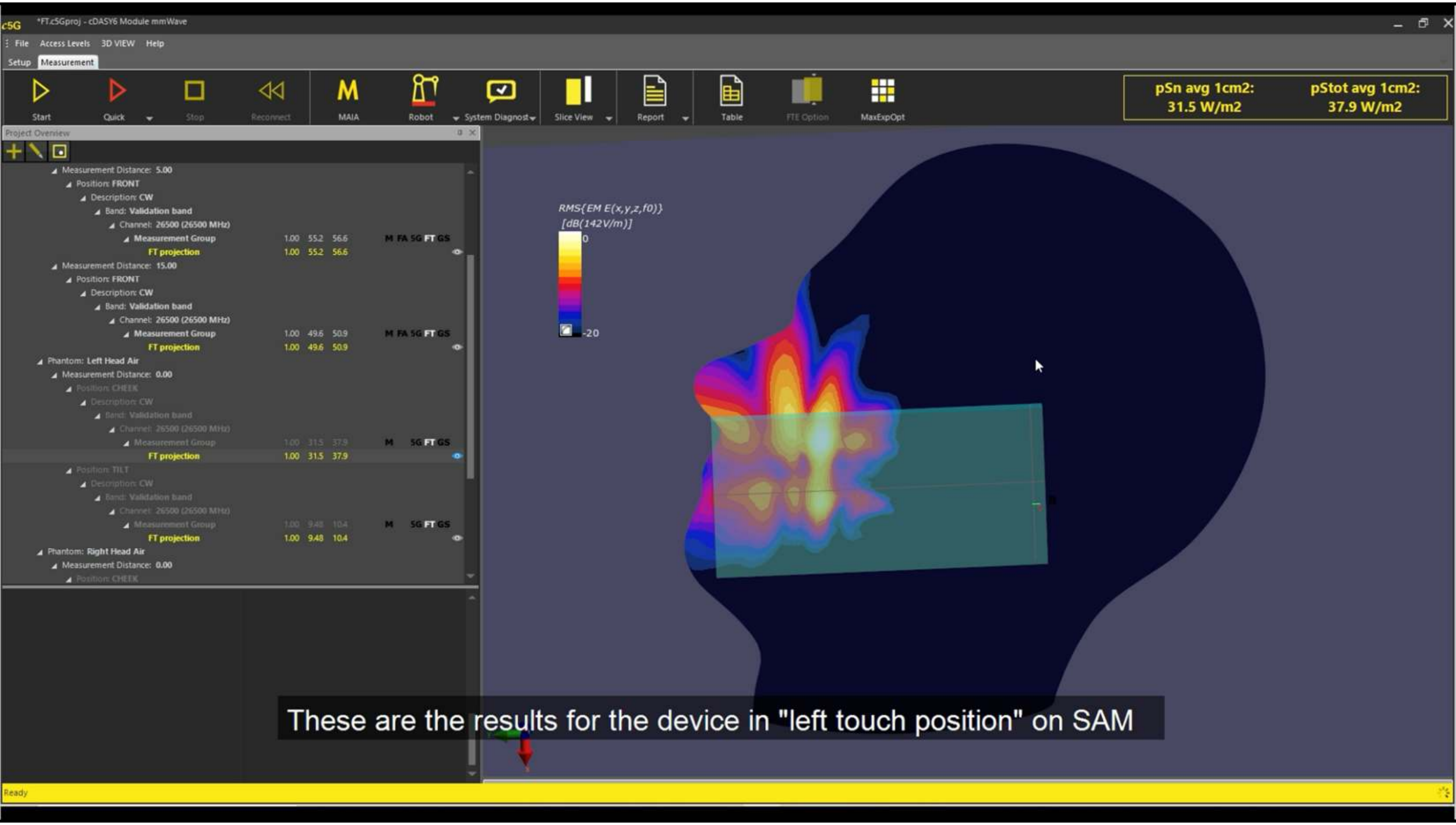
Interim Solution

- measurement on planes above the camera module
- ESR in the phone
- using advanced forward propagation
- evaluate IPD on each plane



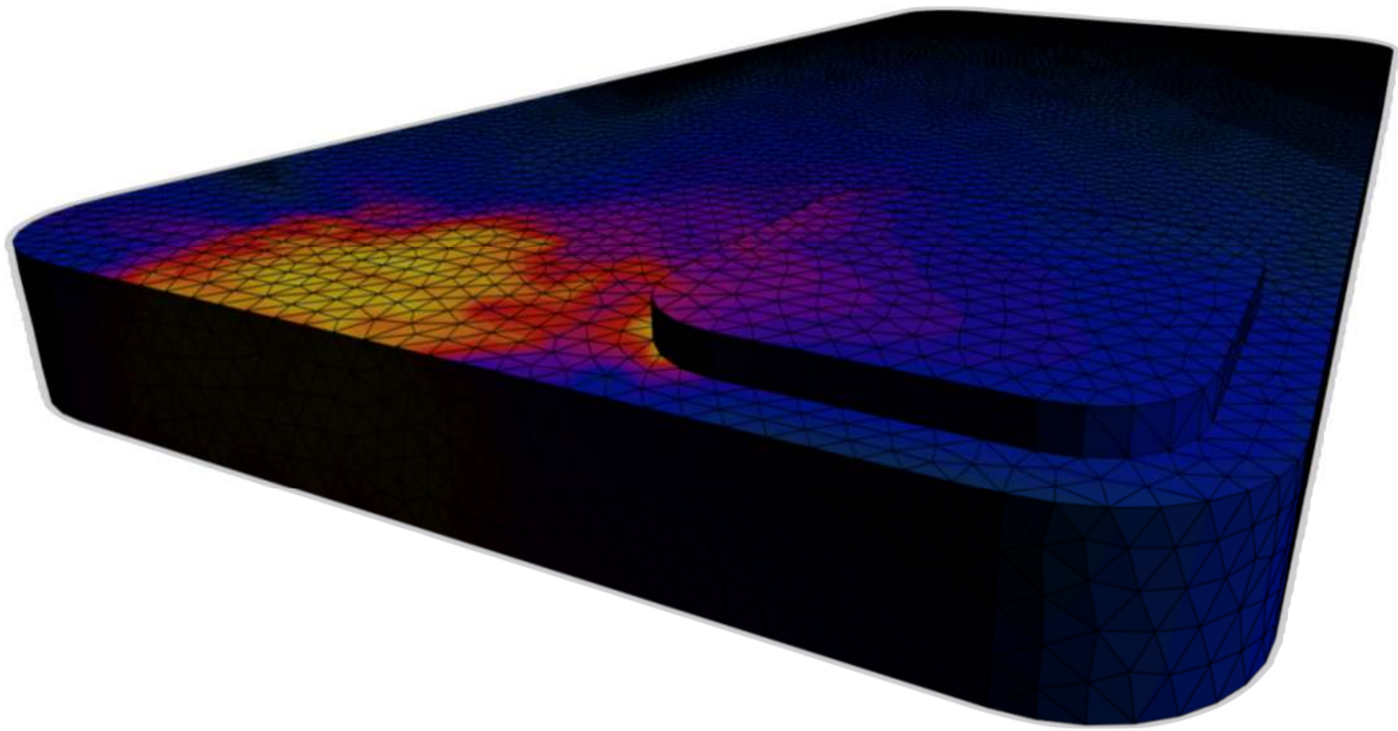





*FT.c5Gproj - cDASY6 Module mmWave
File
Access Levels
3D VIEW
Help
Setup
Measurement
Start
Quick
Stop
Reconnect
MAIA
Robot
System Diagnost
Slice View
Report
Table
FTE Option
MaxExpOpt
pSn avg 1cm2: 31.5 W/m2
pStot avg 1cm2: 37.9 W/m2
Project Overview
Measurement Distance: 5.00
Position: FRONT
Description: CW
Band: Validation band
Channel: 26500 (26500 MHz)
Measurement Group 1.00 55.2 56.6 M FA 5G FT GS
FT projection 1.00 55.2 56.6
Measurement Distance: 15.00
Position: FRONT
Description: CW
Band: Validation band
Channel: 26500 (26500 MHz)
Measurement Group 1.00 49.6 50.9 M FA 5G FT GS
FT projection 1.00 49.6 50.9
Phantom: Left Head Air
Measurement Distance: 0.00
Position: CHEEK
Description: CW
Band: Validation band
Channel: 26500 (26500 MHz)
Measurement Group 1.00 31.5 37.9 M 5G FT GS
FT projection 1.00 31.5 37.9
Position: TILT
Description: CW
Band: Validation band
Channel: 26500 (26500 MHz)
Measurement Group 1.00 9.48 10.4 M 5G FT GS
FT projection 1.00 9.48 10.4
Phantom: Right Head Air
Measurement Distance: 0.00
Position: CHEEK
RMS{EM E(x,y,z,f0)}
[dB(142V/m)]
0
-20
These are the results for the device in "left touch position" on SAM
Ready

Final Solution

- import CAD data
- evaluate IPD on the conformal surface



Challenge 3:
Assessment of APD

Challenge 3: Recap of Science of mmWave Absorption

presented in detail last year

Basic Restrictions > 6 GHz

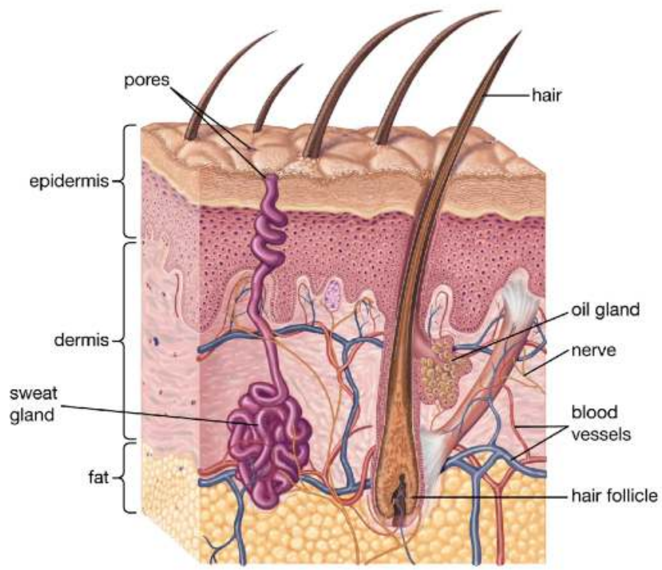
Standard or Region	Occup. psAPD limit (W/m^2)	Gen. Public psAPD limit (W/m^2)	Occup. & Gen. Public A_{avg} (cm^2)	f_G (GHz)	t_{avg} (min.)
ICNIRP [2], IEEE [1]	100	20	4	6 – 300	6
ICNIRP, IEEE*	200	40	1	30 – 300	6
Can. [8], Aus. [14], Jap. [15]	100	20	4	6 – 300	6
Can., Aus., Jap.	200	40	1	30 – 300	6
USA, EU, India, China	–	–	–	–	–

