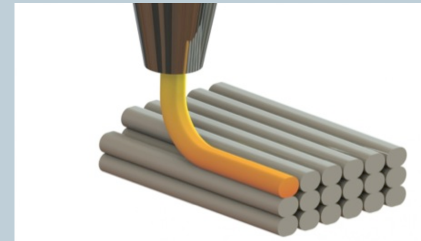

Fused Deposition Modeling: A new technology for the fabrication of microwave loads ?

Lab-STICC / UBO

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SPCD 2018

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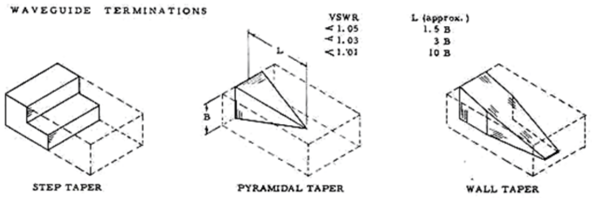
Outline

- ➲ **Technology and materials**
- ➲ **Fabrication and measurements**
  - ➲ **X-band pyramidal loads**
  - ➲ **K-band tapered wedge loads**
  - ➲ **X-band compact loads**
- ➲ **Conclusion and prospects**

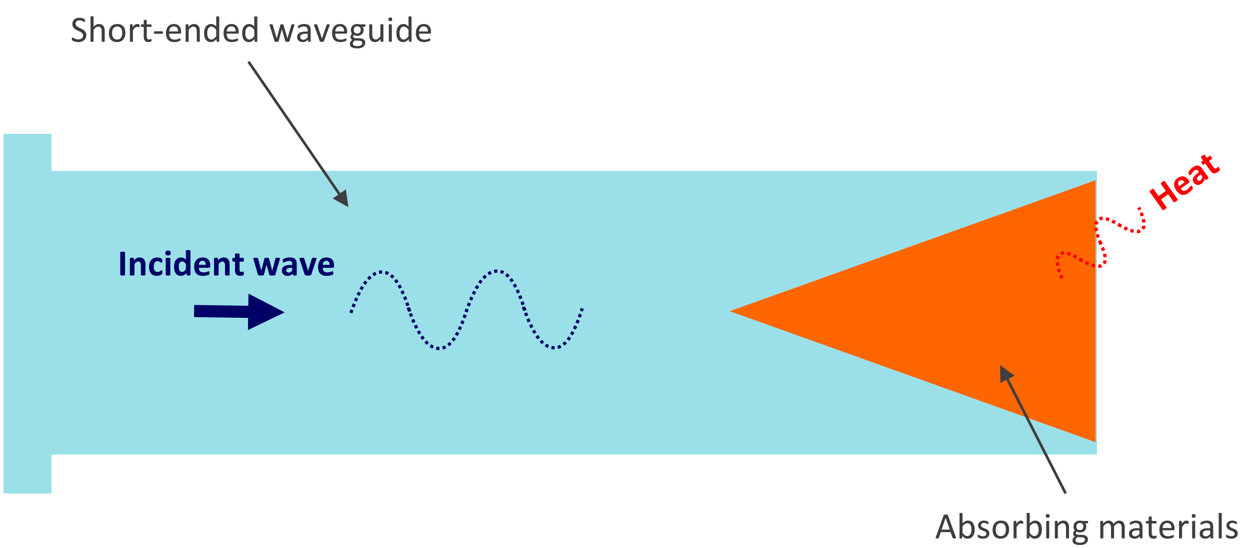
Technology and materials

➲ Microwave loads

- ➲ One port device
- ➲ Applications: isolators, couplers, metrology…
- ➲ Rectangular waveguide: short-ended waveguide + absorbers
- ➲ Characteristics: RL (or VSWR), Power Handling, BW, Size, Cost



Examples of absorber shape



➢ **Additive technology: a low-cost way to shape absorbers**

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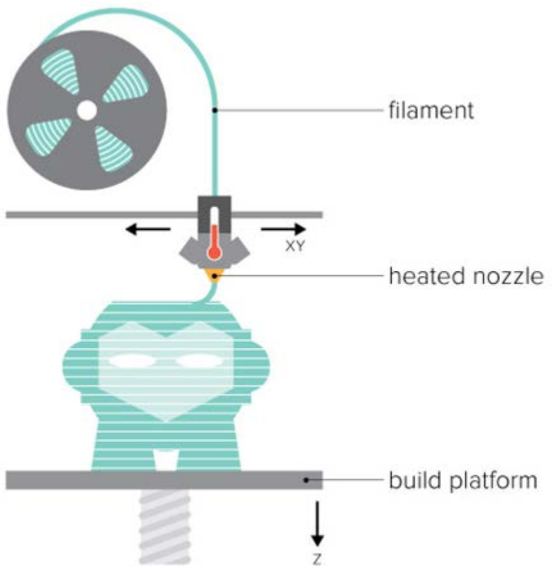
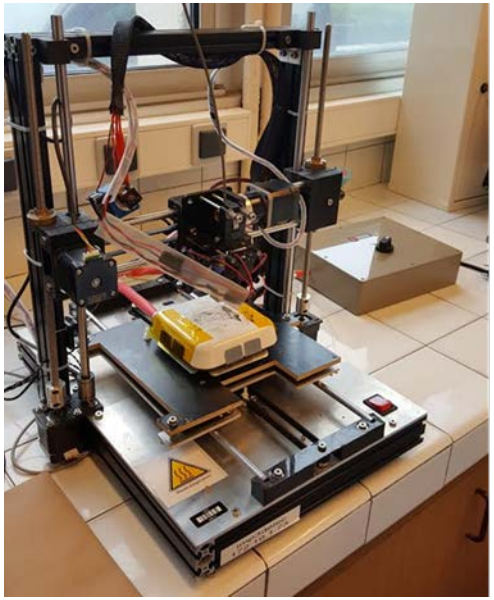
Technology and materials

