Swissto12®

terahertzapplications

Guided THz transmission enabling applications

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@swissto12


swissto12.ch

Outline

- About SWISSto12
- Modular Corrugated wave-guiding components & technology
- Outlook: application platforms based on SWISSto12 components:
  - Material characterization
  - On wafer probing
  - Gas spectroscopy
- Sub-mm wave and THz Antennas
- Additive manufacturing for low-cost wave-guiding components

About SWISSto12

Spin-off from EPFL

- Company founded in 2011
- 4 Patented manufacturing technologies and components
- Supplier of wave-guiding components for millimeter waves and THz waves
    - Antennas
    - Waveguides
    - Quasi optical components

SWISSto12 capabilities

- Component electromagnetic design
- CAD and mechanical design
- Manufacturing through large network of “best in class” Swiss precision mechanics suppliers
- Mechanical QC: 3D measurements

- Electromagnetic measurements:

VNA in collaboration with EPFL
From **1 GHz** to **43 GHz**
(From **75 GHz** to **110 GHz)**
From **220 GHz** to **330 GHz**
From **500 GHz** to **750 GHz**

WR1.0 (750-1,100 GHz) VNA System

Image Courtesy of Agilent

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The problem

Propagation losses of THz waveguides

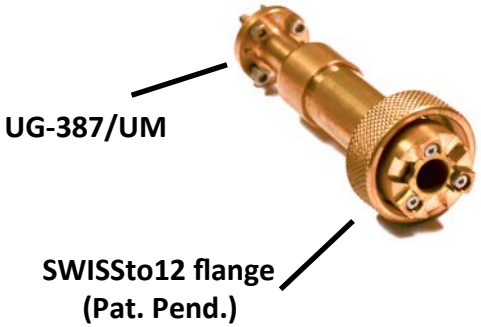
Rectangular waveguides have increasing losses for sub-mm and THz wave

	Theoretical losses
WR-5.1 (**140 – 220 GHz**) :	**7.4 - 12 dB/m**
WR-4.3 (**170 – 260 GHz**) :	… **10 - 14 dB/m**
WR-3.4 (**220 – 330 GHz**) :	… **14 - 20 dB/m**
WR-2.8 (**260 – 400 GHz**) :	… **18 - 28 dB/m**
WR-2.2 (**330 – 500 GHz**) :	… **26 - 39 dB/m**
WR-1.9 (**400 – 600 GHz**) :	… **34 - 50 dB/m**
WR-1.5 (**500 – 750 GHz**) :	… **49 - 70 dB/m**
WR-1.2 (**600 – 900 GHz**) :	… **64 - 95 dB/m**
WR-1.0 (**750 – 1100 GHz**) :	… **93 - 135 dB/m**

SWISSto12 waveguides (Corrugated waveguides)
Losses ≈ **0.1 – 0.01 dB/m**

The solution

SWISSto12 Waveguide Modules
WR 1.5 (500-750 GHz)



SWISSto12 Converter
For efficient coupling between traditional rectangular waveguide components (UG-387/UM flange) and SWISSto12 corrugated waveguide modules.

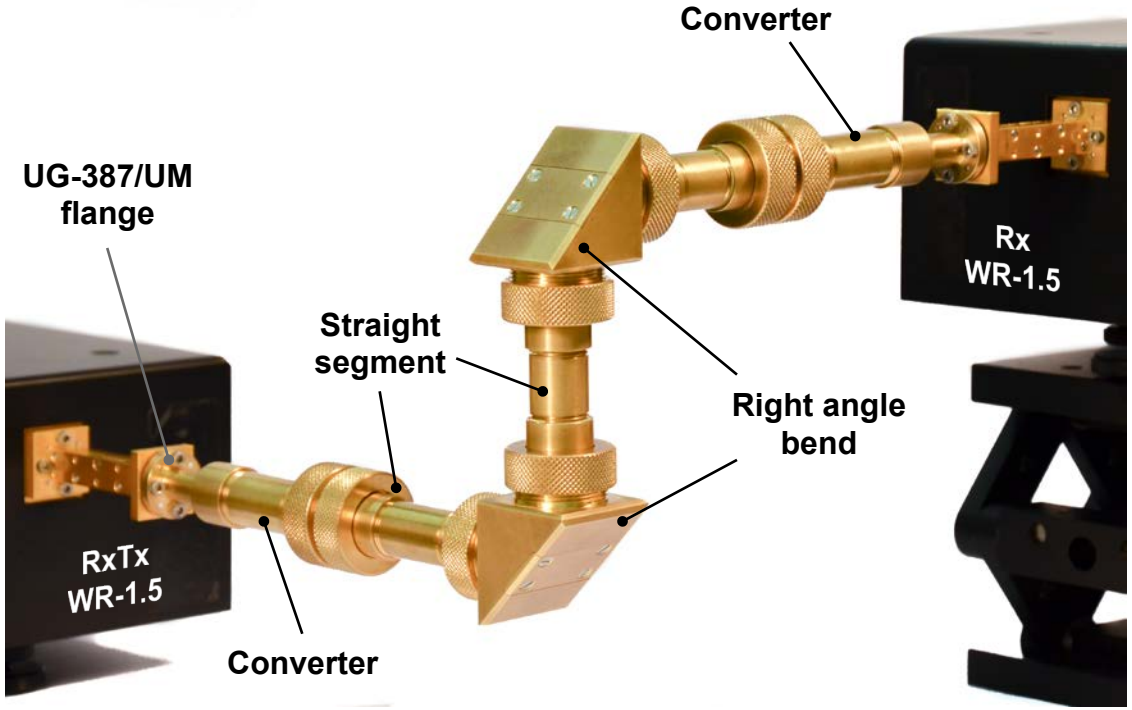
SWISSto12 Waveguide
Corrugated waveguide, inner diameter 8 mm

SWISSto12 Right Angle Bend

The solution

SWISSto12 Waveguide Modules
WR 1.5 (500-750 GHz)

Components allow for modular path-building



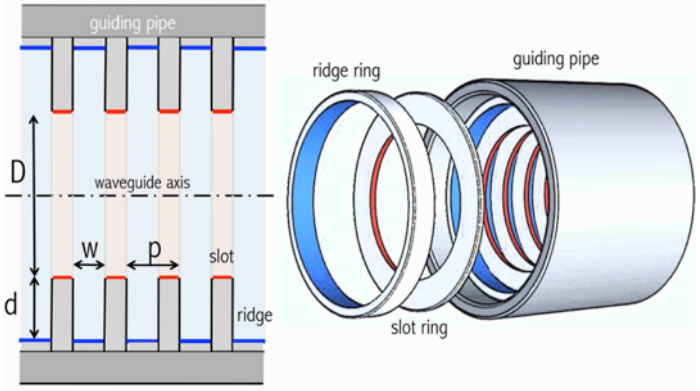
Technology

Stacked Rings for Corrugated Waveguides

- Corrugated waveguides offer low loss transmission of sub-mm and THz waves
  Example: WR-1.5 (500 – 750 GHz) corrugated waveguide: losses ≈ 0.1 db/m

- Corrugated waveguides propagate an HE_{11} mode, analogous to an optical fiber
  (E. De Rijk, Rev. Sci. Instr. , Vol. 82, 2011)

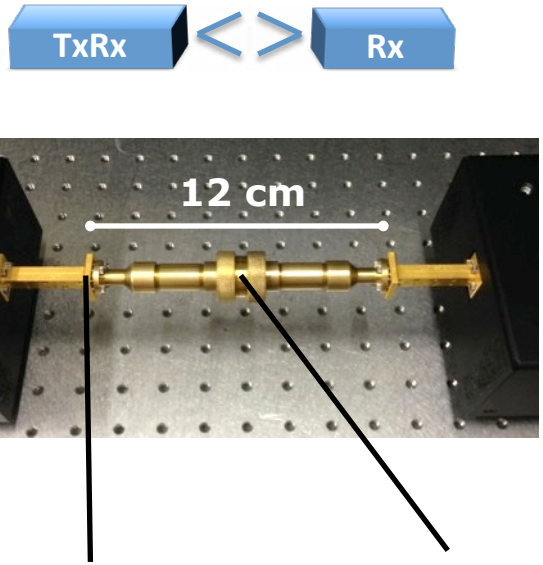
- Corrugated waveguides are hard to manufacture with conventional techniques
  Overcome limitations of conventional manufacturing with SWISSto12's Stacked Rings technology (Pat. Pend.)



