

Milan, 25 September 2022

Workshop / Recent developments in mmw measurement : S-parameters and material properties

Free-space characterization in the millimeter and sub-millimeter wave ranges : application to solid and non-solid dielectric material properties... Effect of rain on a radome

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Outline

Slab
Multi layers
Non-solid (powder)
Non-Solid (Liquid)
Rain



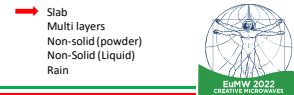
- Dielectric characterization
- Radome & multilayer characterization
- Non-solid material characterization
- Liquid characterization
- Effect of rain on a radome
- Conclusion & prospects

WM7: Recent developments in mmw measurement : S-parameters and material properties

Free-space characterization in the millimeter and sub-millimeter wave ranges: application to solid and non-solid dielectric material properties

2

Dielectric characterization (1/7)

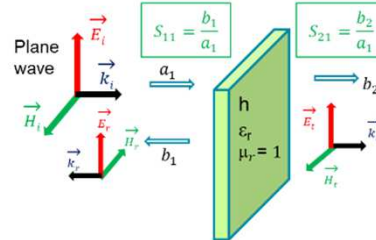


- Slab model
 - Parallel faces
 - Plane wave
 - Normal incidence

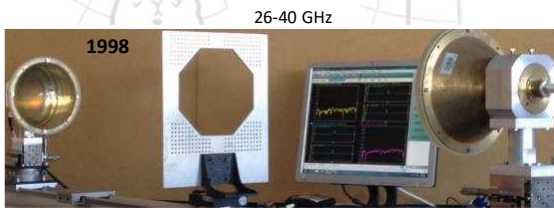
$$S_{21.th}(h, \epsilon_r) = \frac{(1 - \rho^2) \cdot e^{-j\Gamma h}}{1 - \rho^2 \cdot e^{-2j\Gamma h}}$$

$$\rho = \frac{1 - \sqrt{\epsilon_r}}{1 + \sqrt{\epsilon_r}}$$

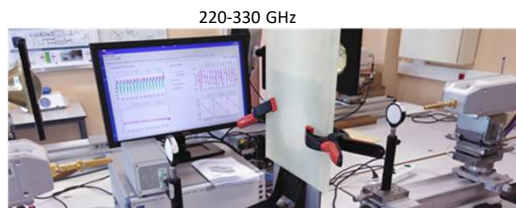
$$\Gamma = \frac{2}{\lambda_0} \cdot \sqrt{\epsilon_r}$$



- Test bench
 - Free space [S]: gaussian beam (mono-mode)
 - TRL calibration: control of reference planes and phases
 - Measured data: no filtering & no averaging



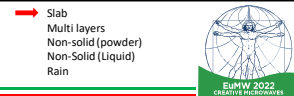
26-40 GHz



220-330 GHz

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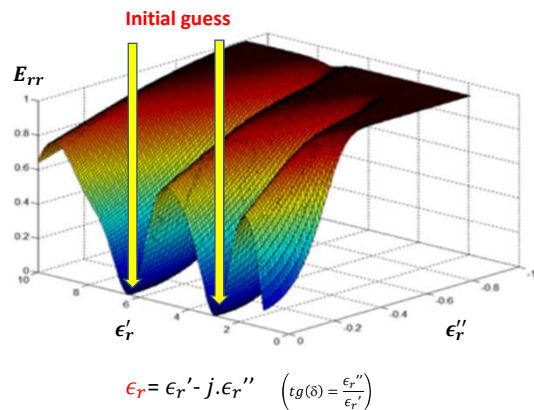
Dielectric characterization (2/7)