➲ Fused Deposition Modeling

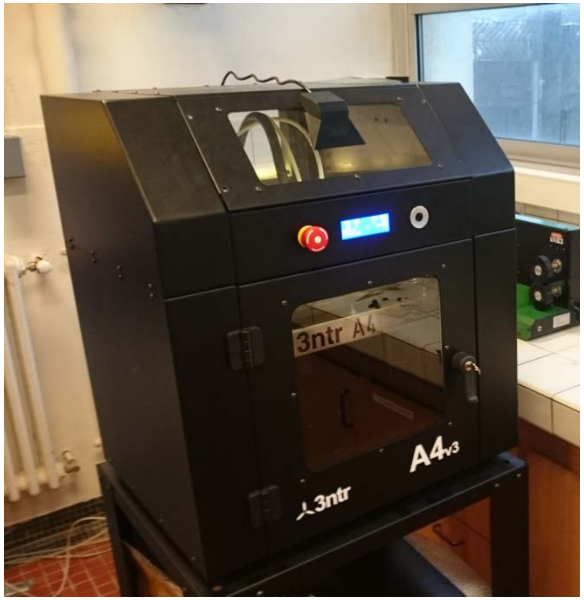
- ➲ Low-cost technology
- ➲ Layer-by-layer deposition of a fused polymer
- ➲ Thickness of layer: 50 to 200 µm



FDM principle



RepRap Asimov



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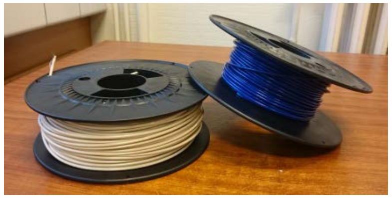
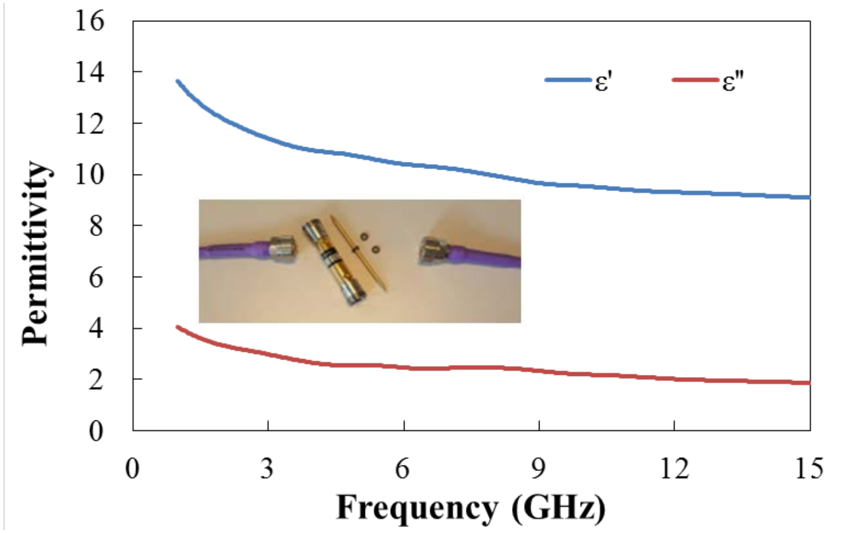
Technology and materials



➲ Printable materials

- ➲ A lot of commercial references (mainly ABS, PLA)
- ➲ Pure polymers not of interest (low to medium losses)
- ➲ Composite materials (carbon, ferromagnetic particles): potential candidates for microwave absorption

- ➢ **Selected material: Carbon-loaded ABS (Torwell)**
- ➢ **3D printers: RepRap Asimov, Leapfrog Creatr HS, Makerbot Replicator 2X**



EM properties of ABS-C

- ➢ **EM properties: standard coaxial line method**
- ➢ **Dispersive dielectric properties**
- ➢ **X-band (8-12 GHz):**
  - ➢ $\varepsilon_r = 10$
  - ➢ $\tan\delta = 0.27$