Notes to table:

- f_G, A_{avg}, and t_{avg} are the frequency in GHz, the averaging area in cm^2 and the averaging time in minutes, respectively.
- The averaging area A_{avg} is in the shape of a square.
- * For IEEE, the 1 cm^2 psAPD limit applies only if the 3 dB contours around the peak are less than 1 cm^2 in size.
- Both the 4 cm^2 and 1 cm^2 psAPD limits apply above 30 GHz.
- for IEEE and ICNIRP, the whole body SAR limit of 0.08 W/kg (gen. public) or 0.4 W/kg (occup.) must be met at frequencies from 6 GHz to 300 GHz.
- For Canada, both the psAPD limits and psSAR limits (e.g., 1.6 W/kg for 1-gram average, for general public exposure at the head or torso) must be met if the frequency range of the communication system crosses 6 GHz (i.e., it has both a minimum frequency below 6 GHz and a maximum frequency above 6 GHz).
- EU does not presently have psAPD limits but is expected to adopt ICNIRP limits in the near future.
- USA does not presently have psAPD limits. However, it extends SAR measurements to frequencies up to 8.5 GHz including an IPD measurement at the configuration with the highest psSAR [16].

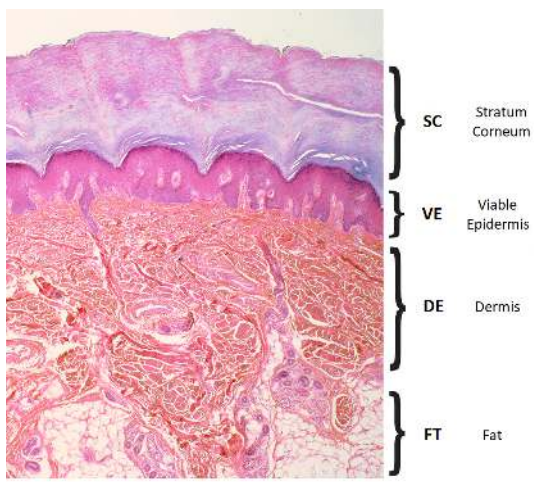
Skin Anatomy

Schematic diagram



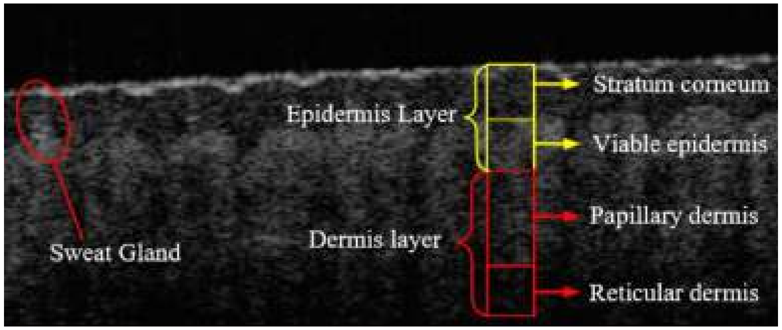
H&E-stained image

(Thick skin, fingertip)



OCT-scan image

(Thick skin, fingertip)



Absorbed Power Density

- > 6 GHz, EM energy is more localized in superficial tissues
  - SAR in 10-gram mass does not correlate well with temperature rise
  - APD is a better representation of temperature rise in superficial tissues
- definition of APD
  - energy flow per unit area directly under the body surface
  - based on Poynting vector

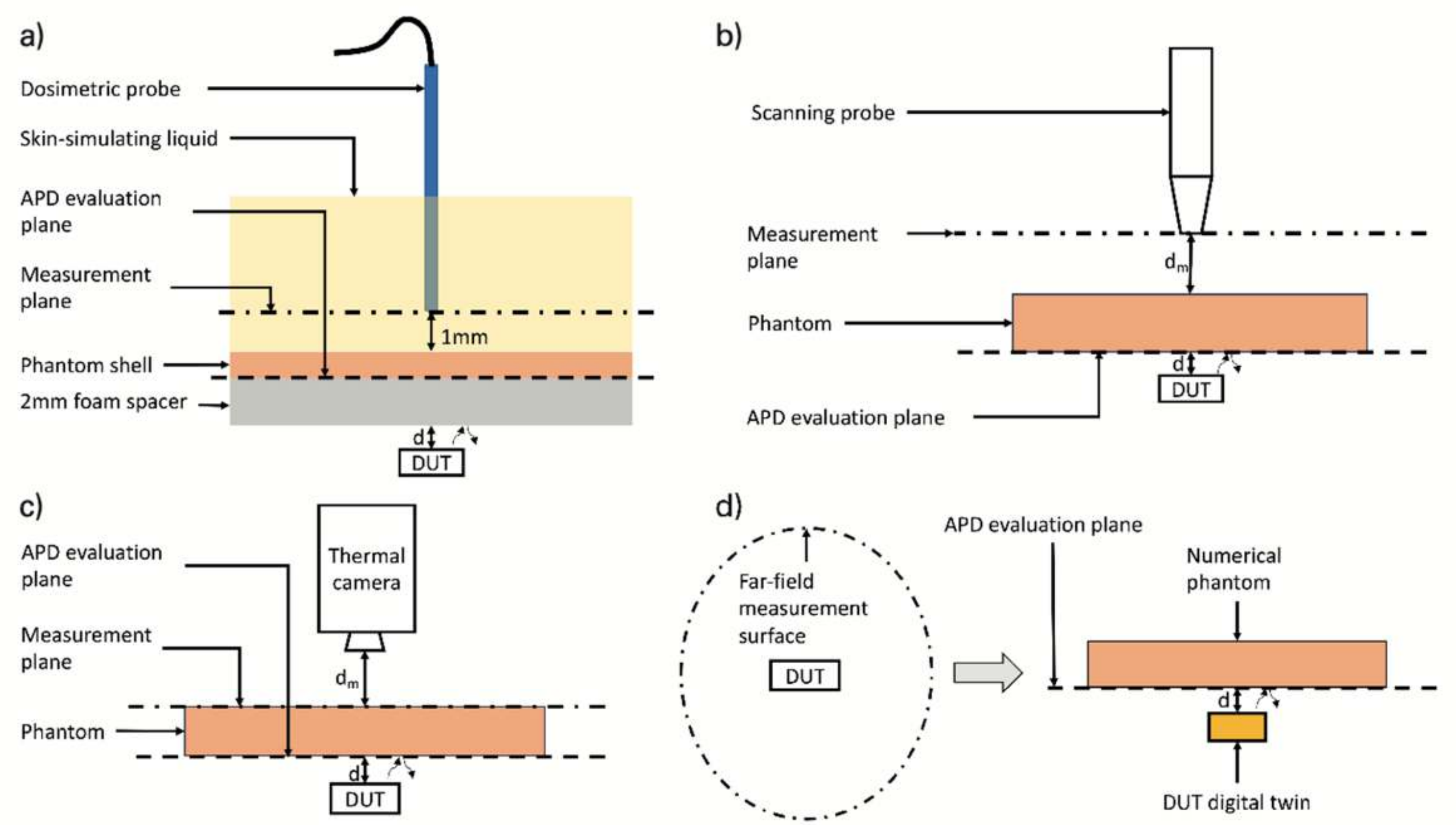
$$S_{ab} = \iint_A \mathrm{Re}[\mathbf{S}] \cdot d\mathbf{s}/A = \iint_A \mathrm{Re}[\mathbf{E} \times \mathbf{H}^*] \cdot d\mathbf{s}/A$$

Research Projects to Solve Challenge 3

- partners
  - ETH Zurich
  - IT'IS Foundation
  - SPEAG
- Funding
  - Innosuisse
  - SEAWave
- objectives
  - development of the basic science (appropriate skin model)
  - dosimetric scanning techniques (10 – 45 GHz)
  - fast techniques (10 – 300 GHz)