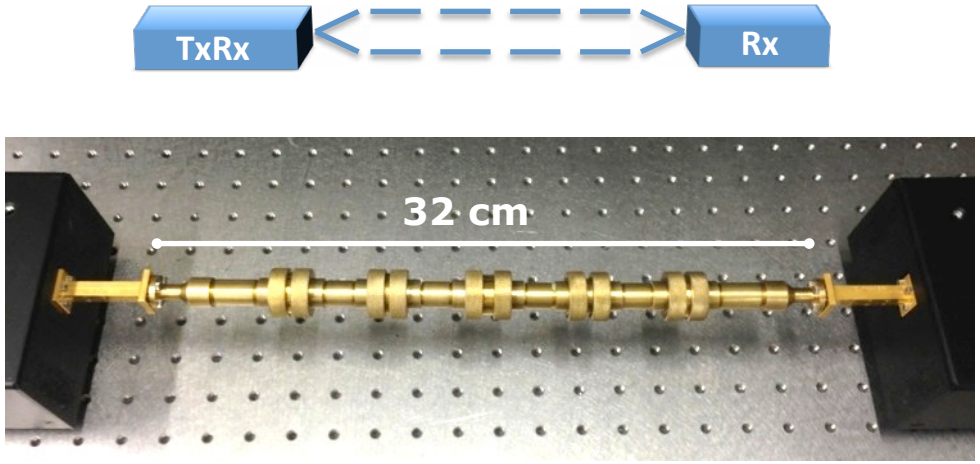
Technology

Stacked Rings for Corrugated Waveguides

Reference:
Converter-Converter (12 cm propagation)



Measurement configuration:
Converters + 4 waveguides (32 cm propagation)



UG-387/UM Flange
Rectangular waveguide

SWISSto12 Flange (Pat. Pend.)
Corrugated waveguide

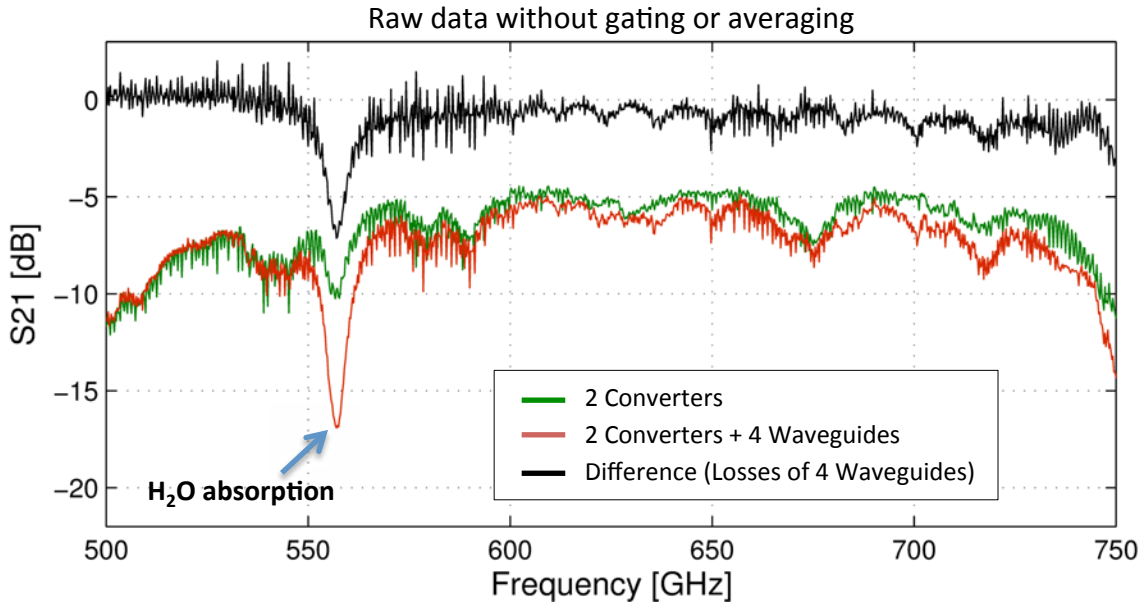
SWISSto12 Waveguides and Bends

Transmission results (S21)

Converter-Converter (12 cm propagation)

Converters + 4 waveguides (32 cm propagation)

Raw data without gating or averaging



- **Losses dominated by the two Converters** (12cm with ≈ 6-8 dB loss)
  Note: Equivalent 12cm of WR-1.5 rectangular waveguides : 5.6 to 8 dB losses

- **SWISSto12 Waveguide modules introduce low losses** (including converters: 32cm with ≈ 6-8 dB loss)
  Note: Equivalent 32cm of WR-1.5 rectangular waveguides : between 16 to 22 dB losses

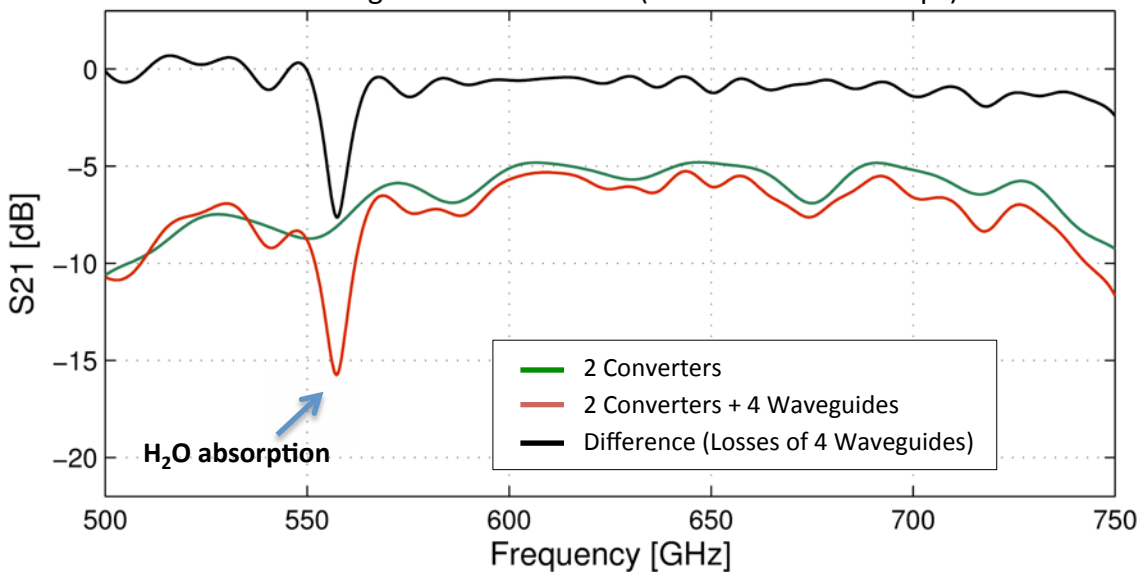
SWISSto12 Waveguides and Bends

Transmission results (S21)

Converter-Converter (12 cm propagation)

Converters + 4 waveguides (32 cm propagation)

Time gated measurement (window width ~ 100 ps)

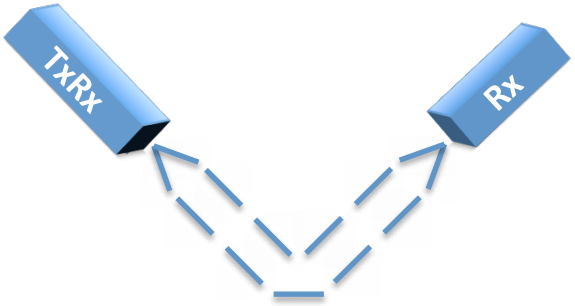


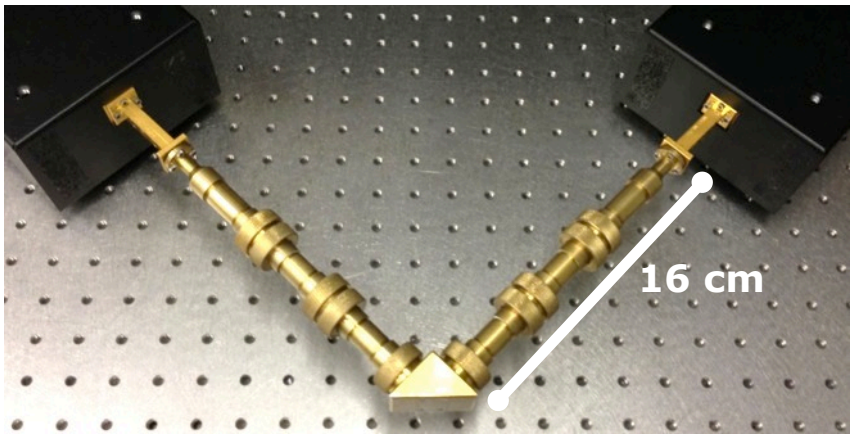
- **Time gating smoothens the S_{21} parameter curves**

SWISSto12 Waveguides and Bends

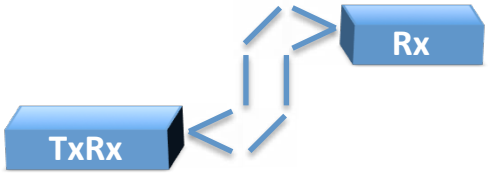
Transmission results (S21)

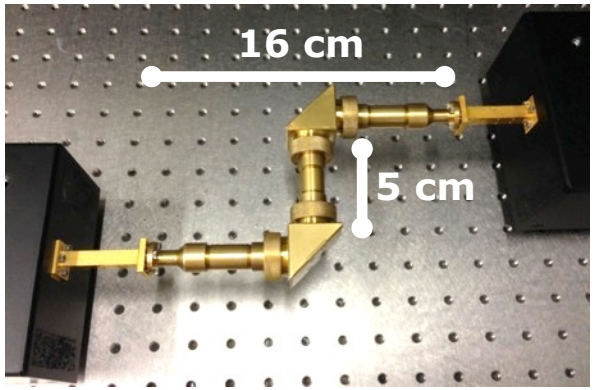
Converters + bend + 4 waveguides
(32 cm propagation)





Converters + 2 bends + 1 waveguide
(21 cm propagation)



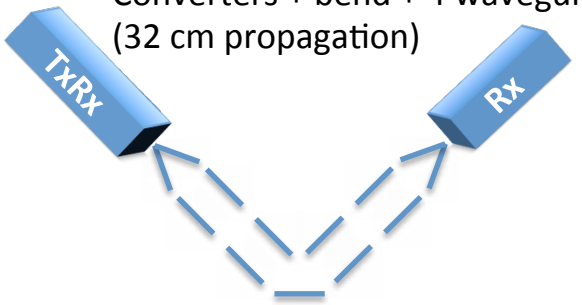


SWISSto12 Waveguides and Bends

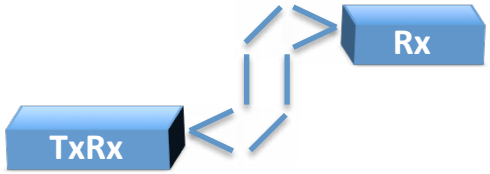
Transmission results (S21)