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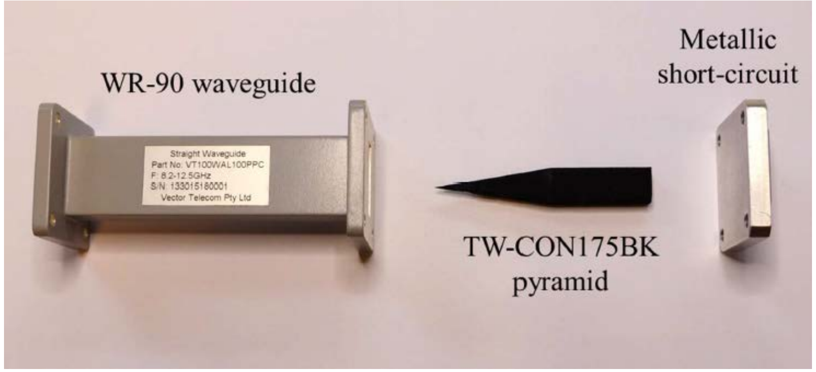
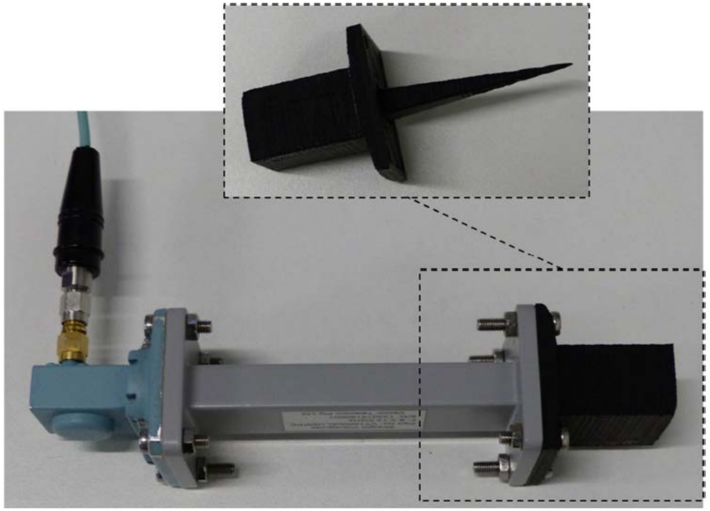
Fabrication and measurements

➲ X-band pyramidal loads

- ➲ Hybrid load: pyramidal absorber + short-ended waveguide
- ➲ Full 3D printed load: 3D printing of absorber + waveguide + flange



Hybrid load



Full 3D printed load

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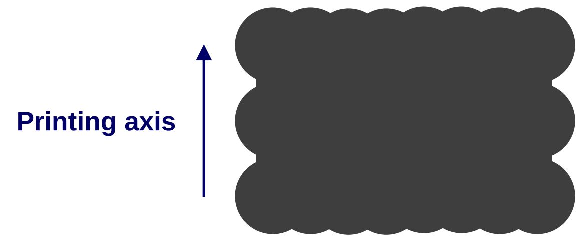
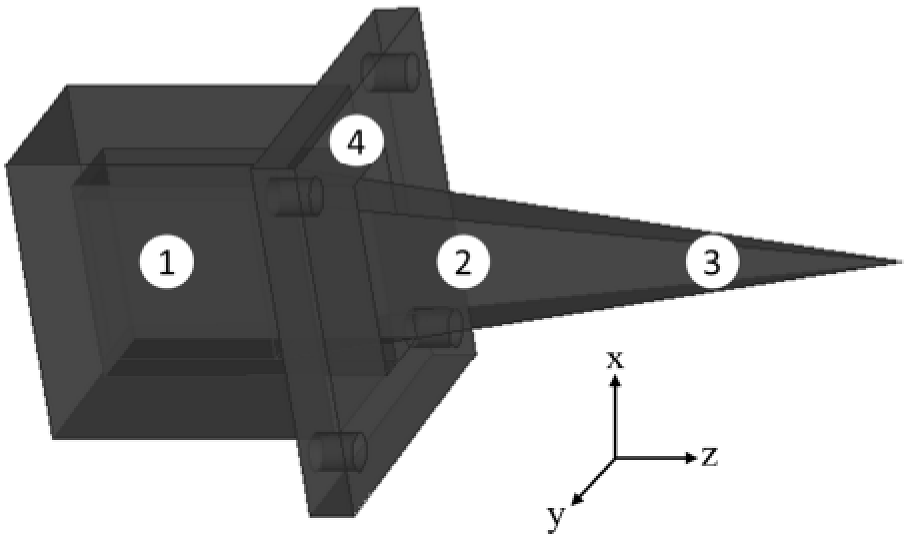
Fabrication and measurements

➲ X-band pyramidal loads

- ➲ Rugosity: profilometer Veeco Dektak 150





Zone	R_a (µm)	R_q (µm)
1	43.6	51.9
2	37.5	43.0
3	16.4	22.3
4	10.4	14.0

Measured rugosity of a full 3D printed load

- **Printing axis: z**
- **Higher rugosity along printing axis (mechanical polishing of tip)**
- **Flange sufficiently smooth to ensure a good contact**

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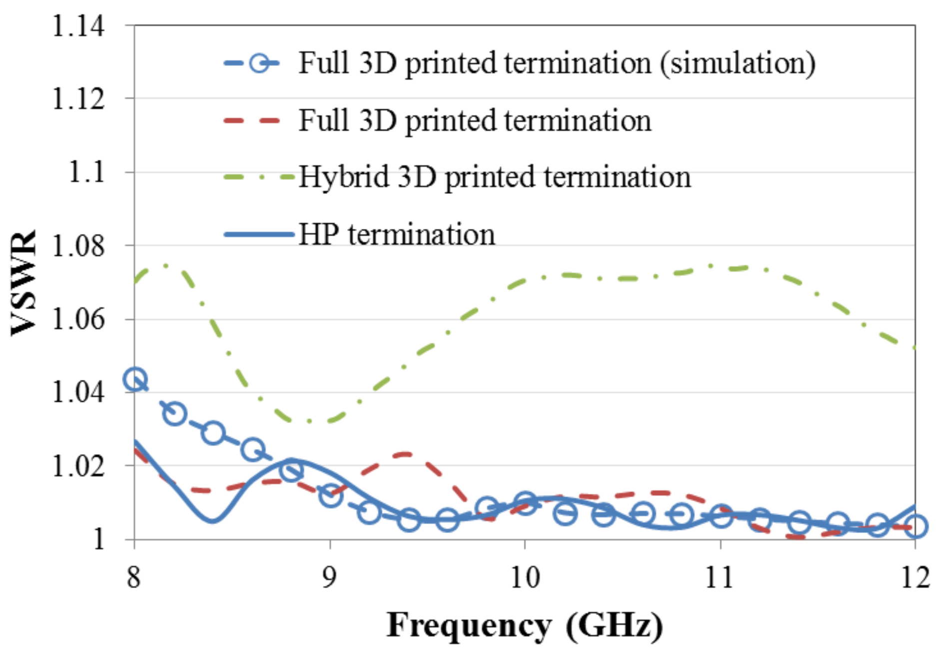
Fabrication and measurements