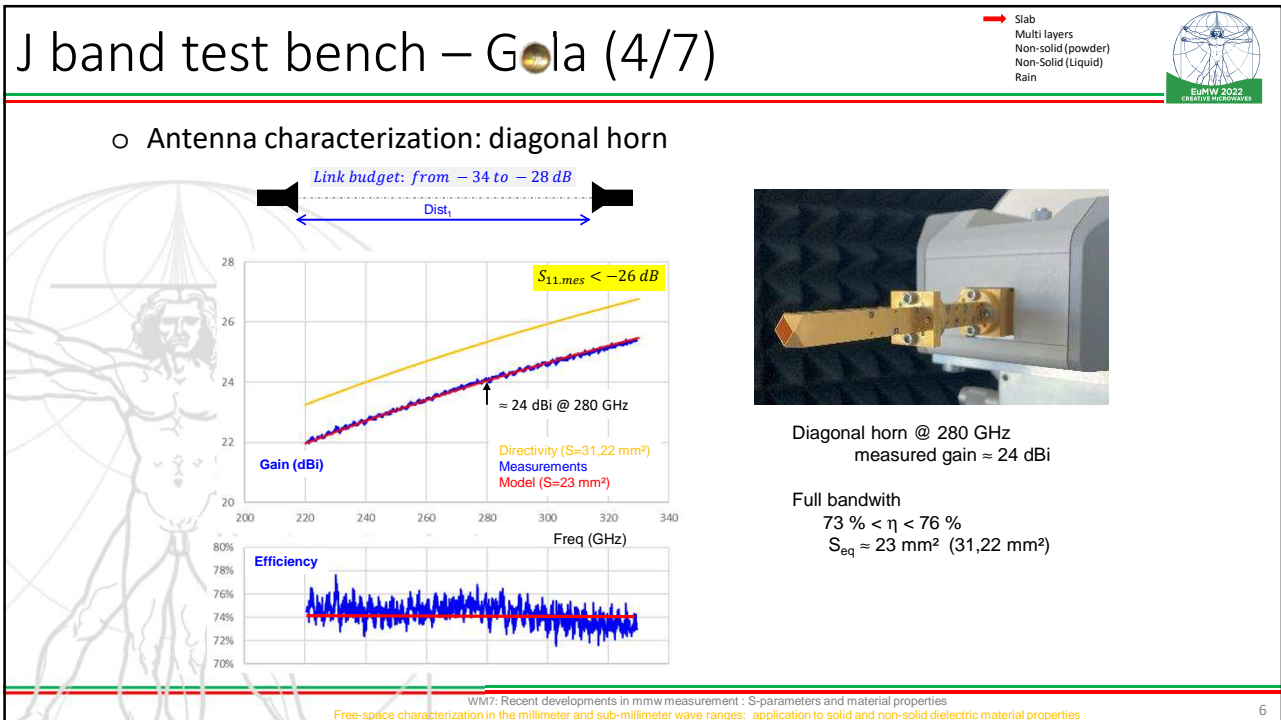
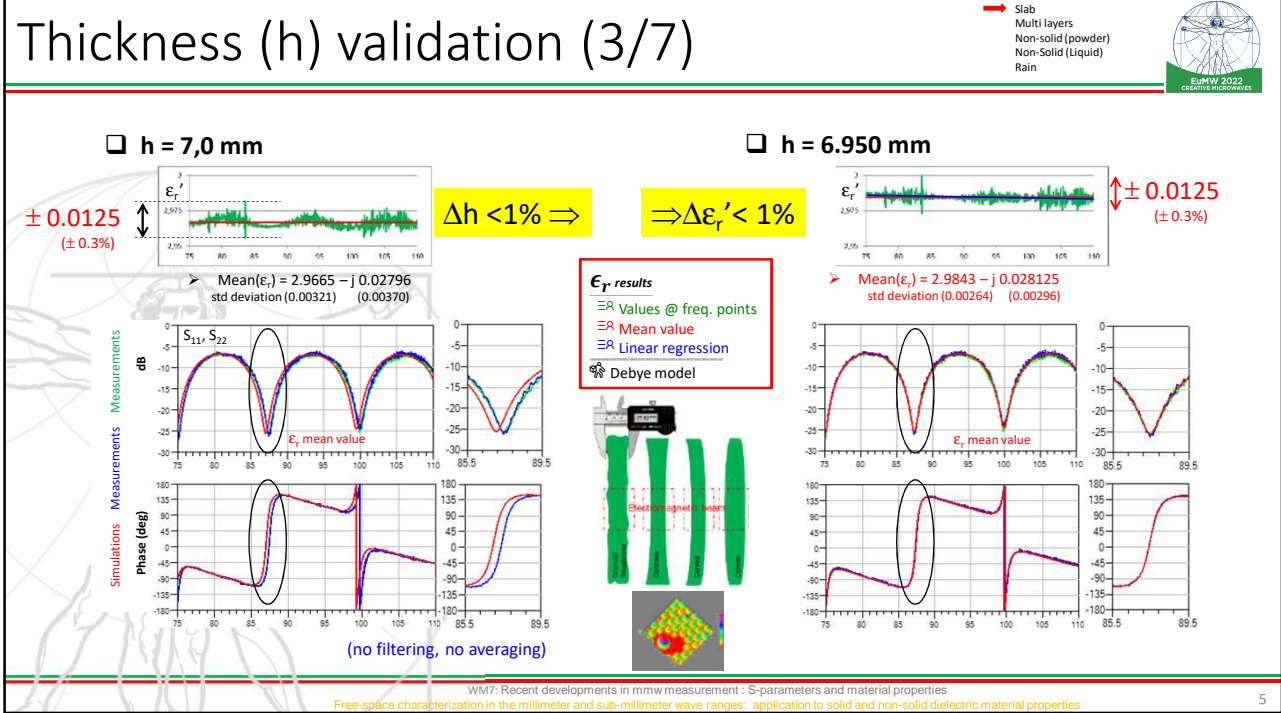
□ $\epsilon_r(f)$ extraction $\rightarrow S_{21.th}(h, \epsilon_r) = S_{21.meas}$