Converter-Converter
(12 cm propagation)

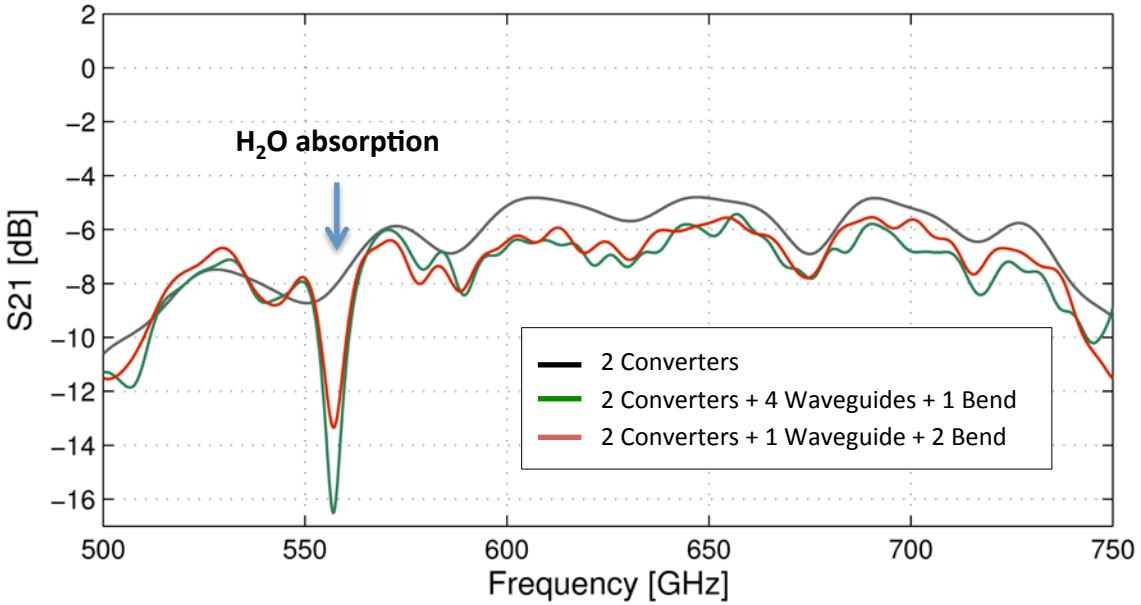
Converters + bend + 4 waveguides
(32 cm propagation)



Converters + 2 bends + 1 waveguide
(21 cm propagation)



Time gated measurement (window width ~ 100 ps)

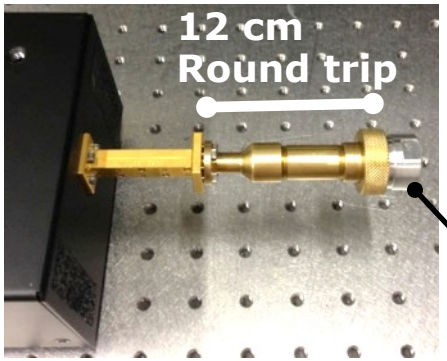


- **Low losses introduced by bends (≈ 1dB per bend)**

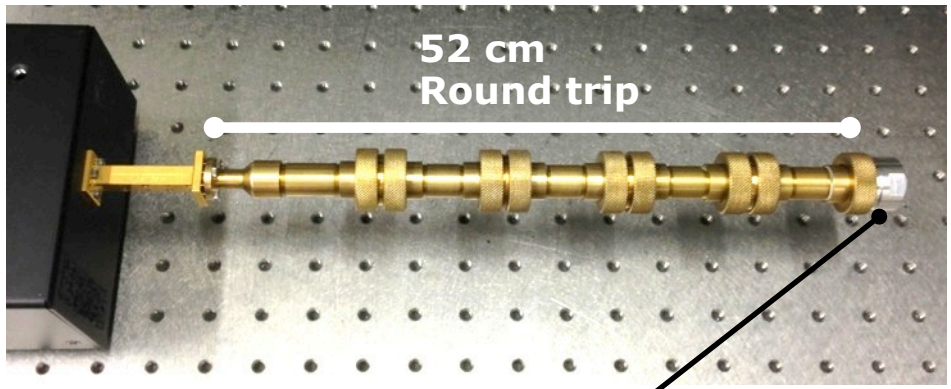
SWISSto12 Waveguides and Bends

Reflection results (S11)

Converter-short
(12 cm round trip)



Converter + 4 waveguides
(52 cm round trip)



Waveguide short = Aluminum mirror

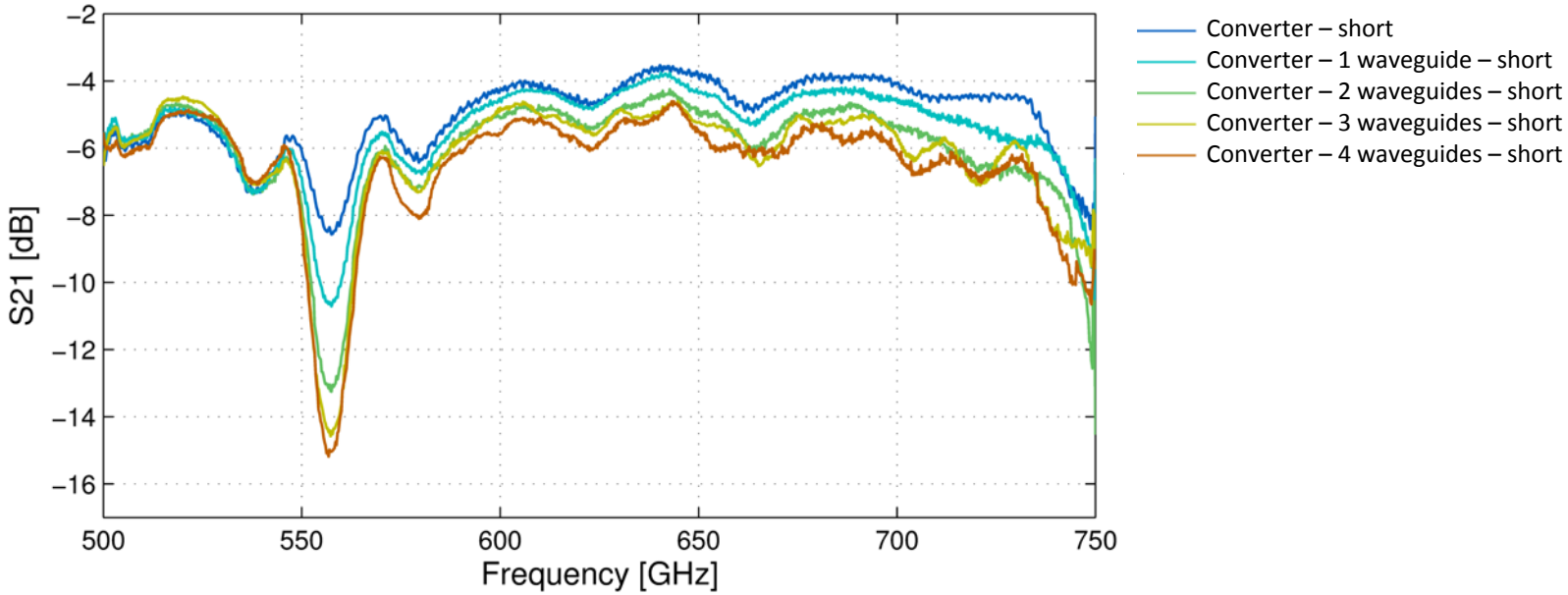
SWISSto12 Waveguides and Bends

Reflection results (S11)

Converter-short
(12 cm round trip)

Converter + 4 waveguides
(52 cm round trip)

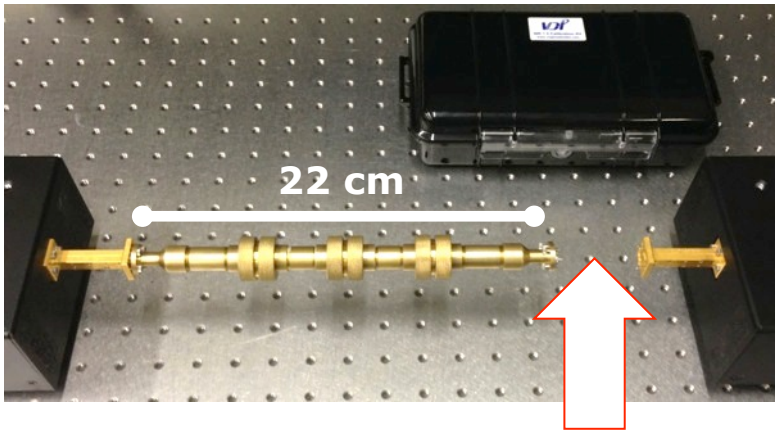
Raw data is flattened using a 40-samples moving-average-filter



- **Low losses observed when adding waveguide modules: < 3 dB/m for f < 700 GHz**
  Note: 12cm of WR-1.5 rectangular waveguide: between 5.6 and 8 dB of propagation losses
  Note: 52cm of WR-1.5 rectangular waveguide: between 24 and 34.9 dB of propagation losses