➲ X-band pyramidal loads

➲ Microwave measurements



Comparison of measured VSWR

- **Hybrid load: VSWR < 1.075**
- **Agilent and full 3D printed loads: VSWR < 1.025**
- **Consistent with simulations**
- **Cost: 10 to 100 times cheaper than commercial loads**

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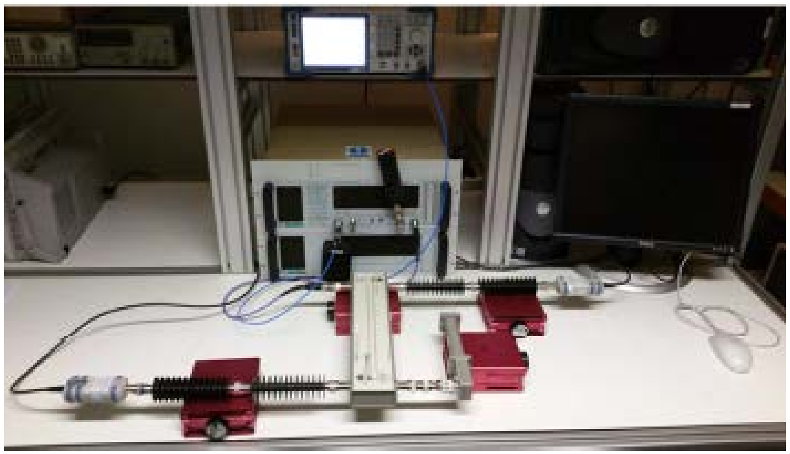
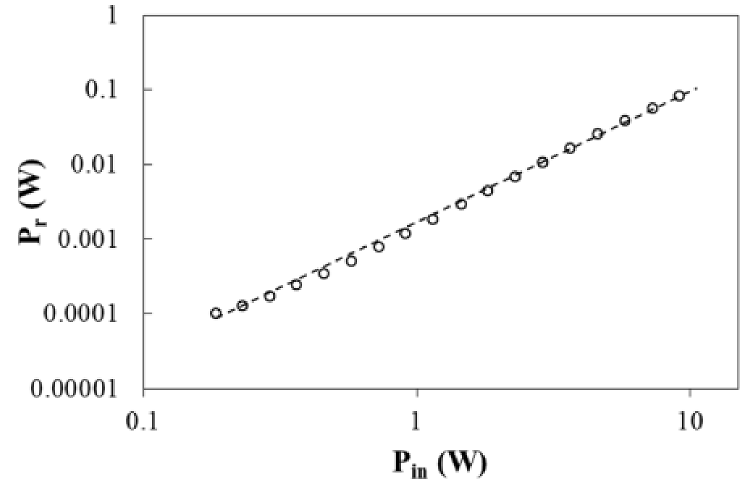
Fabrication and measurements

➲ X-band pyramidal loads

➲ Power handling





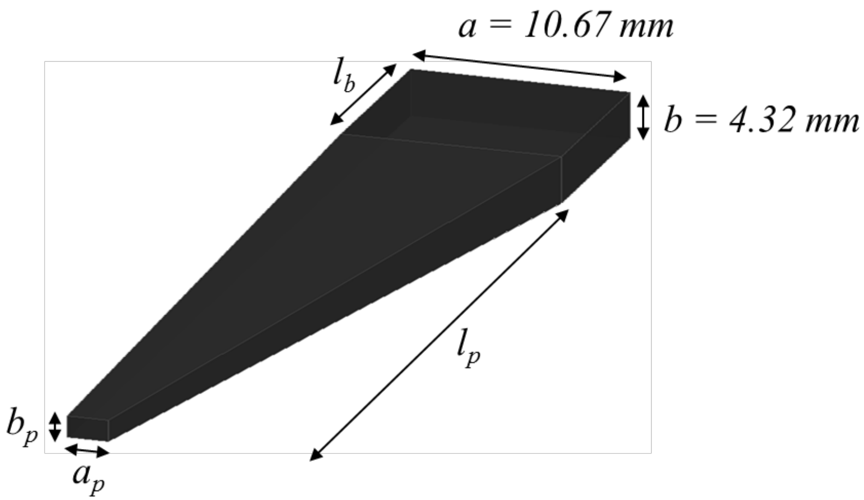
Test bench and measured power handling at 10 GHz