- **h measured**
 - $Err(S_{21.meas}, f, h, \epsilon_r) = 0 \Leftrightarrow \epsilon_r(f)$
 - 4 S-parameter model/measurement comparison
- $$S_{11.th}(h, \epsilon_r) = \frac{\rho \cdot (1 - e^{-2j\Gamma h})}{1 - \rho^2 \cdot e^{-2j\Gamma h}}$$
- **h validation**

○ Error function \Rightarrow quasi-Newton Nelder-Mead



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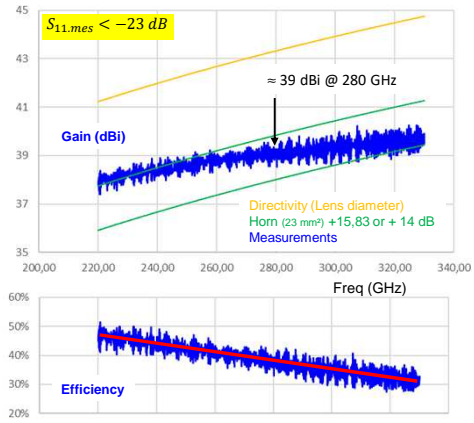
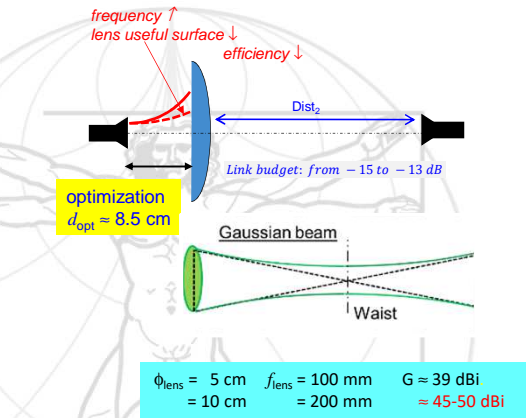


J band test bench – Gola (5/7)