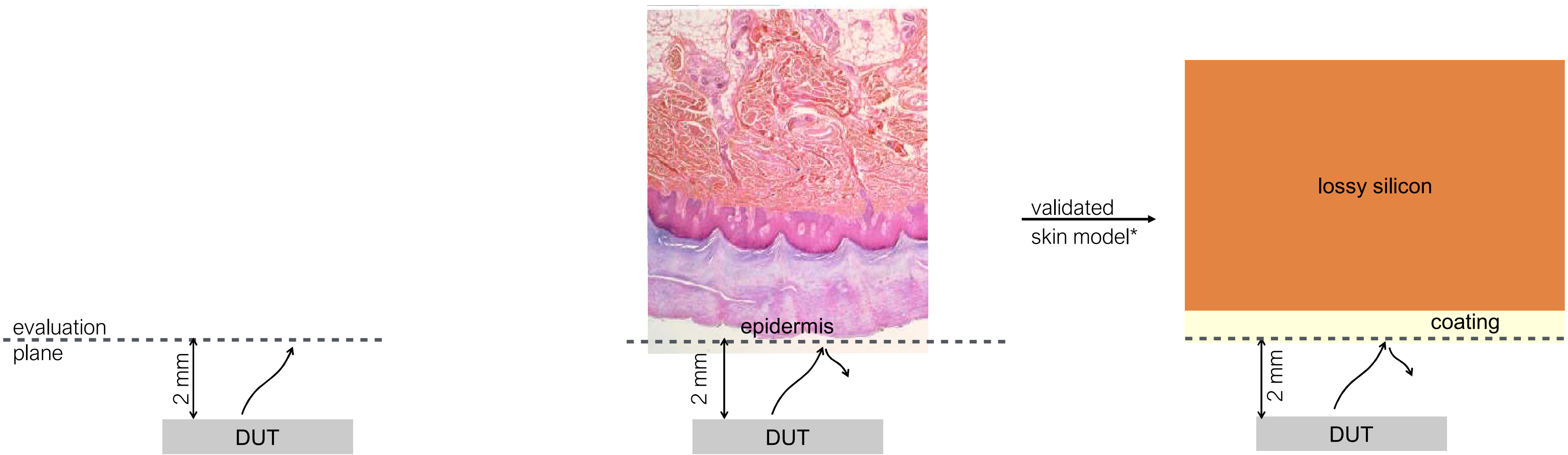
IT'IS FOUNDATION

Proposed APD Assessment Methods



Challenge 3: Phantom for Skin

Sound Representation of the Skin in APD Assessment



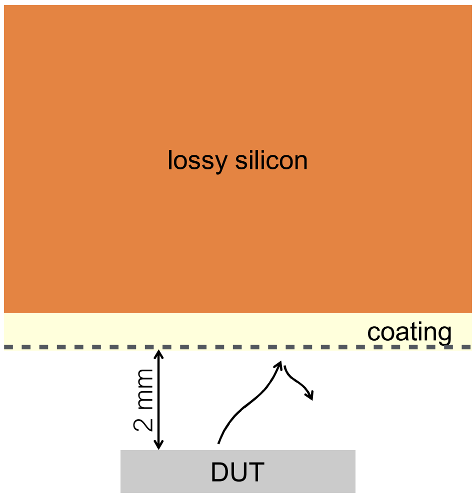
*Christ A, Aeschbacher A, Rouholahnejad F, Samaras T, Tarigan B, Kuster N. Reflection properties of the human skin from 40 to 110 GHz: a confirmation study. Bioelectromagnetics. 2021 Oct;42(7):562-74.

IT'IS FOUNDATION

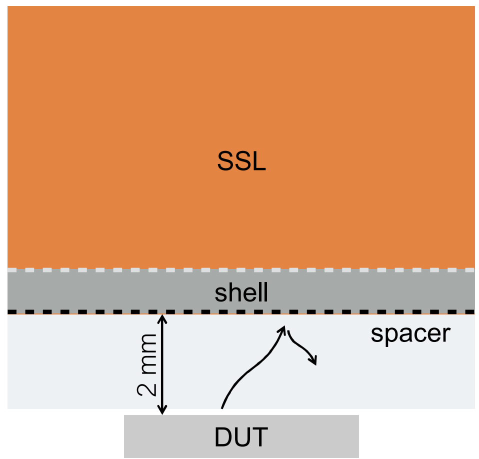
FR2 APD Phantom

validated skin target model

mmW silicon phantom (CTIA)



PHA-30G Phantom 24 – 30 GHz



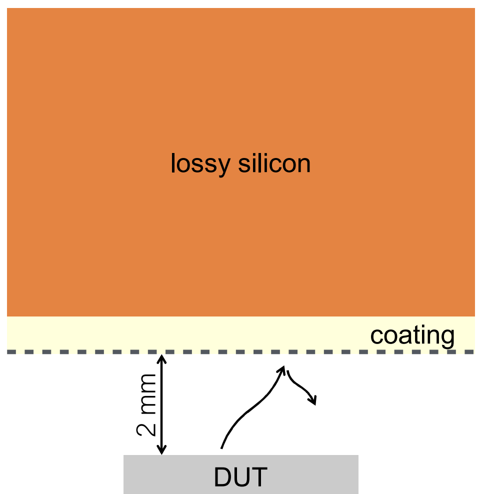
– δ >5 mm (@30 GHz)

IT'IS FOUNDATION

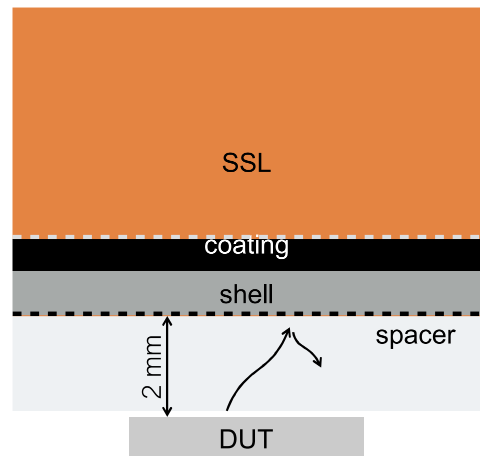
FR3 APD Phantom

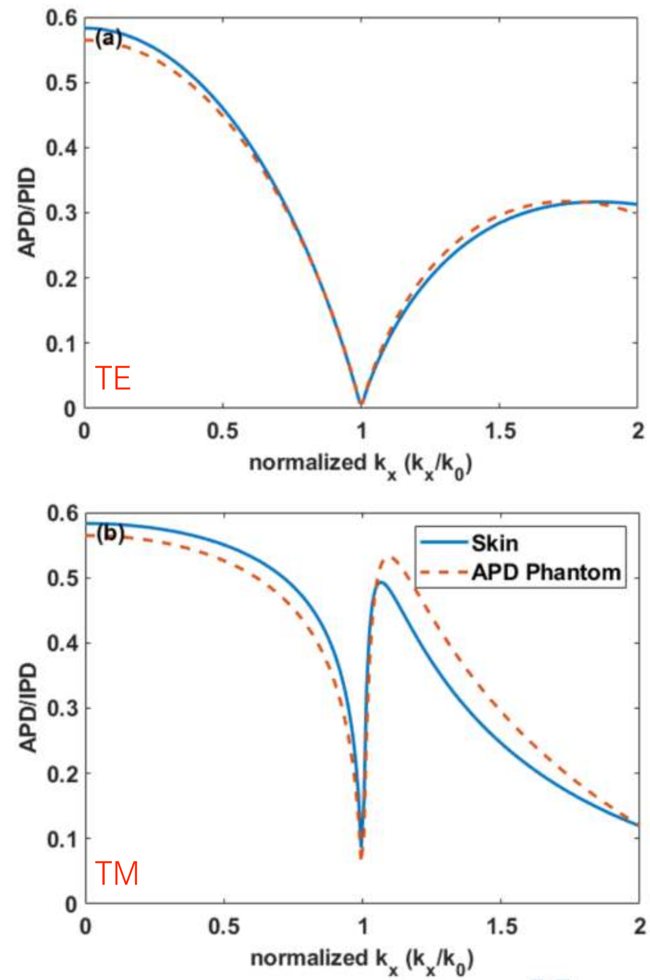
validated skin target model

mmW silicon phantom (CTIA)