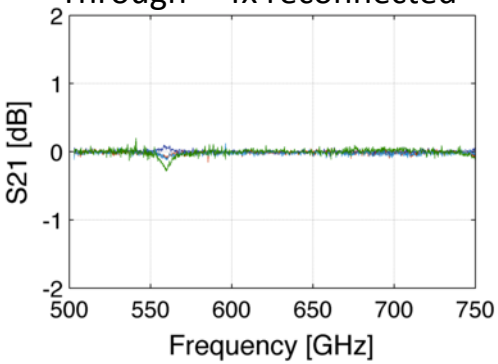
SWISSto12 Waveguides and Bends

TRL calibration on WR 1.5 rectangular waveguide

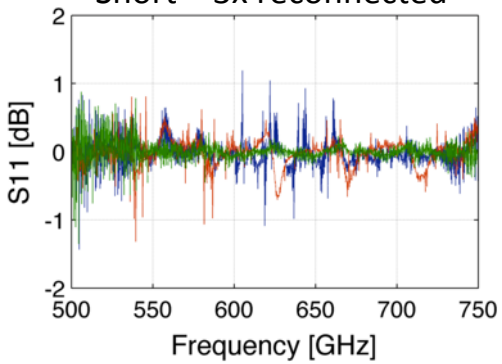


TRL calibration on WR 1.5 rectangular waveguide

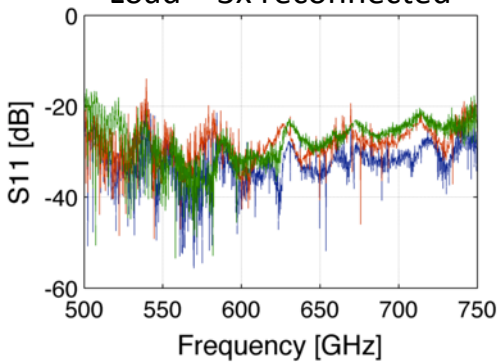
Through – 4x reconnected



Short – 3x reconnected



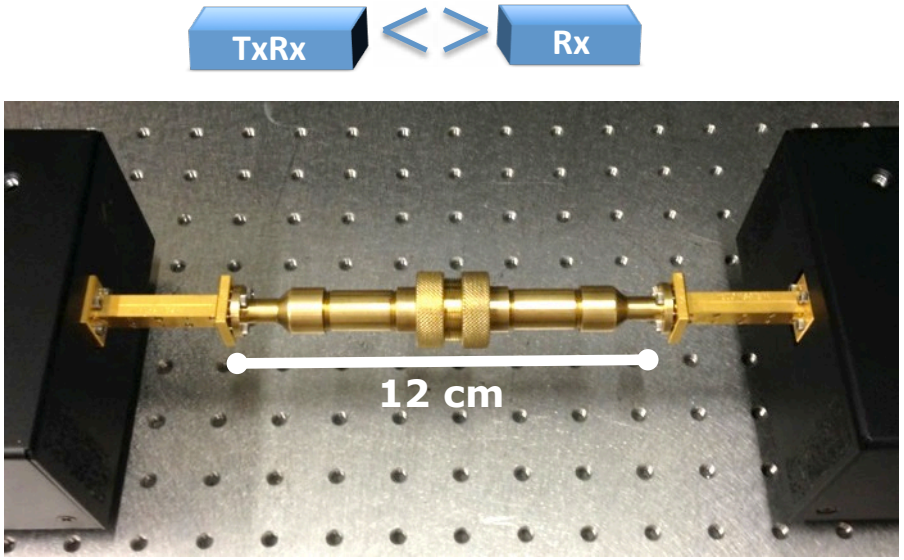
Load – 3x reconnected



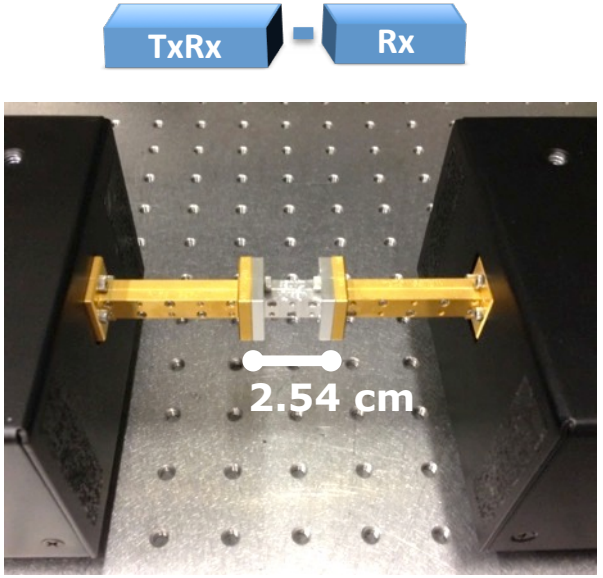
SWISSto12 Waveguides and Bends

Phase stability

Converter - Converter
(12 cm propagation)



WR-1.5 rectangular waveguide
(1 inch propagation)

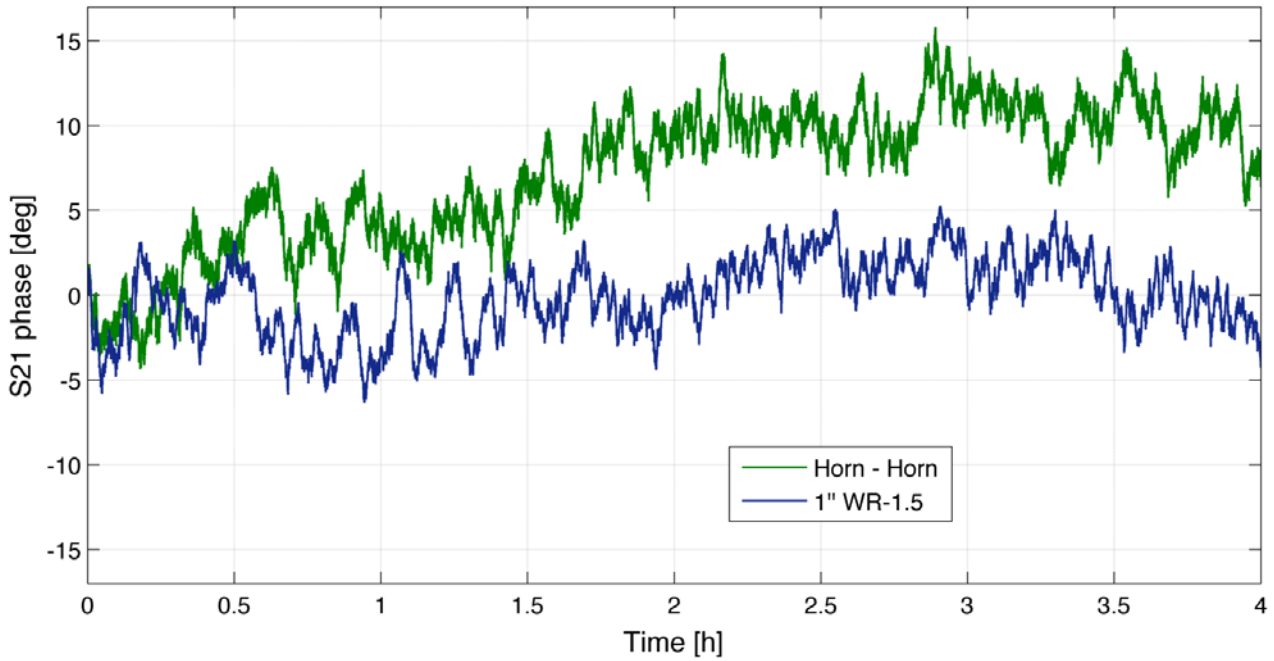


SWISSto12 Waveguides and Bends

Phase stability

Converter - Converter
(12 cm propagation)

WR-1.5 rectangular waveguide
(1 Inch propagation)



- **Phase stability comparable to standard rectangular waveguides**

Summary

SWISSto12 Waveguide Modules

- **Low-loss transmission**
  losses > 10’000 times lower than in rectangular waveguides for WR-1.5

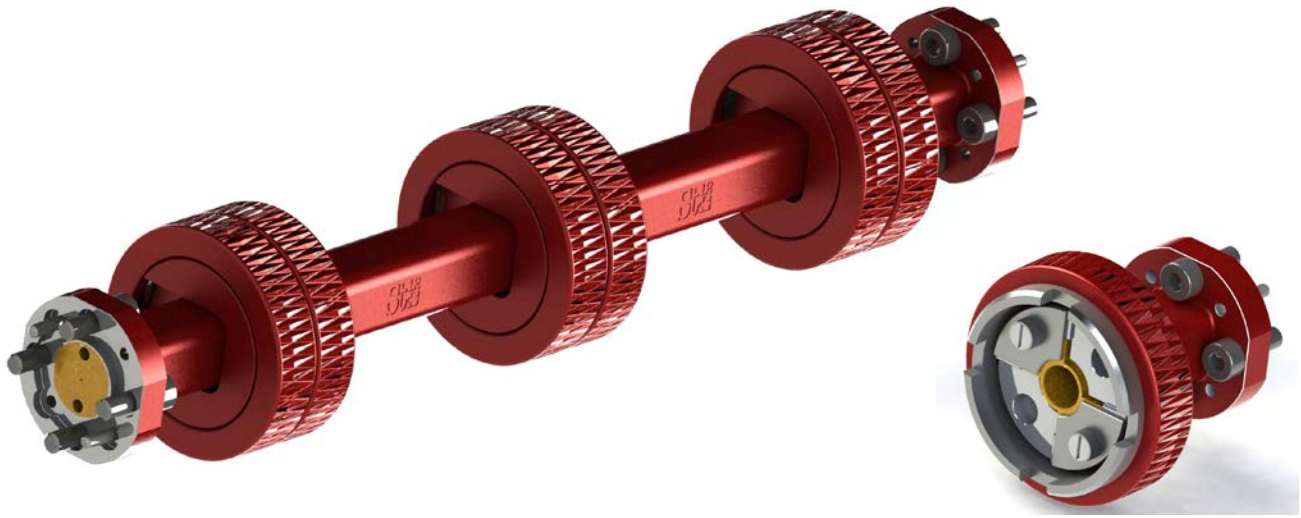
- **High phase stability**
  stability on par with rectangular waveguides