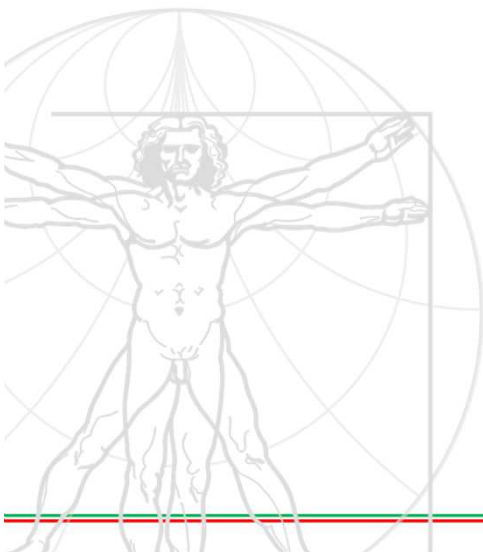
- Slab
- Multi layers
- Non-solid (powder)
- Non-Solid (Liquid)
- Rain



o Antenna characterization: diagonal horn with lens

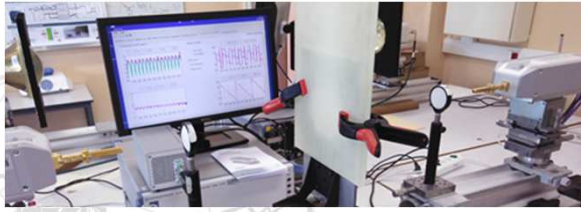


WM7: Recent developments in mmw measurement : S-parameters and material properties
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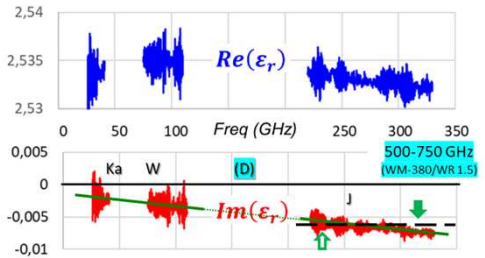
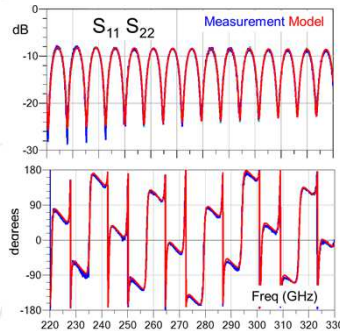
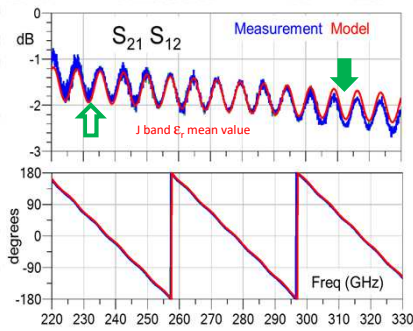
Usefulness of linear regression (7/7)

- Slab
- Multi layers
- Non-solid (powder)
- Non-Solid (Liquid)
- Rain



- ϵ_r results**
- Values @ freq. points
 - Mean value
 - Linear regression
 - Debye model

ReXolite (biblio) : $n = 1.59$ ($\epsilon_r=2.5281$) @ 589 nm
 $\epsilon_r = 2.53 \pm .03$ from 1 kHz to 500 GHz



no filtering, no averaging

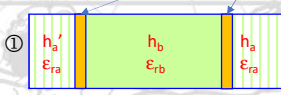
Radomes, multilayer (1/2)

- Slab
- Multi layers
- Non-solid (powder)
- Non-Solid (Liquid)
- Rain

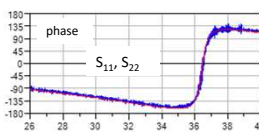
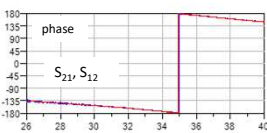
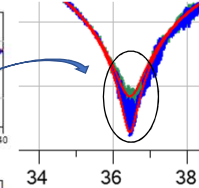
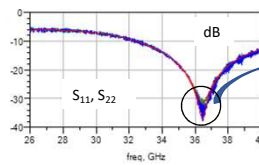
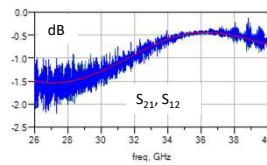
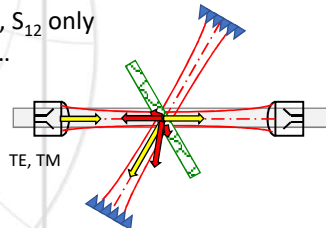


Structure

- Glue included (a few μm)



- On incidence : S_{21}, S_{12} only
- 15°, 30°, 45°, ...