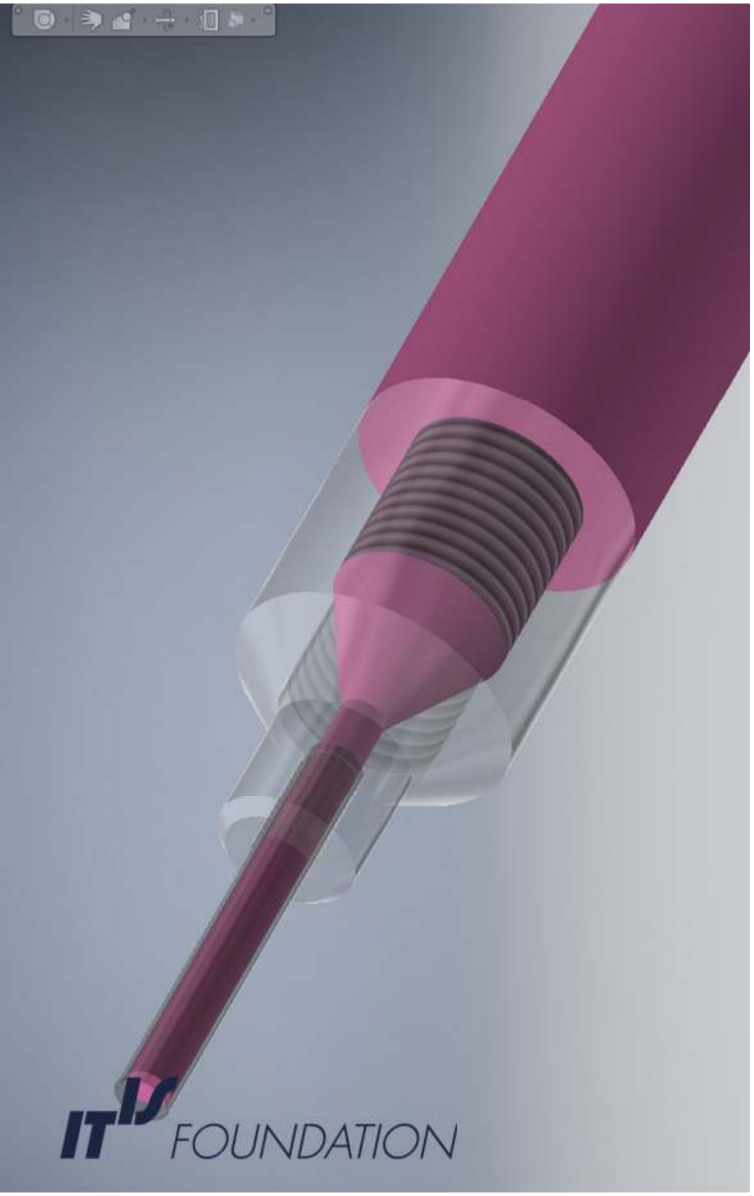


PHA-13G Phantom 10.7 – 15.3 GHz



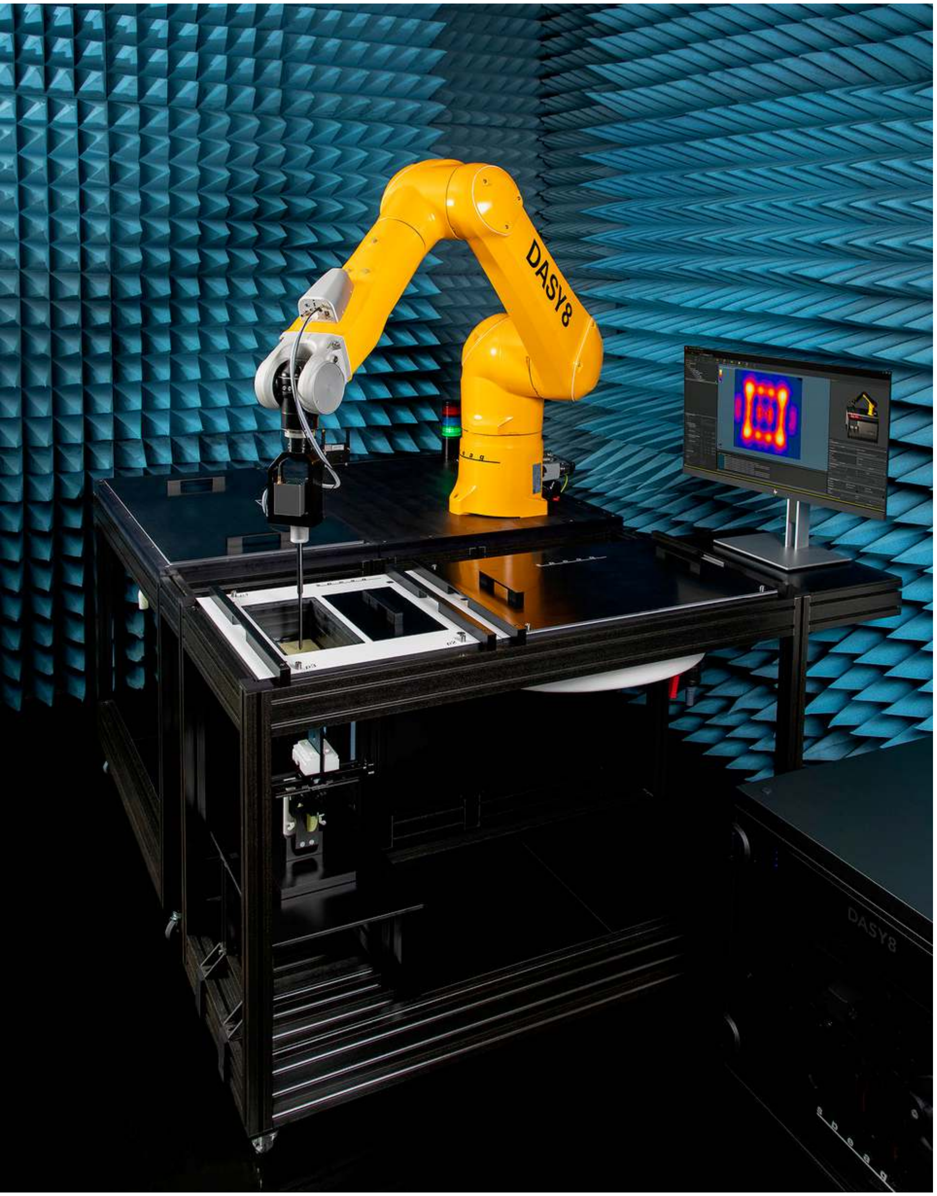


Challenge 3: Dosimetric Probe



Probe Design

- vector field measurement in TSL
- frequency range: 10 GHz → 40 GHz
- isotropy error: < 0.8 dB
- linearity error: < 0.4 dB
- spatial resolution << penetration depth ($0.5\ mm^3$)
- calibrated in TSL; calibration unc. < 0.6 dB
- wideband ≥ 800 MHz (modulation bandwidth)
- low field perturbation (matched to TSL)



SPEAG's Implementation

- DASY8 Module APD of SPEAG
- PHA-30G – APD phantom
- SSL-30G – skin simulating liquid
- MD4APDV5 – mounting device
- EUAPDV2 – dosimetric mmW APD Probe
- Module APD V1 software
- *Verification Source 30 GHz V2*

- probe/system support 10 – 45 GHz
- band-specific phantoms to emulate skin
- FR2 24 – 30 GHz released in 4Q23
- FR3 10 – 15 (24) GHz release 4Q24

APD Uncertainty Budget

#	Descriptor	U in dB	distr.	divisor	c_i	Std. U in dB		#	Descriptor	U in dB	distr.	divisor	c_i	Std. U in dB
	Probe Calibration								**Phantom**					
1	power meter absolute	0.15	n. (k=2)	2	1	0.08		13	shell thickness	0.18	rect.	1.73	1	0.10
2	missmatch PM / cable	0.15	u-shape	1.41	1	0.11		14	shell permittivity (5%)	0.25	rect.	1.73	1	0.14
3	source missmatch	0.33	u-shape	1.41	1	0.23		15	liquid permittivity (10%)	0.27	rect.	1.73	1	0.16
4	coupler missmatch	0.15	u-shape	1.41	1	0.11		16	liquid conductivity (10%)	0.04	rect.	1.73	1	0.02
5	coupler directivity	0.05	u-shape	1.41	1	0.04		17	flatness (f)	0.60	rect.	1.73	1	0.35
6	liquid permittivity	0.20	rect.	1.73	1	0.12			**Post-processing**					
7	liquid conductivity	0.05	rect.	1.73	1	0.03		18	APD reconstruction	0.96	rect.	1.73	1	0.55
8	probe positioning	0.17	rect.	1.73	1	0.10		19	APD in skin	0.30	rect.	1.73	1	0.17
	Probe Dynamic								**DUT**					
9	linearity (P)	0.2	rect.	1.73	1	0.12		20	DUT holder	0	rect.	1.73	0	0.00
10	flatness (f)	0.25	rect.	1.73	1	0.14		21	DUT positioning	0.46	rect.	1.73	1	0.27
11	directivity error	0.1	rect.	1.73	1	0.06		22	DUT power drift	0.20	rect.	1.73	1	0.12
	Scanning												RSS	0.87
12	probe positioning	0.17	rect.	1.73	1	0.10							**Expanded uncertainty**	**1.52**