- **Modular system with self-aligning fast connection system**
  waveguide can be rapidly adapted to test & measurement needs

- **Compatibility with existing technology**
  efficient conversion from/to fundamental rectangular waveguides

SWISSto12 corrugated waveguides

New Design 2014



- More compact design
- Coverage of all bands up to WR 1.0
- Lower-loss converters (Loss: -1.5 dB to -2 dB expected)

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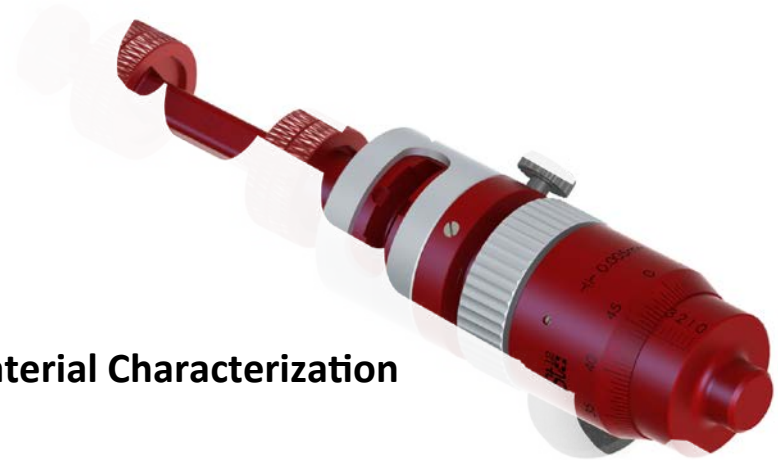
  - **Material characterization**
  - **On wafer probing**
  - **Gas spectroscopy**
- Sub-mm wave and THz Antennas
- Additive manufacturing for low-cost wave-guiding components

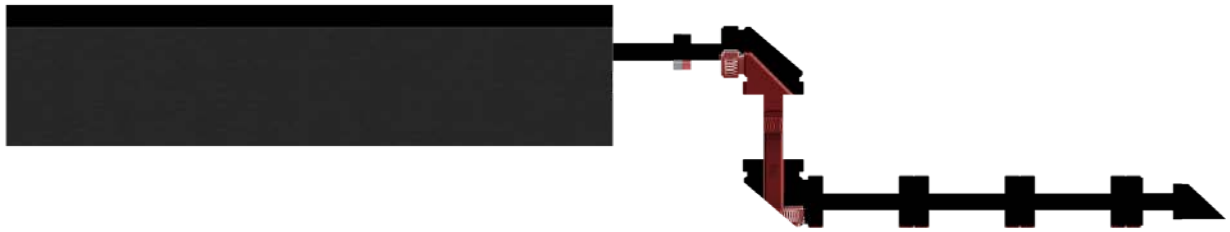
SWISSto12 corrugated waveguides

THz applications overview



Material Characterization

Gas Spectroscopy

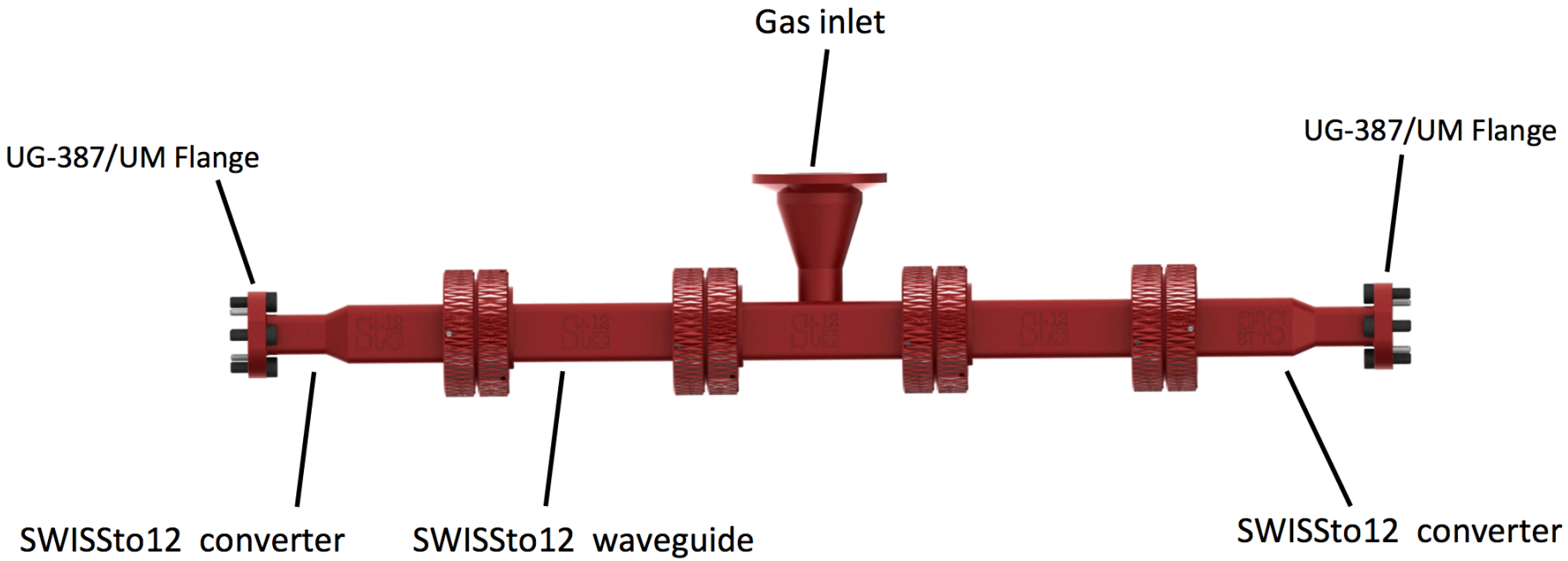


On wafer Probing

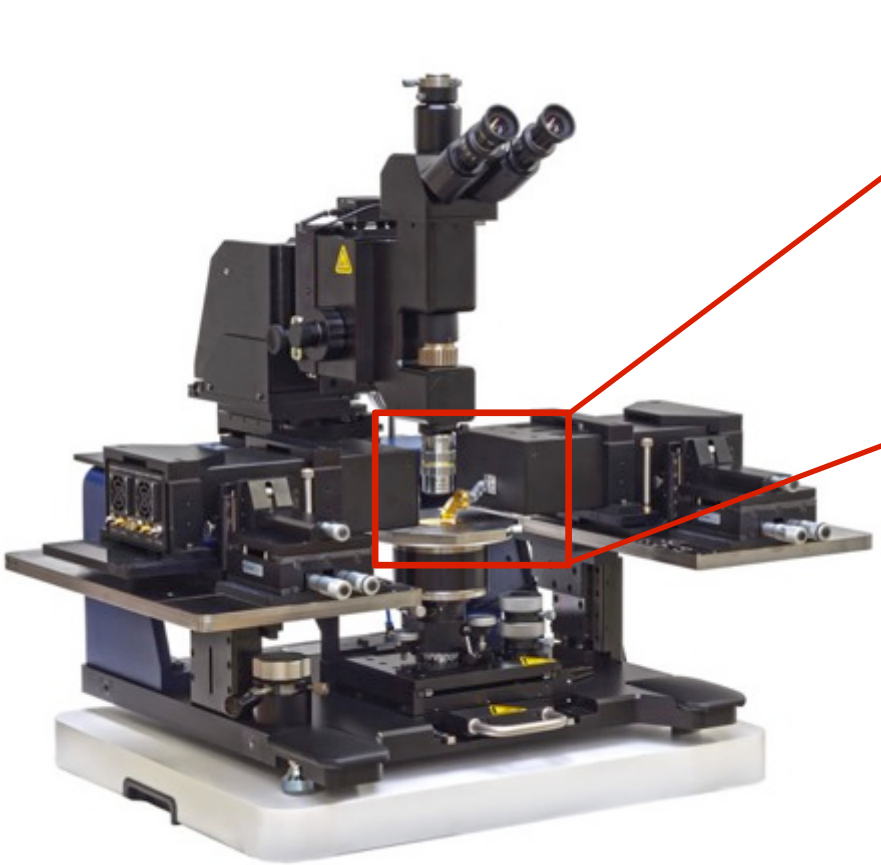
Gas detection or Spectroscopy with THz

The Concept:

- THz signals (frequencies between 100 GHz and 3 THz) have strong interactions with gases
- Measure THz Spectral absorption of the gas, detect low concentrations
- Confine the gas under study inside the large volume of SWISSto12 THz waveguides