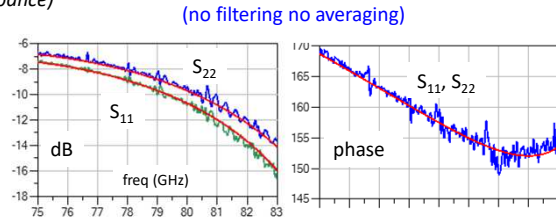
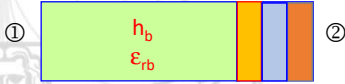


Radomes, multilayer (2/2)

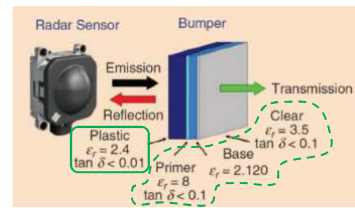
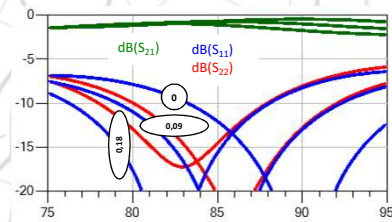
→ Slab
→ Multi layers
→ Non-solid (powder)
→ Non-Solid (Liquid)
→ Rain



- Coat of paints ($h_o = 70-150 \mu\text{m} \approx \text{disturbance}$)
 - (primer, base, clear)



□ Radar modeling



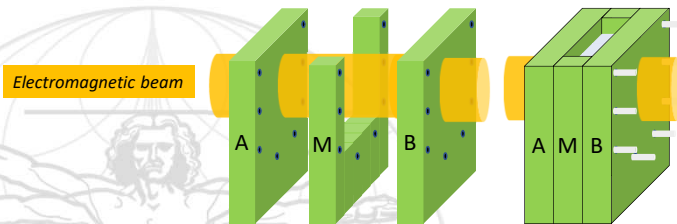
WM7: Recent developments in mmw measurement : S-parameters and material properties
Free-space characterization in the millimeter and sub-millimeter wave ranges: application to solid and non-solid dielectric material properties

Non-solid materials (1/4)

→ Slab
→ Multi layers
→ Non-solid (powder)
→ Non-Solid (Liquid)
→ Rain



□ Pre-characterized cell ([A], [B])



□ Ka & W-band Cells
 $h_M \approx 1.305$
 5.350 mm


$$[S_{AMB}] \Rightarrow [T_{AMB}] = [A].[M].[B] \Rightarrow h_m \text{ fixed} \Rightarrow \epsilon_{rM}(f)$$

- Powders (sugar, fine sand,...)
- Liquids (tap water) ↔ seals
- Mixtures

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Non-solid materials (2/4)

- Slab
- Multi layers
- Non-solid (powder)
- Non-Solid (Liquid)
- Rain

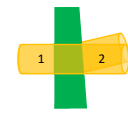
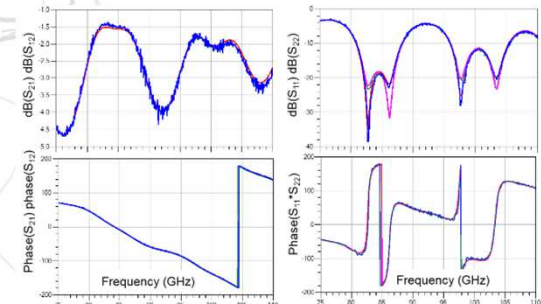
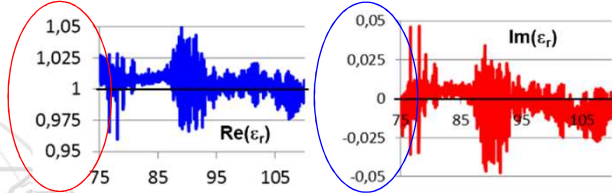