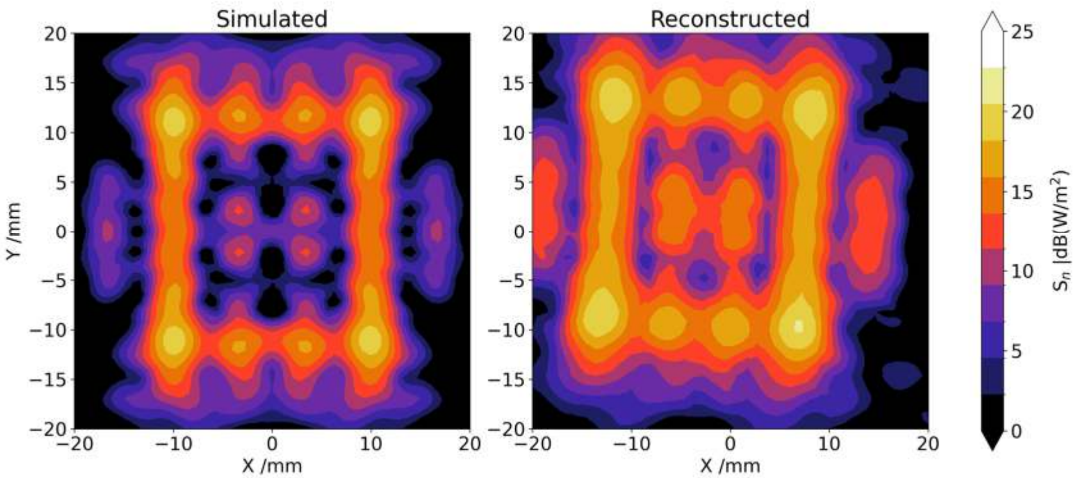
IT'IS FOUNDATION

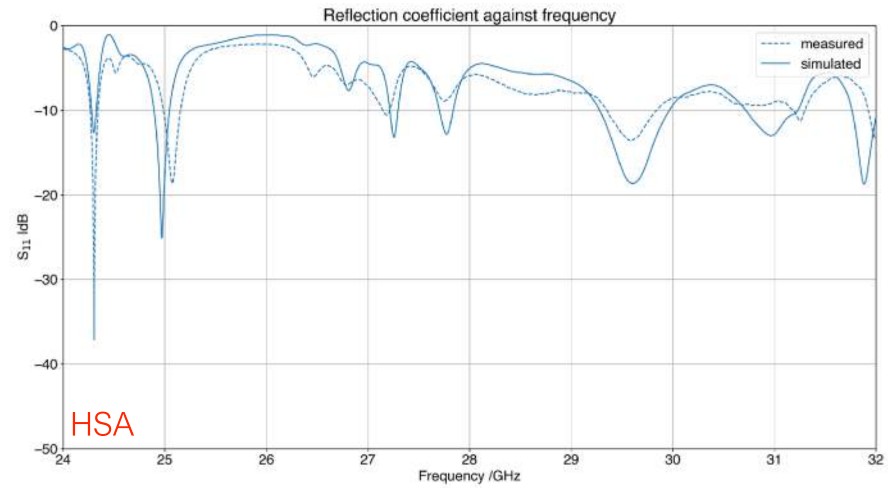
Challenge 3: Validation

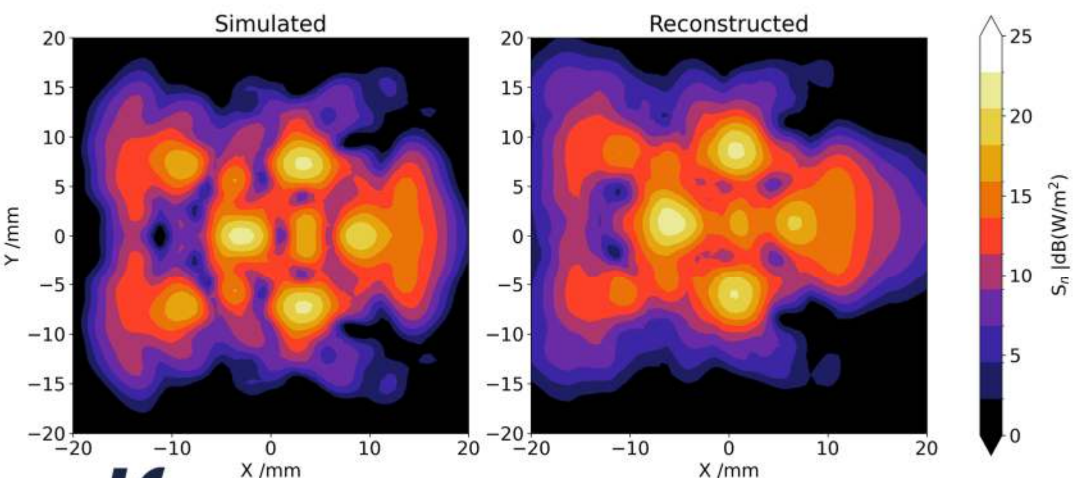
Validation Test Setup

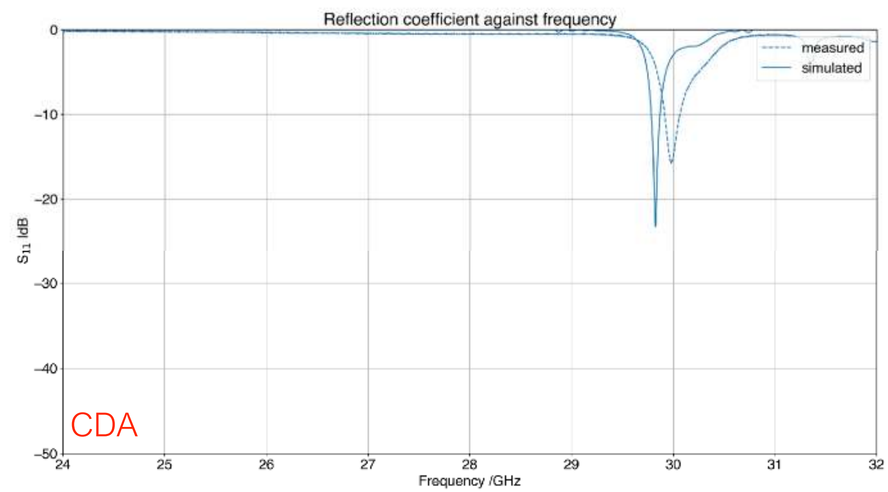
- pt63195-3 validation sources:
  - horn slot array (HSA)
  - cavity back dipole array (CDA)
- d = 2 mm from skin
- target data generated for mmW skin model
- measurements on SPEAG's PHA-30G

ITIS FOUNDATION


Simulated
Reconstructed
Y /mm
X /mm
S_n |dB(W/m^2)


Reflection coefficient against frequency
measured
simulated
S_{11} /dB
Frequency /GHz
HSA


Simulated
Reconstructed
Y /mm
X /mm
S_n |dB(W/m^2)


Reflection coefficient against frequency
measured
simulated
S_{11} /dB
Frequency /GHz
CDA

APD Validation Summary 6.5 – 30 GHz

f /GHz	Source antenna	d /mm	signal	U meas |dB	U sim |dB	ΔpsAPD |dB		normalized error En	
						1 cm^2	4 cm^2	1 cm^2	4 cm^2
6.5	patch antenna	5	CW	1.2	0.68	-0.13	-0.02	0.05	0.01
10	horn with slot array	2	CW	1.2	0.26	0.59	0.11	0.26	0.05
	cavity-fed dipole array	2	CW	1.2	1.03	-1.03	-0.97	0.29	0.28
27	horn with slot array	2	CW	1.52	0.89	0.64	1.06	0.22	0.38
27	open-ended waveguide	2	BPSK	1.52	0.89	0.24	0.39	0.08	0.13
30	cavity-fed dipole array	2	CW	1.52	1.17	-0.87	-1.05	0.23	0.28

$$|E_n| = \left| \frac{(psAPD_{meas}/psAPD_{sim} - 1)}{\sqrt{U_{sim}^2 + U_{meas}^2}} \right|$$

IT'IS FOUNDATION

Absorbed Power Density Measurement System

Fariba Karimi, *Member IEEE*, Ninad Chitnis, Sven Kühn, Arya Fallahi, *Senior Member IEEE*, Andreas Christ, *Member IEEE*, and Niels Kuster, *Fellow IEEE*

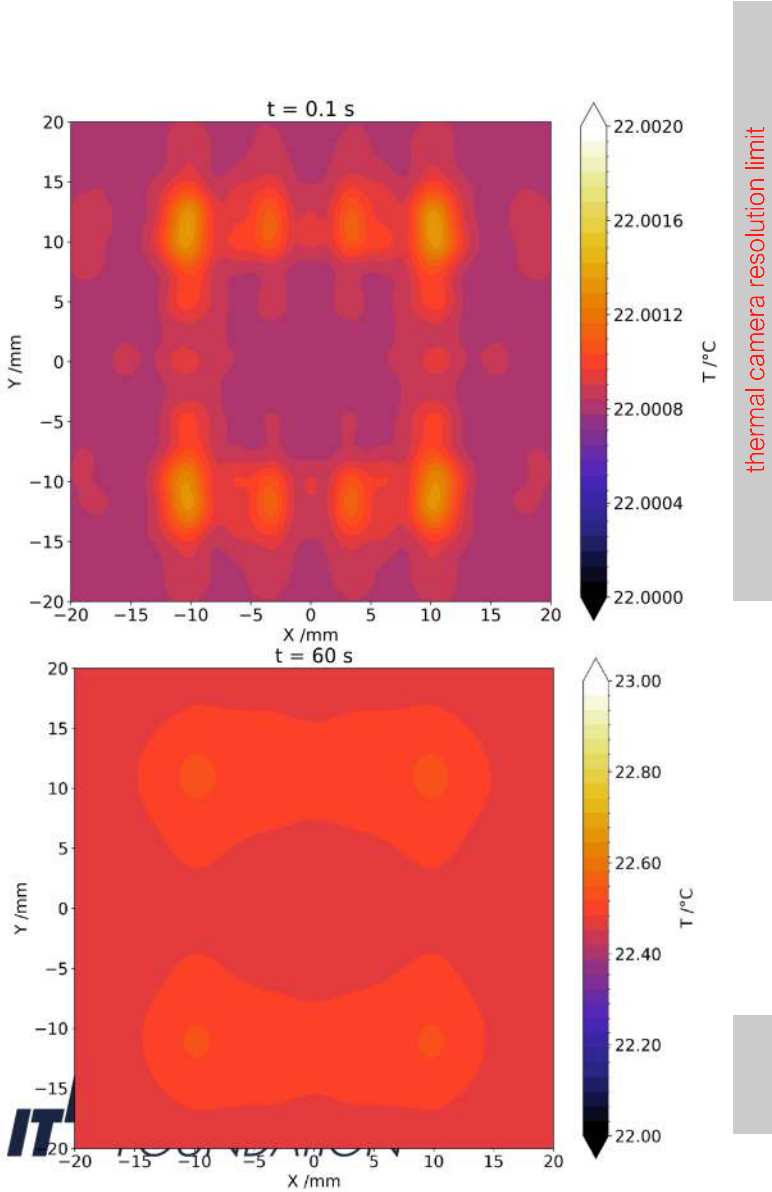
***Abstract*—In this study, a new complete solution for the experimental assessment of the absorbed power density (APD) is developed that includes several novel components (i) probe, (ii) phantom, (iii) reconstruction, (iv) calibration and (v) validation. The described solution is optimized for the frequency range from 24 to 30 GHz, but can be extended to all frequency bands between 10 GHz and 45 GHz. The phantom emulates the reflection and transmission coefficient of human skin for both propagating and evanescent modes while increasing the penetration depth in the skin-simulating liquid (SSL) to enable the measurement of the induced electromagnetic fields (EMFs) with a new miniaturized dosimetric broadband probe. The APD at the phantom surface is reconstructed from the measured field at 1 mm distrnace from the surface. The calibration .... For the validation of the measurement system, a set of reference antennas with known numerical target values for the APD has also been designed. The validation demonstrates that the uncertainty is less than 1.x dB ($k = 2$), the dynamic range is between $<1\%$ and 500 times the general public exposure limits and the spatial resolution is $<0.5\,\text{mm}^3$.**

near-field exposure in the millimeter-wave (mmW) range, which means that the absorption is confined to superficial tissues. While at first, incident power density (IPD) [5] was used as a pseudo dosimetric limit, IPD neglects the effects of the human body on the transmitter (coupling, backscattering, etc.) and is a poor metric to assess the exposure in the near-field of sources [6]. Therefore, absorbed power density (APD) [1] or epithelial PD [2] averaged over a square area of $4\,\text{cm}^2$ for frequencies between 6 –30 GHz and $1\,\text{cm}^2$ for frequencies above 30 GHz was introduced in the most recent safety guidelines in order to limit the maximum tissue heating (see Table **??**). The relation of tissue heating as functions of peak APD, beam width, pulse repetition rate, environmental parameters and skin composition has recently be investigated by Neufeld et al. [7] showing that the proposed guidelines are not generally consistent but for all forseenable exposure szerarios of 5 G and 6 G.