THz on-wafer probes



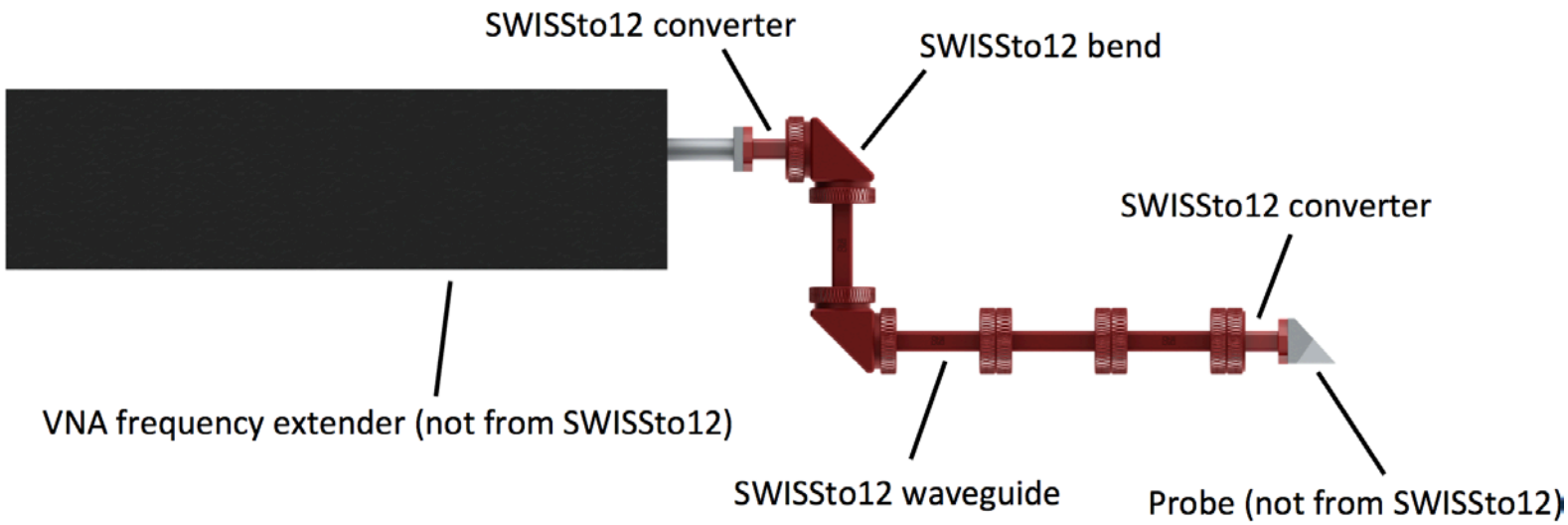
Fundamental rectangular waveguides between VNA extension head and Probe Tip:

> Propagation losses

> Limits on directivity of the VNA measurements

> Constraints on geometry

THz on-wafer probes
via SWISSto12 waveguide



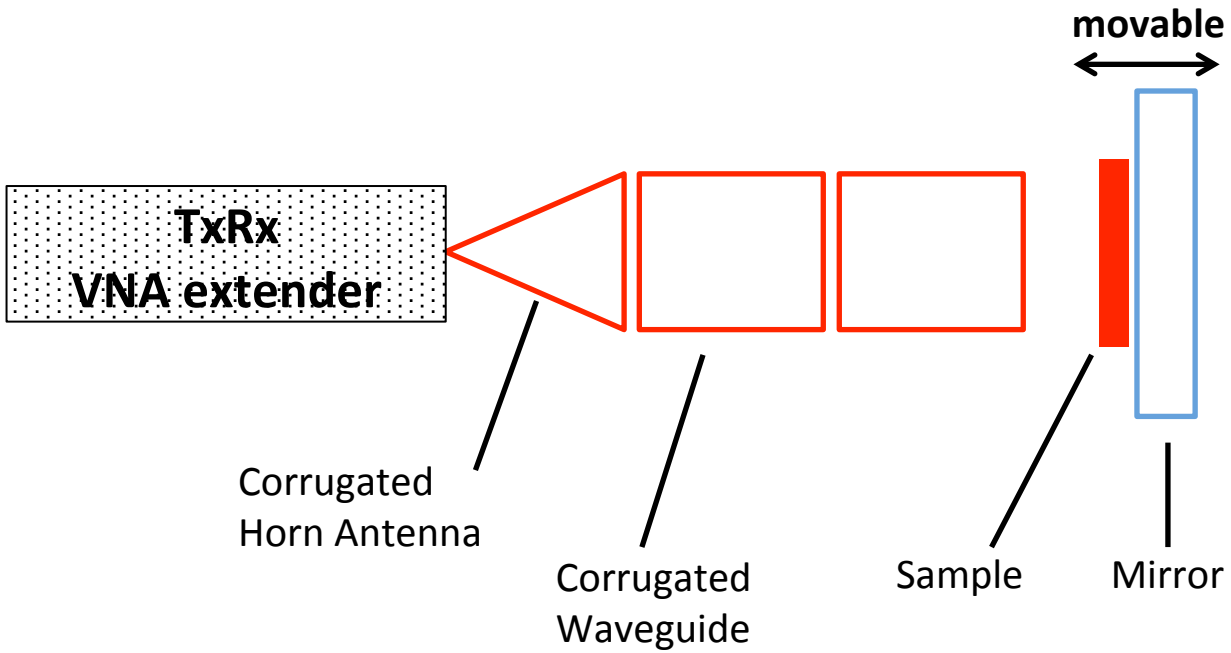
- **Low propagation losses**
  More than four orders of magnitude lower than rectangular waveguides
- **No constraints on geometry**
  Compact modules can be easily reconfigured
- **Compatible with cryogenic systems**

Material characterization at THz frequencies

- Existing solutions are expensive, bulky and require expert knowledge
- SWISSto12 offers a **novel material characterization kit** that is compact, versatile and easy to use

Material Characterization

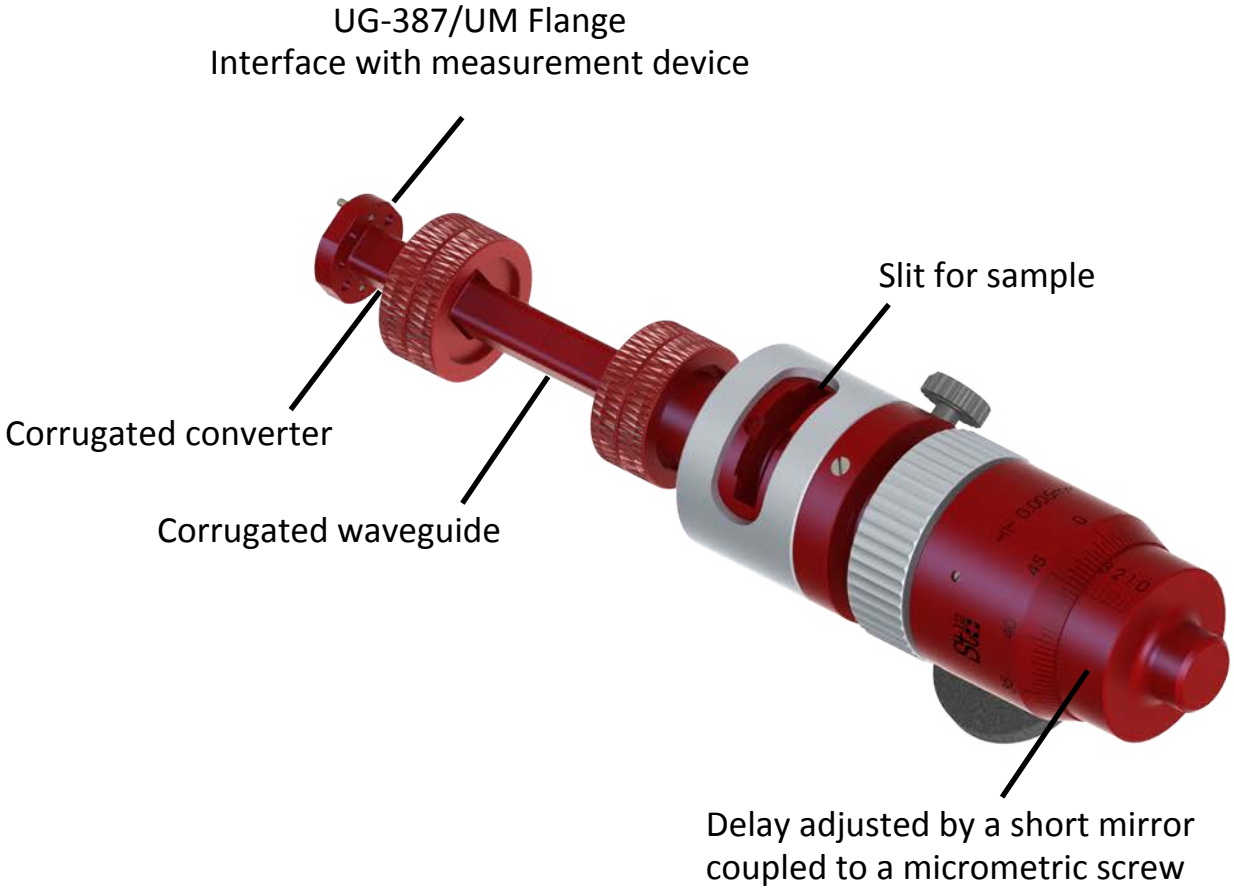
1-Port configuration (S11)



- Calibration plane on the surface of an adjustable mirror closing the waveguide aperture (over-determined calibration algorithm)
- Sample placed on the surface of the mirror
- Enables efficient measurement of **permittivity (ε‘) vs. frequency**