❑ Empty tank

$H_M \approx 1,305$ mm

$\epsilon_r \text{ av} = 1.0049 (\sigma=0.0099) - j 0.0021 (\sigma=0.0104)$

$(\epsilon_r \text{ dry air} \approx 1.00059.. - j. \text{????})$




Tank Simulations
 S_{AMB} Measurements
 Measurements

(no filtering no averaging)

Non-solid materials (3/4)

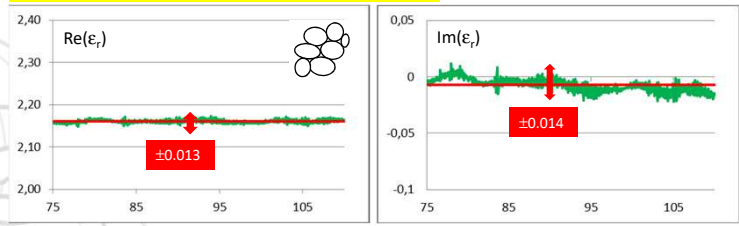
- Slab
- Multi layers
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- Rain



❑ Powdered sugar

$\epsilon_r = 2.160 (0.004) - j 0.007 (0.006)$

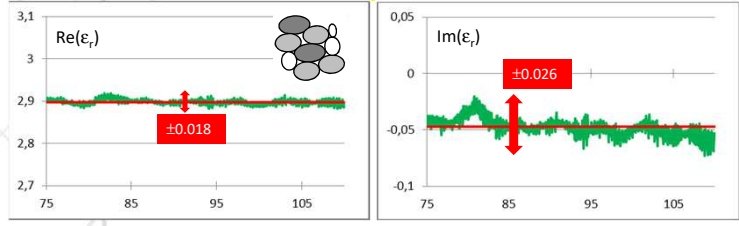
ϵ_r results
 ≡R Values @ freq. points
 ≡R Mean value



❑ Fine sand (no gravels)

$\epsilon_r = 2.898 (0.006) - j 0.0474 (0.008)$


(no filtering no averaging)



$h_M \approx 5.350$ mm

Non-solid materials (4/4)

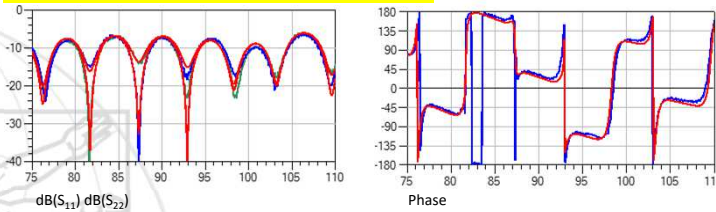
→ Slab
→ Multi layers
→ Non-solid (powder)
→ Non-Solid (Liquid)
→ Rain



Powdered sugar

$\epsilon_r = 2.160 (0.004) - j 0.007 (0.006)$

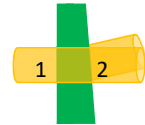
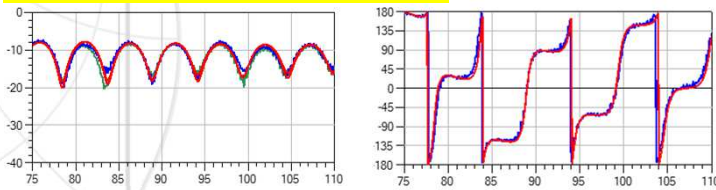
W band ϵ_r mean value



Tank Simulations
→ Measurements
→ Measurements

Fine sand (no gravels)

$\epsilon_r = 2.898 (0.006) - j 0.0474 (0.008)$




$h_M \approx 5.350 \text{ mm}$

(no filtering no averaging)

Liquid (1/2)