- **Max Power available 11.5 W / Measurement of reflected power P_r as a function of incident power P_{in} à 10 GHz**
- **Linear behavior of P_r/P_{in}**
- **No degradation up to 11.5 W**

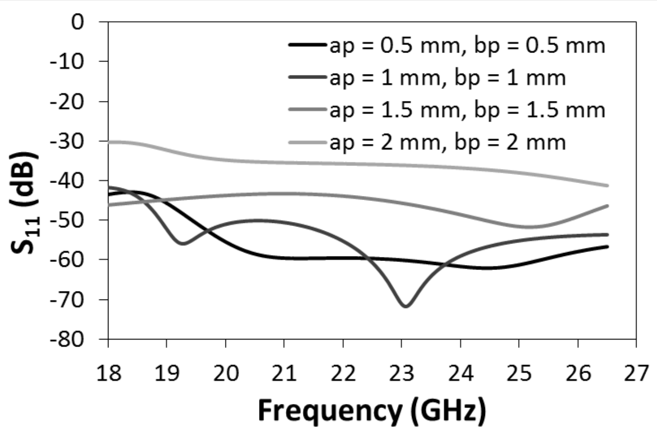
Fabrication and measurements

➲ Increase of frequency: K-band ?

- ➲ Decrease of load size (WR-42 waveguide)
- ➲ Reproducibility issues



Asymetrical Tapered Wedge (ATW)



Effet of tip truncation on reflection coefficient (l = 50 mm)

- **Avoid printing of tip**

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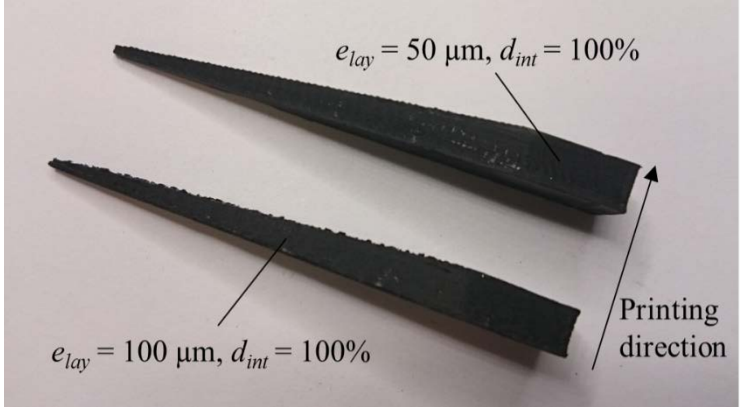
Fabrication and measurements

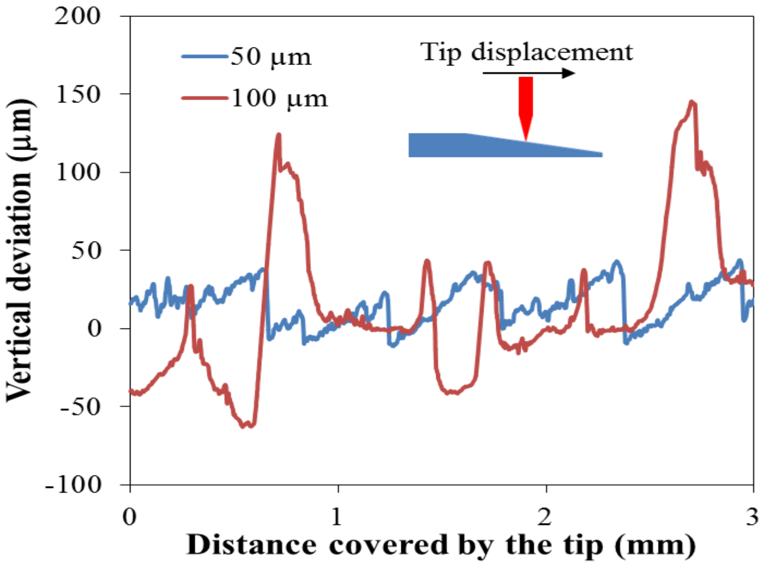
➲ K-band tapered wedge load

➲ Influence of printing parameters



Printed load with a layer thickness of 50 µm and 100 µm

e_{lay} (µm)	50	100
R_a (µm)	10.7	37.4
σ_{Ra} (µm)	2.3	27.6
R_q (µm)	13.6	46.5
σ_{Rq} (µm)	3.6	29.6



Comparison of rugosity for two different layer thicknesses

➢ **Optimization of printing parameters => Control of rugosity and random defects**