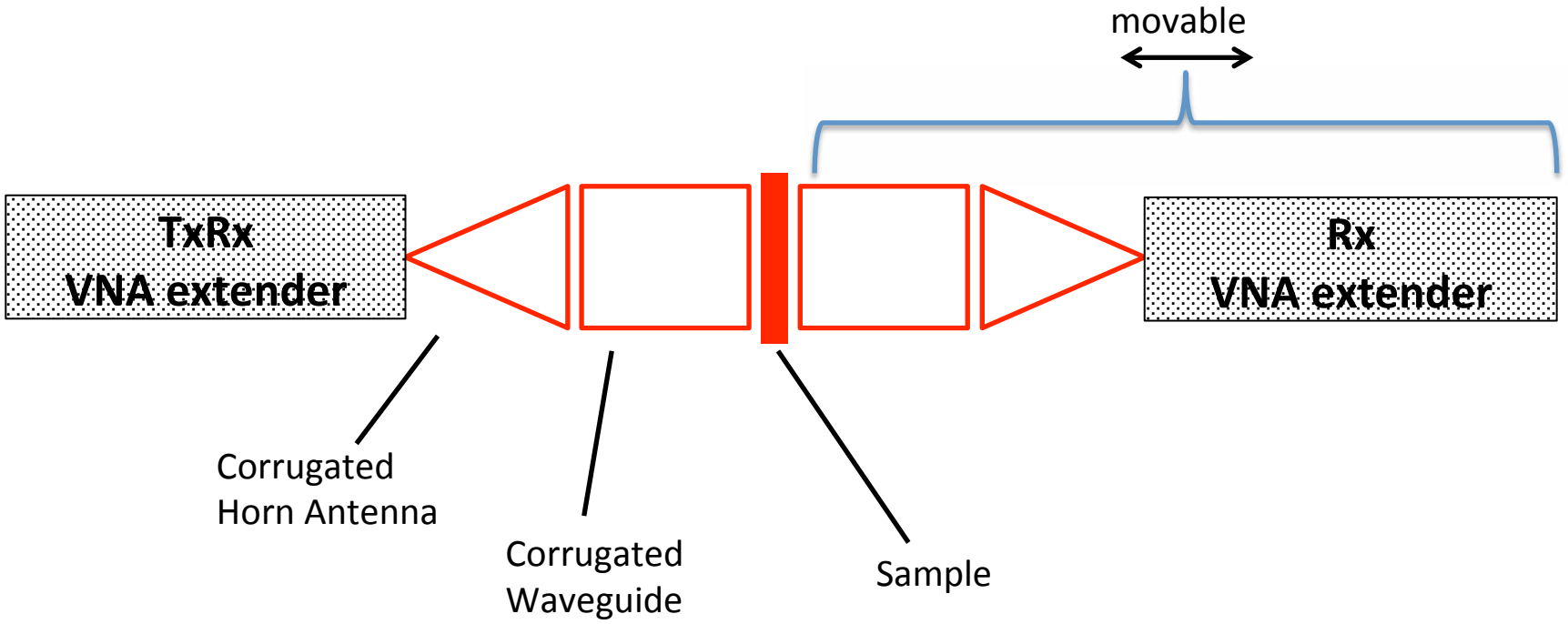
Material Characterization

1-Port configuration (S11)



Material Characterization

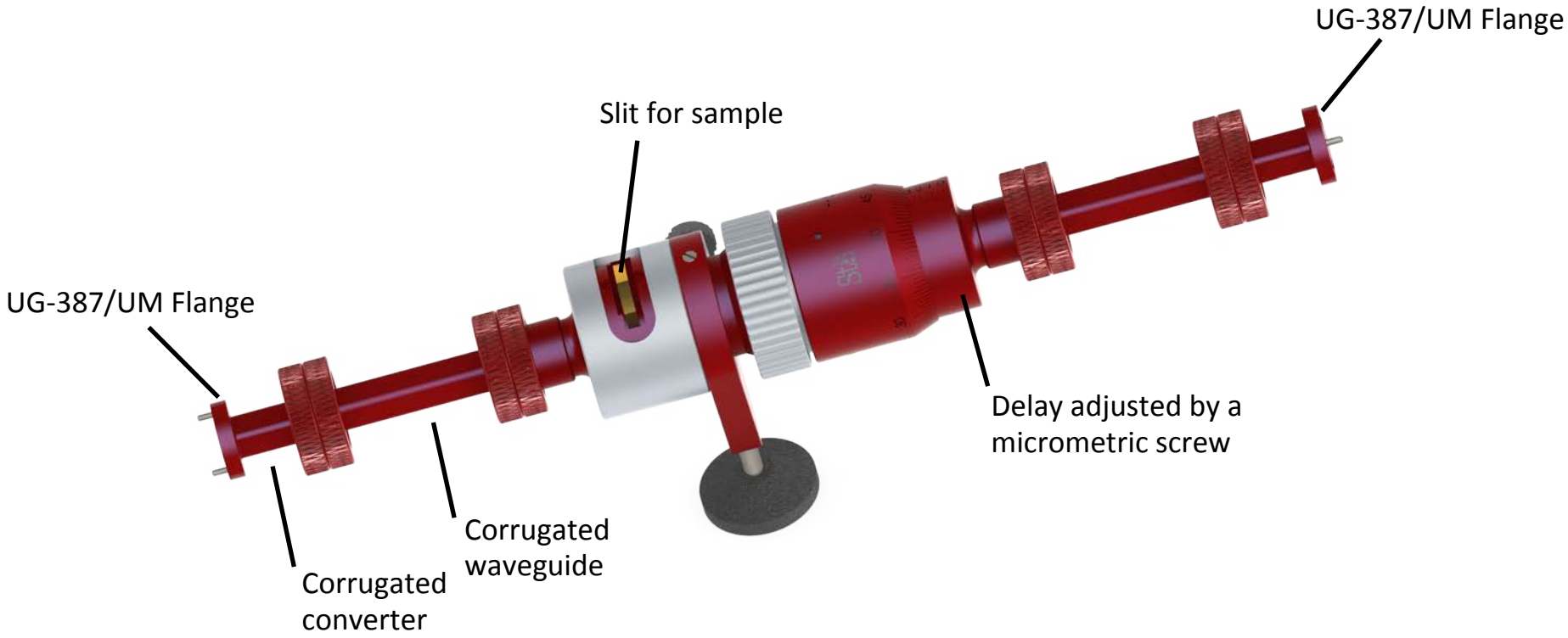
2-Port configuration (S11, S21)



- Calibration made by moving the right part of the setup to generate delays (over-determined calibration algorithm)
- Thin sample inserted into the guided beam path
- Enables efficient measurement of **permittivity (ε', ε'') and permeability (μ', μ'') vs. frequency**

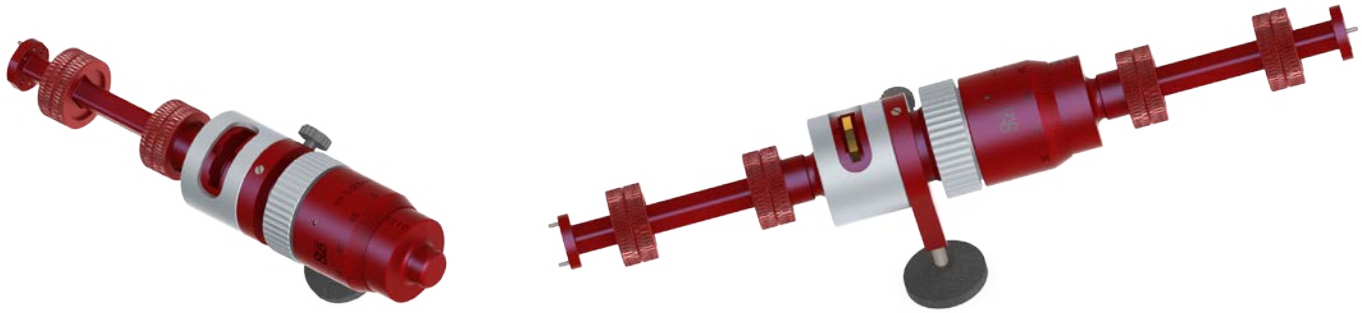
Material Characterization

2-Port configuration (S11, S21)



SWISSto12 material characterization kit

Summary



- **Reflection and transmission measurements**
  Reliable characterization of dielectric and magnetic properties
- **Compact and easy to use**
  Direct connection to VNA frequency extender
  Works with large samples
  no free-space transmission, no time-consuming alignment required
- **Vacuum and high/low-temperature compatible**