Tap water $S_{21} \approx -37 \text{ dB/mm @ 90 GHz}$

→ Slab
→ Multi layers
→ Non-solid (powder)
→ Non-Solid (Liquid)
→ Rain



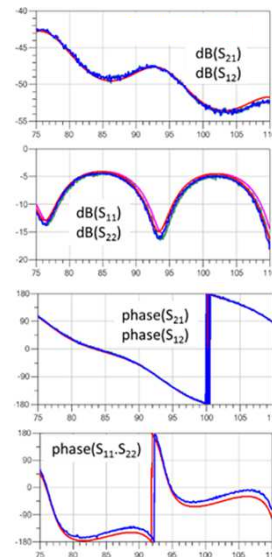
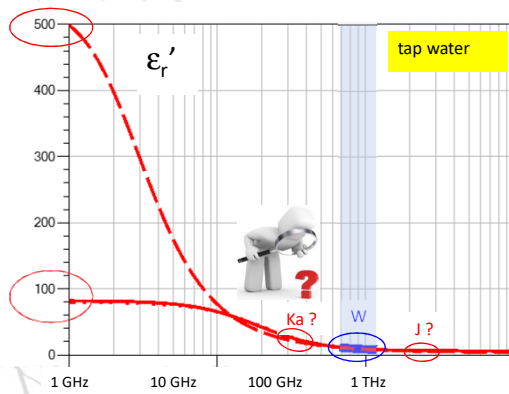
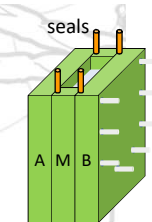
From $\epsilon_r(f)$

o Debye model estimation

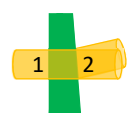
$\epsilon_r = \epsilon_{\infty} + \frac{\epsilon_{st} - \epsilon_{\infty}}{1 + i \cdot \omega \cdot \tau}$

- $\epsilon_{st}, \epsilon_{\infty}$ & τ
- One single band : several sets of values

$H_M \approx 1.305 \text{ mm}$



Tank Simulations
→ Measurements
→ Measurements



(no filtering no averaging)

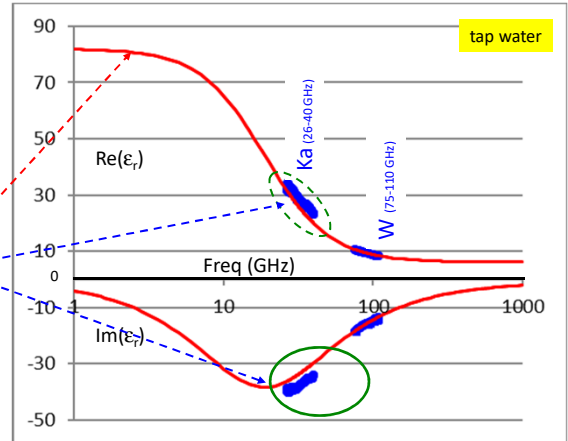
Liquid (2/2)

Slab
 Multi layers
 Non-solid (powder)
 Non-Solid (Liquid)
 Rain

From $\epsilon_r(f)$

- Debye model estimation
 - $\epsilon_{st}, \epsilon_{\infty}$ & τ
 - One single band : several sets of values
 - Depending on the "quality" of the water (demineralized, salinity, impurities, ..., °C)

$$\epsilon_r = \epsilon_{\infty} + \frac{\epsilon_{st} - \epsilon_{\infty}}{1 + i\omega\tau}$$



Debye model parameters from W band extraction
 Ka & W band extractions
 (but not the same water sample...)

On going characterization

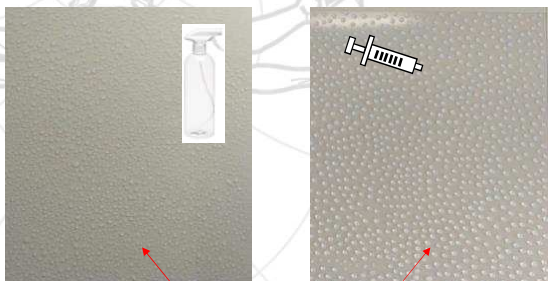
- Ka, W & J bands using identical water sample at the same °C
- Various water samples...