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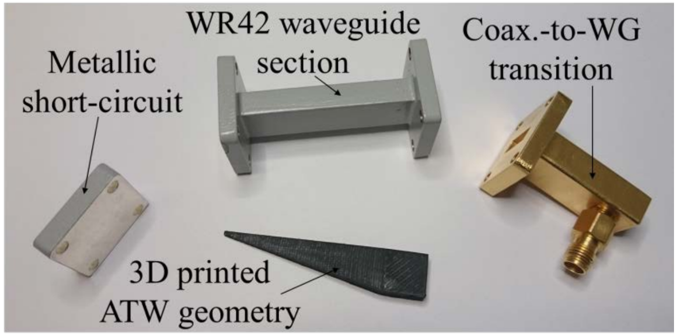
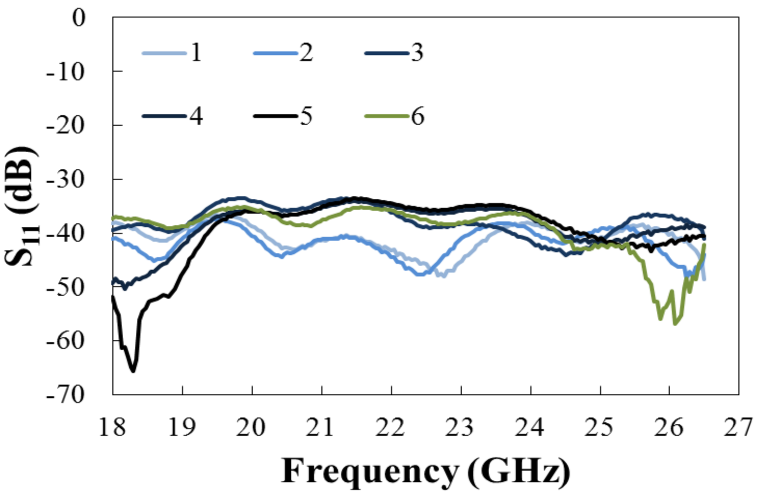
Fabrication and measurements

➲ K-band tapered wedge load

➲ Microwave measurements



Characterization cell



Comparison of reflection coefficient of 6 printed loads between 18 and 26.5 GHz

- **RL > 33.5 dB for 6 loads printed in the same conditions**
- **Good reproducibility (without post-machining)**

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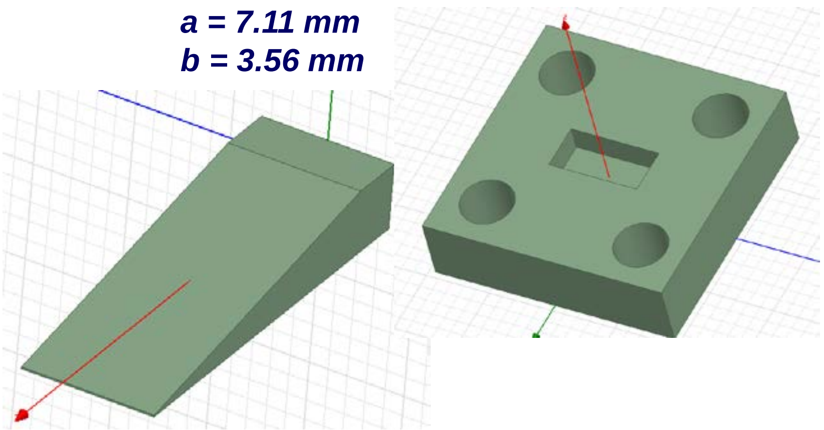
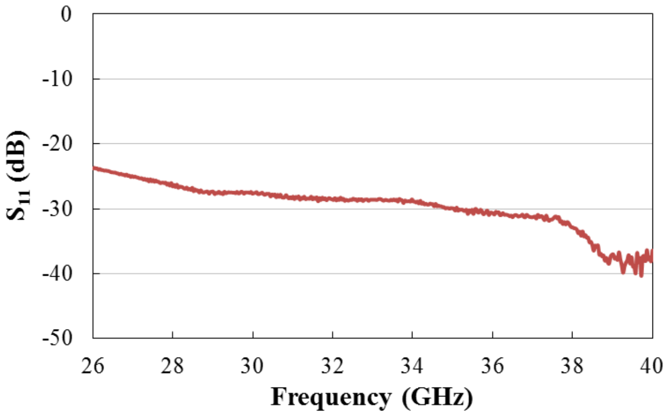
Fabrication and measurements

➲ Ka-band E-plane wedge load

- ➲ « Lego-like » load: wedge insertable in flange



Load principle



Reflection coefficient in Ka-band

- **RL > 27 dB at 30 GHz**
- **Fast development and fabrication**
- **Modular design / Adjustment of RL levels as a function of length**

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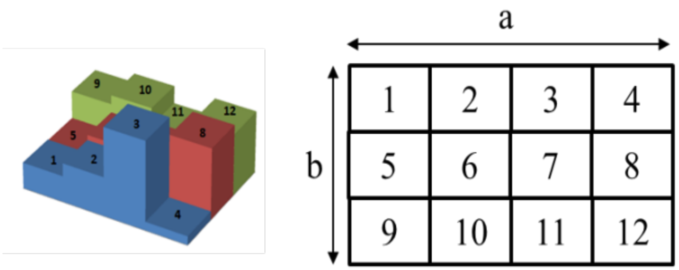
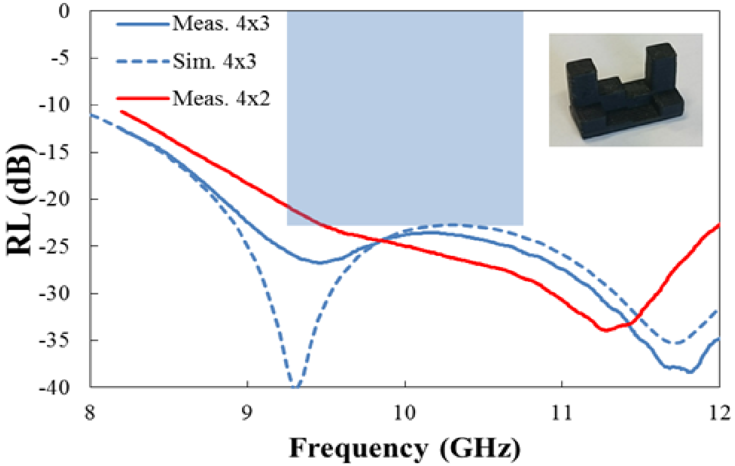
Fabrication and measurements