Challenge 3: Remaining Issues

- enhanced human study < 45 GHz
- skin model > 110 GHz
- phantoms for 40 GHz including validation sources
- fast techniques

ΔT Sensitivity



t = 0.1 s

- T-distribution correlates well with APD
- standing waves appear in phantom
- ΔT << thermal camera sensitivity

t = 60 s

- ΔT > thermal camera sensitivity
- but lacks correlation with APD

Challenge 3: APD Regulatory Update

IEC TC106 WG12

- IEC PAS 63446:2022 (6 – 10 GHz)
  - published
- IEC/IEEE TR 63572:2024 ED1 (6 – 300 GHz)
  - CD circulated, comments due 2024-05-17
  - inter-laboratory comparison:
  - inter-laboratory equipment and procedures available
  - planned start postponed from 05/2024 to 09/2024
- IEC/IEEE pt63195-3 (6 – 300 GHz)
  - development started in 1Q24
  - very first draft discussed in Kista meeting (05/24)

China

- ICNIRP 2020 APD adoption
- domestic product test standard under development
- planned release by end 2025

Canada, Australia, Japan

- ICNIRP2020 APD adoption (6 – 10 GHz)

Challenge 4:
Comprehensive but Agnostic Validation

Regulatory / Standardization Gap

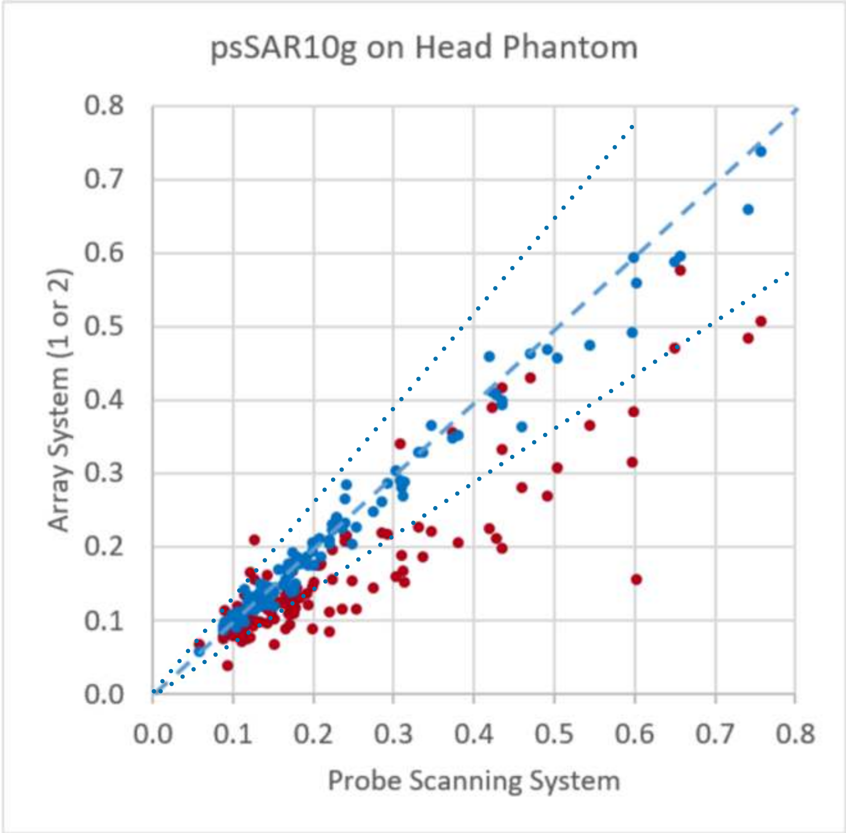
- IEC/IEEE 62209-1528
  - performance standard
  - defines the performance requirements of the system
  - defines the performance requirements of subcomponents (probe, liquid, phantom and scanning procedure)
  - defines rigorous validation of each subcomponent
  - tight compliance criteria (deviation from target < ±10%)
- new IEC/IEEE 62209-3
  - only a few tests (while system degree of freedom is high)
  - soft compliance criteria (deviation from target ± 45%)
  - system can be tuned to meet criteria for only test conditions
- validation is not comparable / equivalence cannot be demonstrated

Equivalence

- if validation system is common and measurement system agnostic and
- if the validation procedures is comprehensive to ensure that all systems provides results within ± 30% of the true value
- the systems are equivalent with respect to the requirement of ± 30%
- open issue: configuration dependent offsets between system type
  – regulators interpretation issue

Indian TestLab Phone Study (2 Array Systems vs Scanning System)

- probe scanning system compared to two commercially-available vector measurement-based systems
- array system 1 (blue) vs probe scanning system
  - min: -1.0 dB
  - max: +1.0 dB
  - std. dev.: 0.4 dB
  - average: -0.1 dB
  - 100% of results within combined uncertainty
- array system 2 (red) vs probe scanning system
  - min: -5.9 dB
  - max: +2.2 dB
  - std. dev.: 1.2 dB
  - average: -1.3 dB
  - 44% of results within combined uncertainty
- organized by IT'IS



IT'IS FOUNDATION

T. Nagaoka et al., BioEM, 2024 (NICT Japan)

- DASY 6, cSAR3D, ART-MAN v2
- 3 smartphones capable of transmitting in test mode
- only LTE bands
- 400 conditions
- one fast SAR measurement system is generally within the expanded uncertainty of the full SAR and fast SAR measurement systems
- the other fast SAR measurement system has many conditions that are outside of its expanded uncertainty range
- we are continuing the SAR measurements in this study for more DUTs and conditions

096B

Comparison of Measured SARs between Full and Fast SAR Measurement Systems Using Various Smartphones

Dr Tomoaki Nagaoka, Dr Yuto Shimizu, Mr Hiroshi Kawakami
National Institute of Information and Communications Technology, Koganei, Japan

Abstract Subject Area(s)

["RF/Microwave","Standards and public health policy"]

Summary

Fast SAR measurment systems are currently used primarily for screening, but are expected to be adopted for compliance testing in the future. Recent research comparing SAR values from over 8,000 conditions on 80 different commercially availablesmartphones using two fast SAR measurement systems revealed significant differences likely influenced by the DUTs. In this study, SAR values from both conventional and fast systems were compared using smartphones in test mode in order to climinate DUT-induced discrepancies.

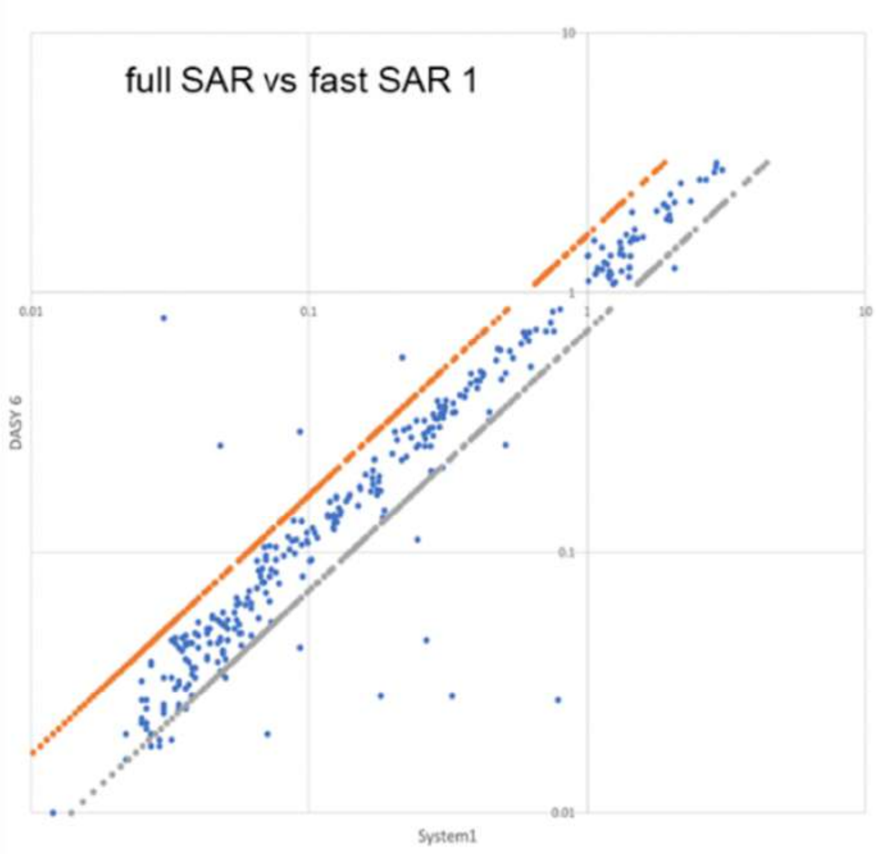
Is the work in progress?

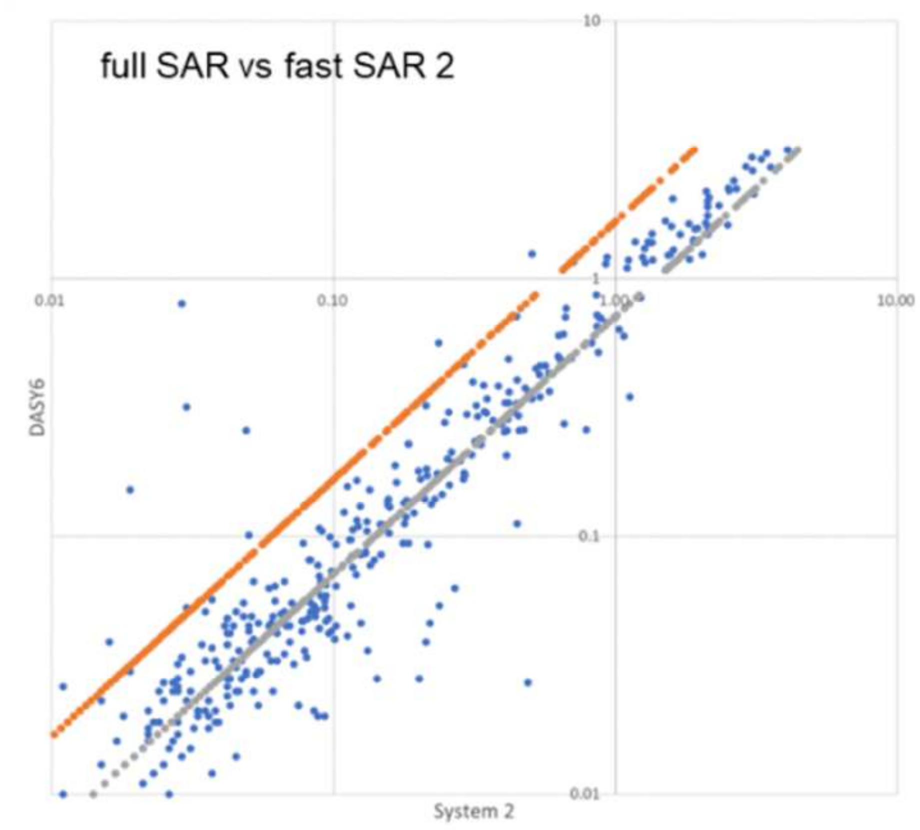
yes

Full abstract

Download file

T. Nagaoka et al., BioEM, 2024 (NICT Japan)





Regulatory / Standardization Gap

- new IEC/IEEE standard
  - performance standard without method and specifying component specifications (incl. open and blackbox systems)
  - only performance requirements: all configurations must be assessed within ± 30% of the true value
  - how can this be demonstrated / validated?!