Effect of rain on a radome (1/2)

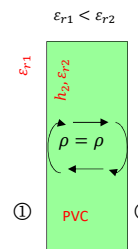
Slab
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Water "shape"

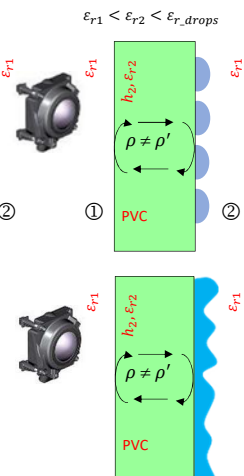
- Fine drops (spray)
- Large drops (syringe)
- Flow



Dry slab (a)




Drop modeling (b)



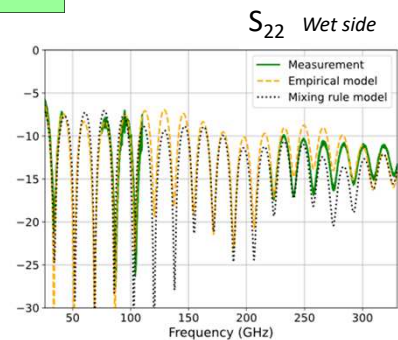
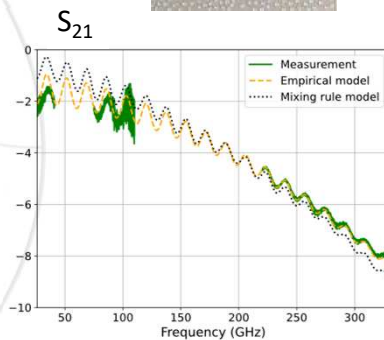
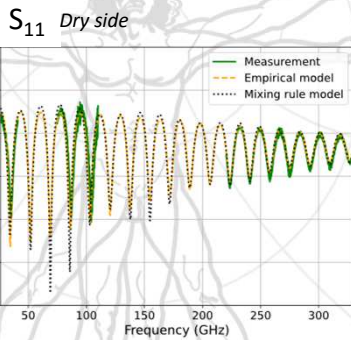
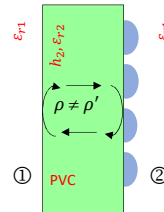
Effect of rain on a radome (2/2)

Slab
 Multi layers
 Non-solid (powder)
 Non-Solid (Liquid)
 Rain →



❑ Drops (constant volume of water)

- Modelling
 - Mixing rule model
 - Empirical model



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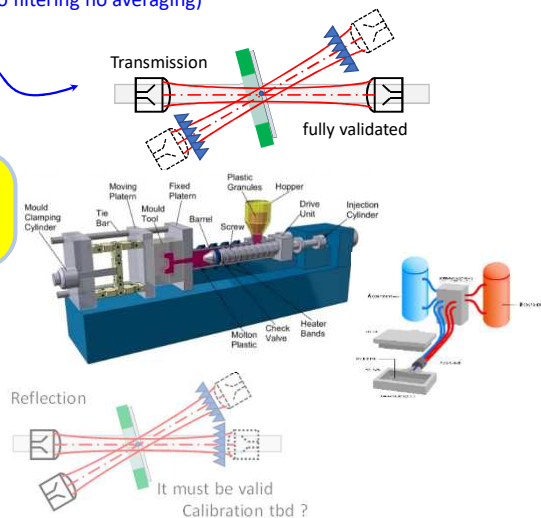
Free space setup capabilities up to 330 GHz



Conclusions & prospects

- ❑ [S] measurements
 - Normal or incident angle (TE & TM)
(Absorber, Radom, FSS, metamaterials, ...)
- ❑ Dielectric characterization (ϵ_r)
 - Slabs
 - Non solid material
 - Powders
 - Liquids
 - Mixture
 - Multilayer slabs
 - Glue included
 - Coat of paints
 - Effect of rain up to 330 GHz
- ❑ Oblique incidence (reflection, ...)
- ❑ Display the precision of results
- ❑ Air measurement ($\epsilon_{r,air} \approx 1.00059... - j...)$

(no filtering no averaging)



for material development including physicochemical properties

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Thank you for your attention