➲ Compact X-band load

- ➲ Decrease of size: complex topologies by 3D printing ?
- ➲ Discretization of absorber in the transverse plane (blocs with different lengths)



Topology description of a 4x3 structure



Reflection coefficient of different configurations

- **Several possible configurations / Design using EM optimizer**
- **Simulation: length divided by 4 / classical topology (pyramid)**
- **Measurement: length divided by 2 (very sensitive structure / air gaps, dimensions variations)**

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Conclusions and prospects

- ➲ **FDM technology: promising low-cost and easy-to-use technology for the fabrication of microwave load**
- ➲ **Several commercial printable composite materials with appropriate EM properties**
- ➲ **Useable up to 40 GHz (and more ?)**
- ➲ **Complex topologies: decrease of size and weight**

➲ **Concept limitations:**

- ➲ **Limited resolution: complex topologies at high frequencies ?**
- ➲ **Maximum working temperatures of printable materials (60°C for PLA and 100°C for ABS) => Development of new materials**

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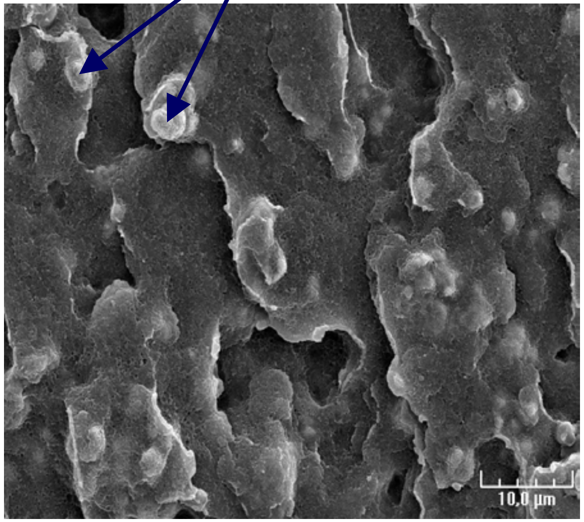
Conclusions and prospects

➲ Development of Fe_{20}-PPS_{80} printable composites

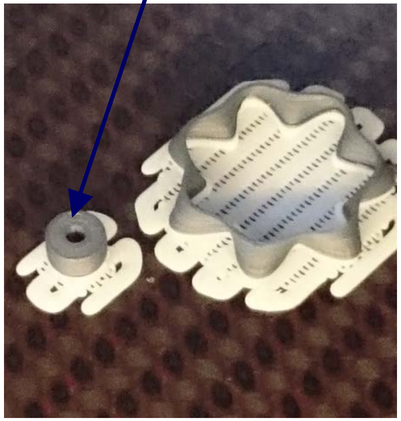
- ➲ PPS: high working temperature (240°C), high chemical resistance, fire resistant…
- ➲ Hot mixing of iron particles (5-6 µm) and PPS polymer
- ➲ Elaboration of printable filament

Fe



PPS-Fe filament

Toroidal sample printed in PPS-Fe



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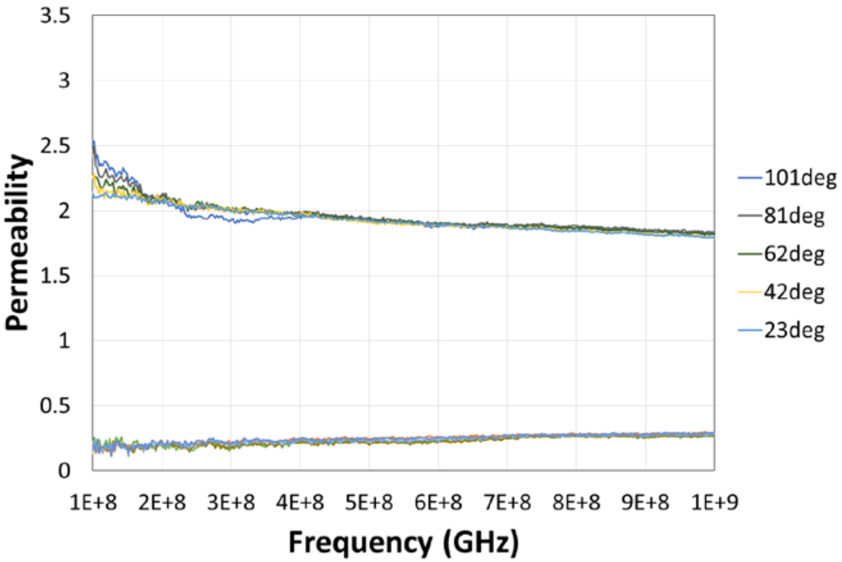
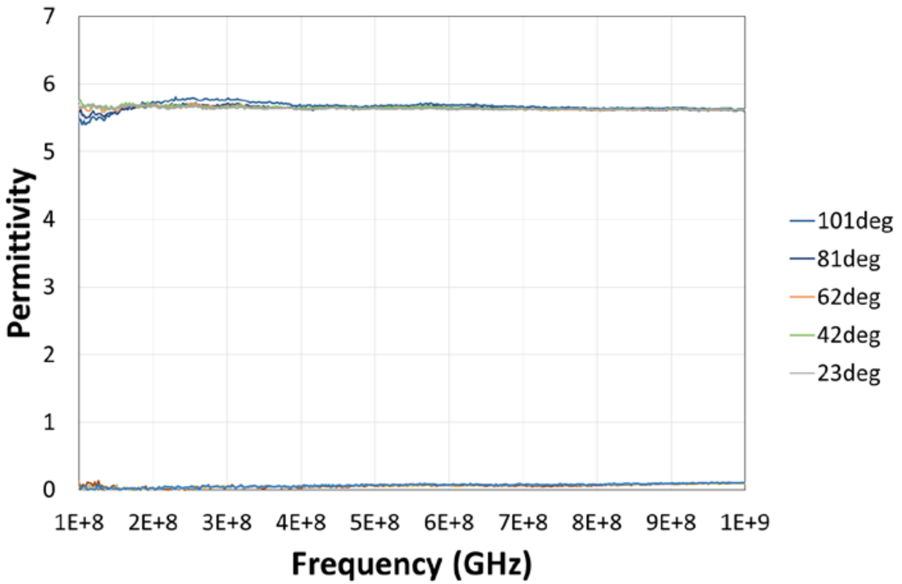
Conclusions and prospects