Objectives of Validation Concept

- common validation procedure for any system
- conclusive demonstration that SAR measurement system performs within manufacturer's stated measurement uncertainty
  – not exceeding ± 30%
- performed by the user at least annually
  – including after hardware or software changes, recalibration, or installation of new system
- ensures reliable and reproducible measurements
- any system passing this validation can be considered equivalent

Validation Requirements

- universally applicable to any SAR measurement system
  - agnostic to measurement methodology, implementation and system
  - reduced scope (e.g., frequency)
- tests shall be equivalent to evaluating all exposure conditions
  - millions of tests
- affordability (max 2 – 3 days)
- statistical approach
  - based on latest from surrogate modeling
  - reduction to ~200 – 400 randomly selected cases
  - critical data space search based on model validation results
- test reduction
  - test not falling within the scope of the system (e.g., frequency)
  - redundant tests can be skipped, if it can be demonstrated that tests are equivalent
- open software available to support selection and interpretation

IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received 15 February 2024, accepted 6 April 2024, date of publication 25 April 2024, date of current version 3 May 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3393778

RESEARCH ARTICLE

A Gaussian Process Based Approach for Validation of Multi-Variable Measurement Systems: Application to SAR Measurement Systems

CÉDRIC BUJARD[1], ESRA NEUFELD[1], MARK DOUGLAS[1], (Senior Member, IEEE), JOE WIART[2], (Senior Member, IEEE), AND NIELS KUSTER[1,3], (Fellow, IEEE)

[1]IT'IS Foundation, 8004 Zürich, Switzerland
[2]Laboratoire de Traitement et Communication de l'Information (LTCI), C2M, Télécom Paris, 91120 Paris, France
[3]Department of Information Technology and Electrical Engineering, Swiss Federal Institute of Technology, ETH Zürich, 8092 Zürich, Switzerland

Corresponding authors: Cédric Bujard (bujard@itis.swiss) and Mark Douglas (douglas@itis.swiss)

This work was supported by the European Union's Horizon Europe Framework Programme under Grant Agreement number 101057622 (Project "Scientific-based Exposure and risk Assessment of radiofrequency and mm-Wave systems from children to elderly (5G and Beyond)"–SEAWave), and by the Swiss State Secretariat for Education, Research and Innovation (SERI).

ABSTRACT Resource-efficient and robust validation of systems designed to measure a multi-dimensional parameter space is an unsolved problem as it would require millions of test permutations for comprehensive validation coverage. In the paper, an efficient and comprehensive validation approach based on a Gaussian

Compliant and Equivalence

- a system is declared non-compliant if it fails validation
  - if multiple validations are performed to achieve a better coverage of the parameters space, all of them must pass
- all systems that pass are compliant and equivalent
- system provider problem
  - as tests performed by the lab is not known, they have to make sure that the system passes all of the million of tests

[1] Bujard C, Neufeld E, Douglas M, Wiart J, Kuster N. A Gaussian process based approach for validation of multi-variable measurement systems: application to SAR measurement systems. IEEE Access. 2024 Apr 25.

Implementation by 62209-5

Device SAR Standards Series			
International Standards (Normative)			Technical Report (Informative)
Part 1 SAR Measurement Procedures	Part 2 SAR Measurement Instrumentation	Part 3 Validation Procedure & Instrumentation	Part 4 SAR Measurement Considerations Rationale and Technical Recommendation
1. Scope	1. Scope	1. Scope	1. SAR test reduction supporting information
2. Normative references	2. Normative references	2. Normative references	2. Studies for potential hand effects on head SAR
3. Terms and definitions	3. Terms and definitions	3. Terms and definitions	3. Skin enhancement factor
4. Symbols and abbreviated terms	4. Symbols and abbreviated terms	4. Symbols and abbreviated terms	4. Wired hands-free headset testing
5. Test site requirements	5. Measurement system specifications	5. Validation signals	5. Applying the head SAR test procedures
6. Quick start guide for SAR measurements	5.1. Performance requirements of scanning and array systems	6. Validation sources	6. Rationale for time-period averaged SAR test procedure
7. SAR measurement system description	5.2. Specifications of single probe systems	7. Validation phantoms	7. Determination of the margin for compliance evaluation using the Uni-phantom
8. SAR measurement protocols	5.3. Specification of array systems with sealed phantoms	8. Power control setup	8. Automatic input power level control for system validation
8.1. General	5.4. Specification of array systems with open phantoms	9. Validation target values	9. LTE test configurations supporting information
8.2. System check	6. Instrumentation uncertainty	10. System validation	10. General considerations on uncertainty estimation
8.3. Protocols for scanning systems	7. Specifications of phantoms	10.1. Validation protocol	11. Bibliography
8.4 Protocols for array systems	8. System calibration	10.2. Site validation	
9. System validation	9. Bibliography	10.3. Acceptance criterion	
10. SAR measurement uncertainty estimation		11. Validation uncertainty	
11. SAR measurement report		12. Validation report	
12. Interlaboratory comparisons		13. Bibliography	
13.Bibliography			

Challenge 4: Remaining Issues

- solution known
- deadlock for fast SAR system within reach
- implementation not done yet
- challenge to define test reduction to make it affordable

Challenge 5:
Evaluation of Exposure Mitigation Features

Regulatory / Standardization Gap

- communication requirements for smart phones increasing
  - high data rate, lower latency, higher reliability
  - more bands
  - more simultaneous transmission
- more demanding test conditions
  - separation distance (d) = 0 mm
  - hand SAR (ISED)
- smart phones are getting much smarter
  - time average SAR
  - proximity sensors
  - motion sensors
  - position sensors
  - use case differentiation

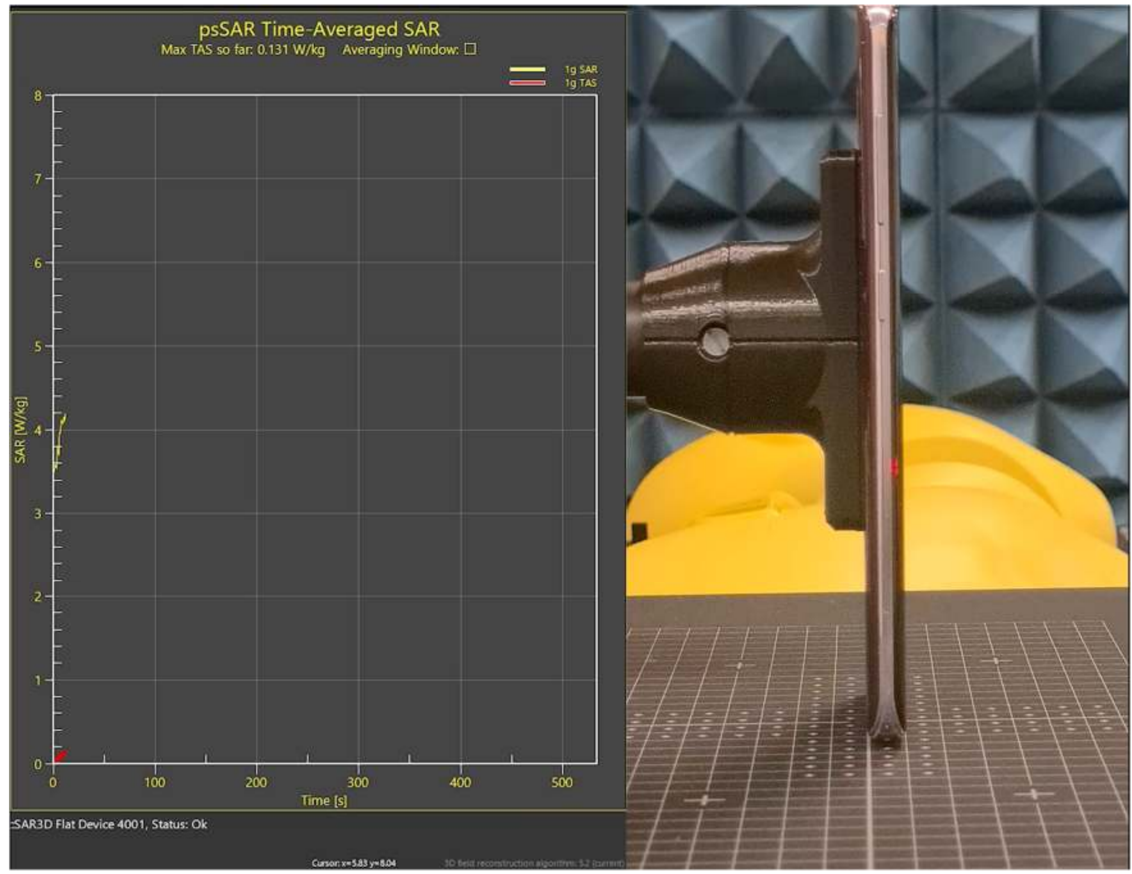
Research Project TyProxi

- IT'IS Foundation
- Partners
  - ETH Zurich
  - SEMTECH
- Funding
  - InnoSuisse