➲ PPS-Fe microwave properties





- **Very stable EM properties up to 100°C**
- **X-band properties:**
  - $\varepsilon_r = 6.1$
  - $\mu_r = 1.2$
  - $\tan\delta_\varepsilon = 0.02$
  - $\tan\delta_\mu = 0.32$

- **Useable as a temperature-stable microwave absorber**
- **PPS-Fe loads under progress**

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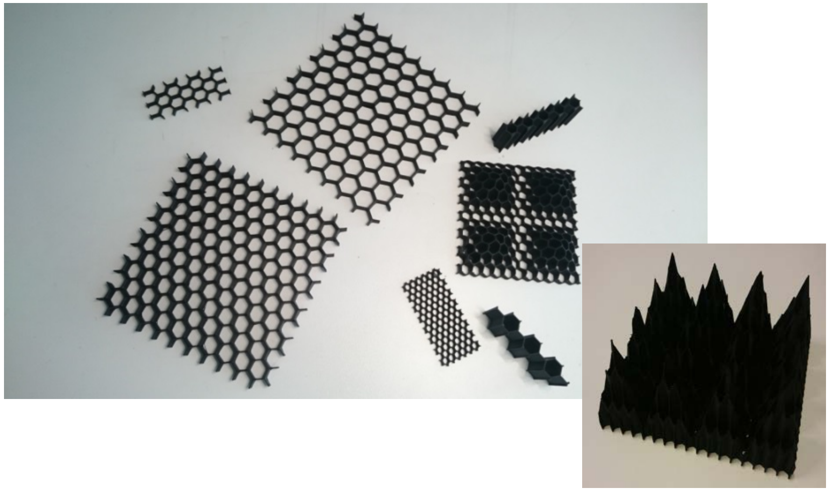
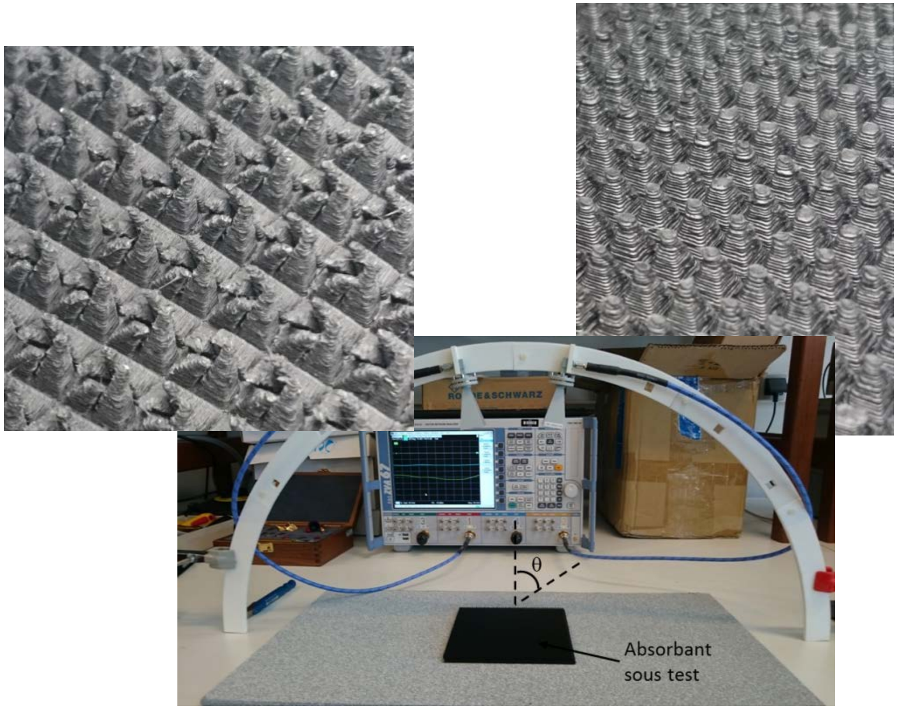
Conclusions and prospects

➲ Other applications of the technology: plane-wave absorbers



Printed honeycomb microwave absorbers



Printed grazing incidence millimeter-wave absorbers

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Acknowledgements

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Thank you for your attention

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