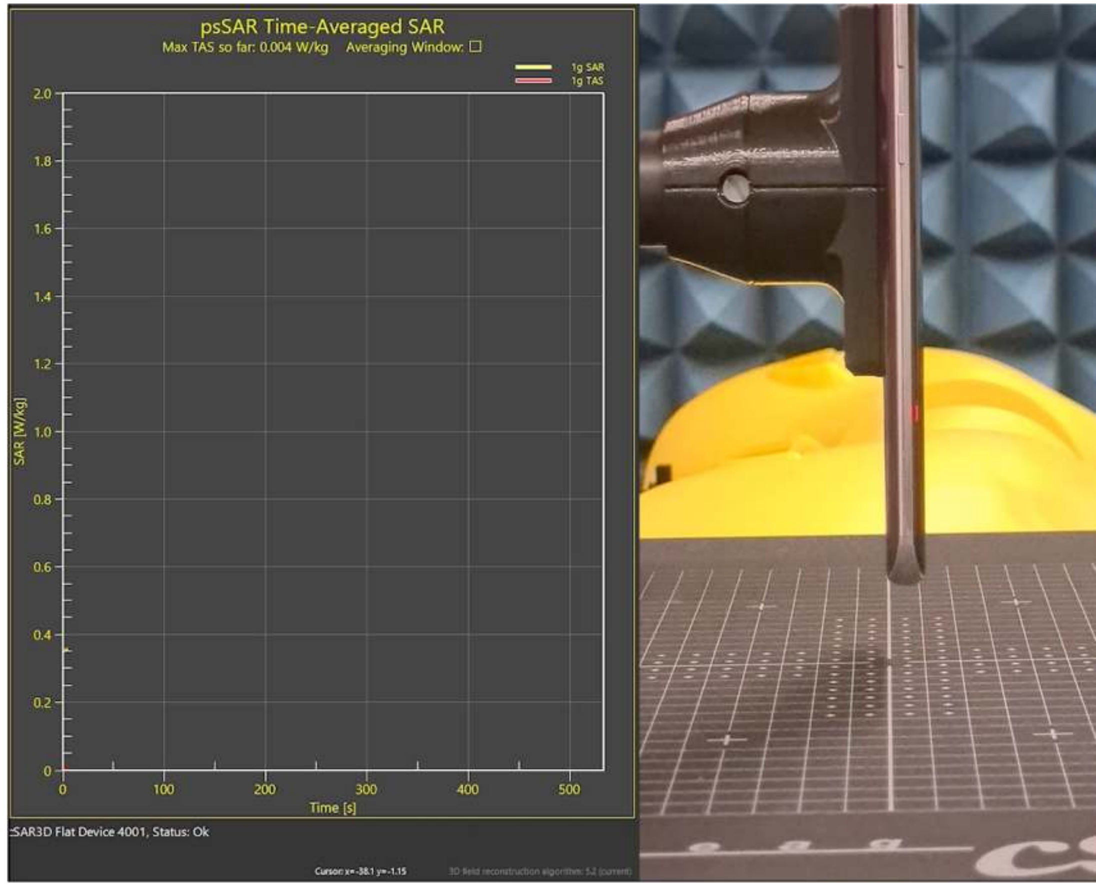
Results

- human study
- surrogate phantoms for capacitance-based sensors determined
- evaluation of fingers vs flat phantom
- procedures of the latest IEC standards
  - IEC TR 63424-1
  - IEC/IEEE 62209-1528 - Amendment 1
- 6 test sequences defined in standards
  - **continuous: away from phantom**
  - continuous: toward phantom
  - stepwise: away from phantom
  - stepwise: toward phantom
  - quasi-static
  - dynamic

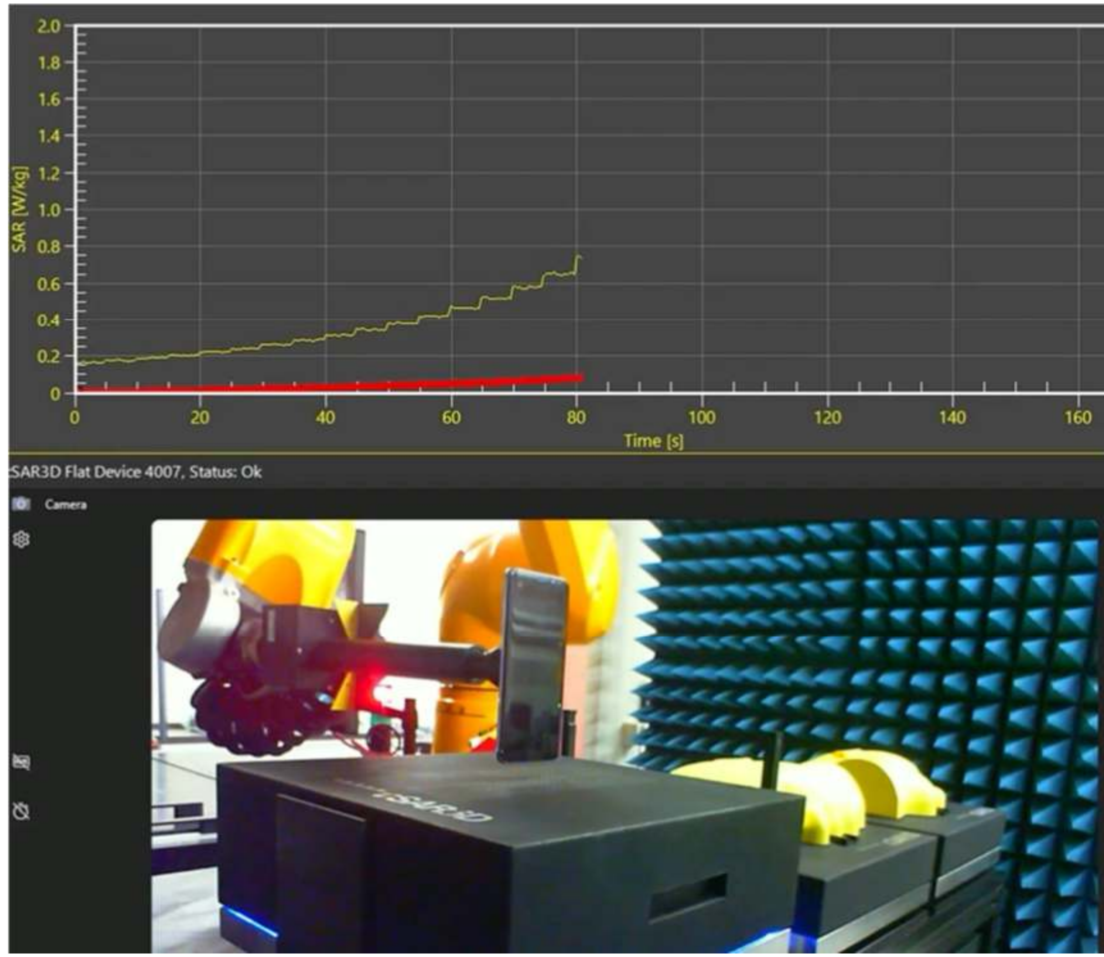
Sequence — Continuous Away



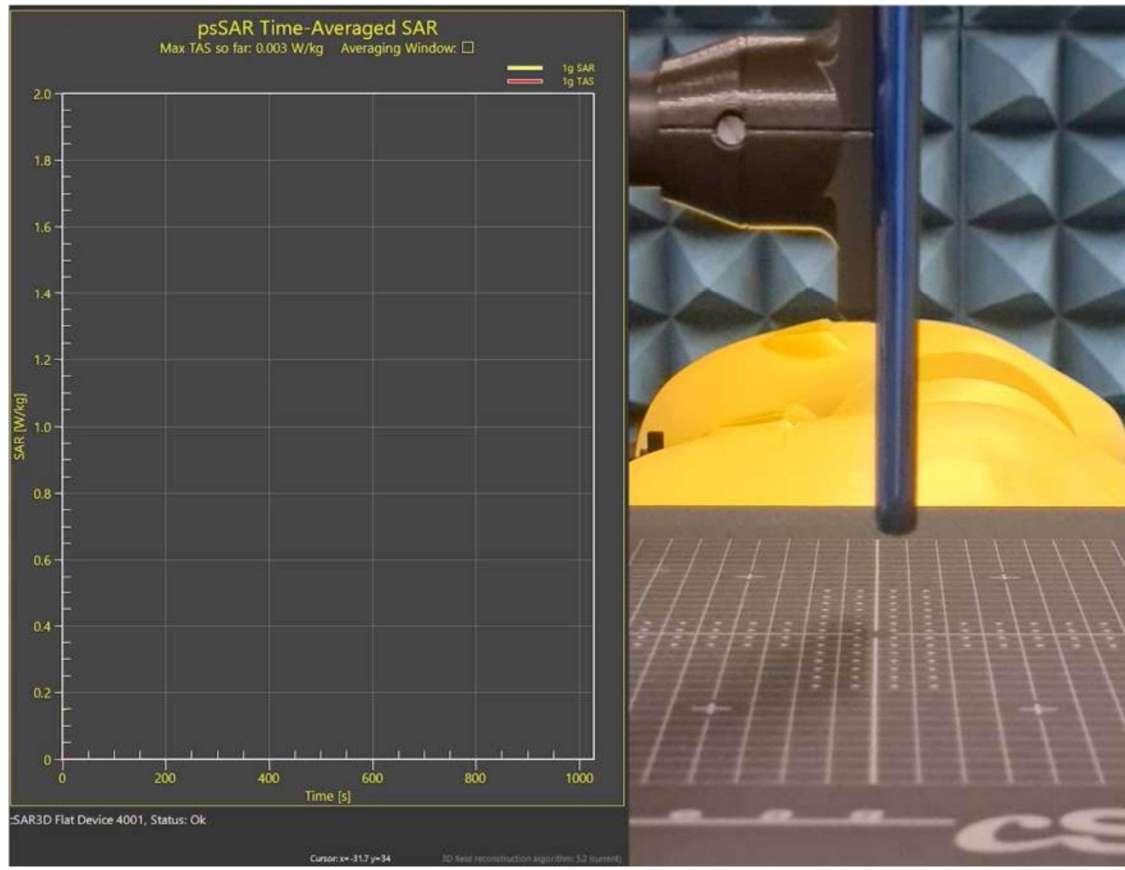
Sequence — Continuous Toward



Sequence — In Steps



Sequence — Quasi-Static Test



Challenge 5: Remaining Issues

- proximity sensors evaluation according to standard
  - automated system
  - efficient and comprehensive
  - also when combined w/ TAS
  - different angles
  - prepared to measure power control for approaching fingers (standardization lacking)
- motion sensors
- testing of combinations of multiple features

Status Summary of Scientific Challenges

- 1: assessment of IPD in the reactive near-field
  - novel, robust ESR close to completion
- 2: surface conformal IPD
  - fundamentals solved, waiting for 1
- 3: assessment of APD
  - 24 – 30 GHz done
  - 10 – 20 GHz fundamentals resolved
  - 40 GHz within reach
  - fast APD fundamentals still being addressed
- 4: comprehensive but agnostic validation systems
  - scientifically solved, now within IEC
- 5: evaluation of exposure mitigation features (TA, spatial diversity, proximity, motion, etc.)
  - automated testing of proximity sensors combined with TA according to standard resolved
  - major challenges for motion sensors and further techniques for exposure mitigations still unresolved

The Katja Poković Research Fellowship

- For **female scientists** in the fields of electromagnetics and information technology
- Deadline: **April 30, 2025**, 23:59h Swiss local time
- Contact: kpresearchfund@itis.swiss

https://itis.swiss/
fellowships/katja-pokovic-
research-fund/
research-fellowships

IT'IS FOUNDATION