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- **Sub-mm wave and THz Antennas**
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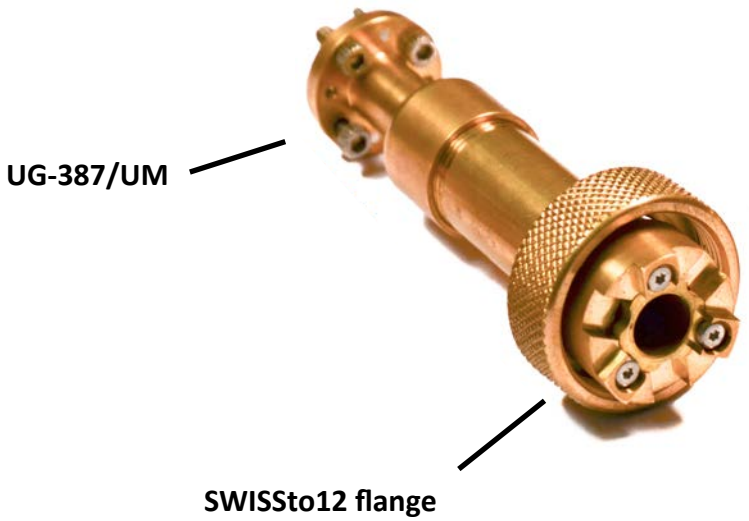
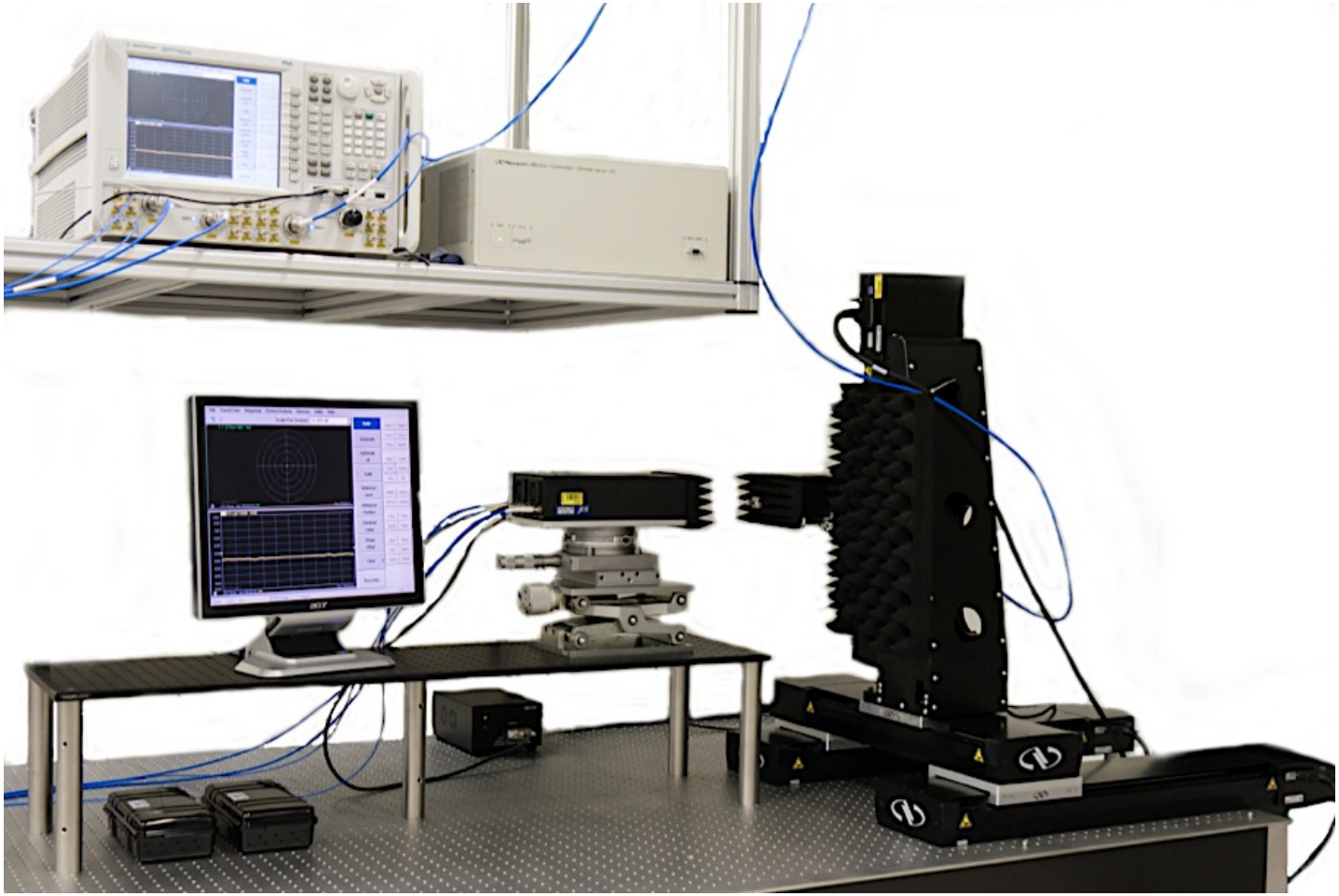
SWISSto12 antennas

SWISSto12 Converters are also antennas!



SWISSto12 corrugated antennas

Antenna radiation pattern measurements

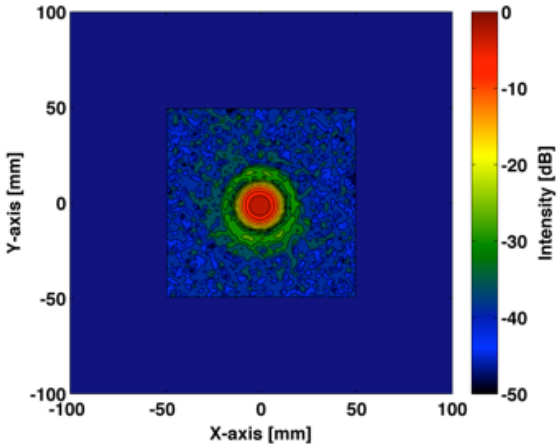


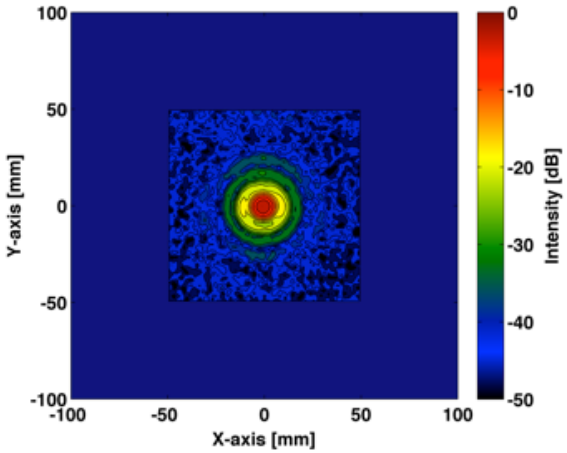
SWISSto12 corrugated antennas

Radiation Patterns, Far Field, 10cm

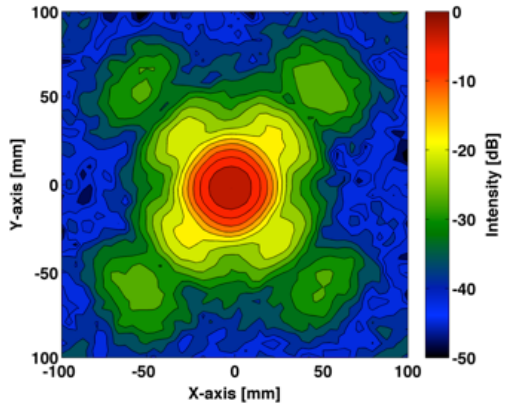
500 GHz **700 GHz**

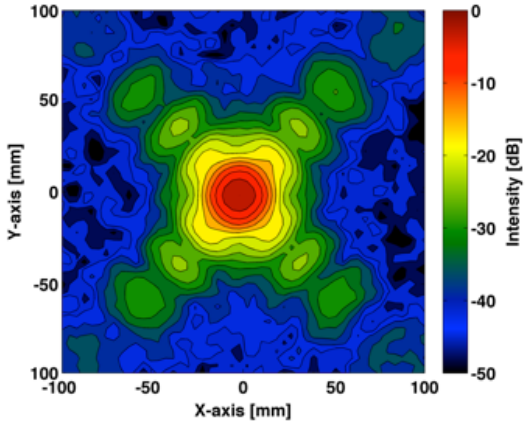
SWISSto12 corrugated converter





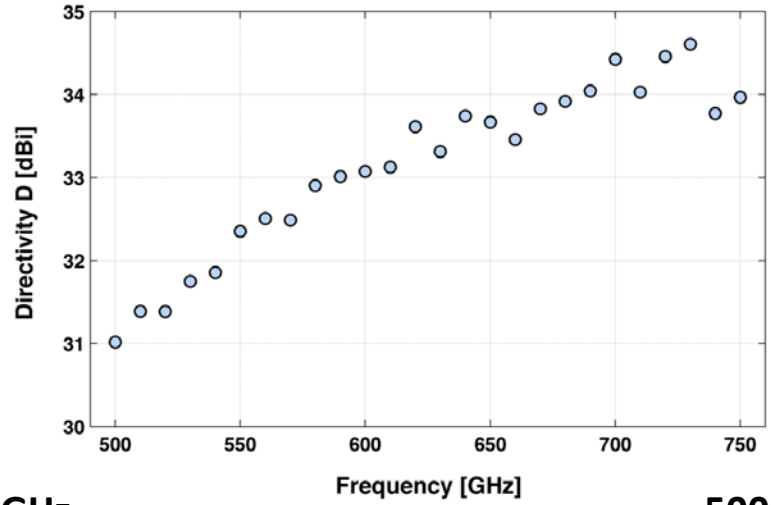
Conventional Diagonal horn





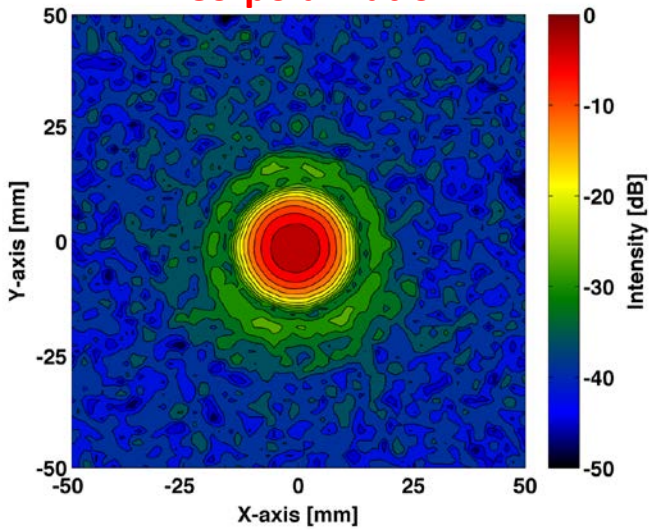
SWISSto12 corrugated converter

Antenna Directivity, Cross-Pol



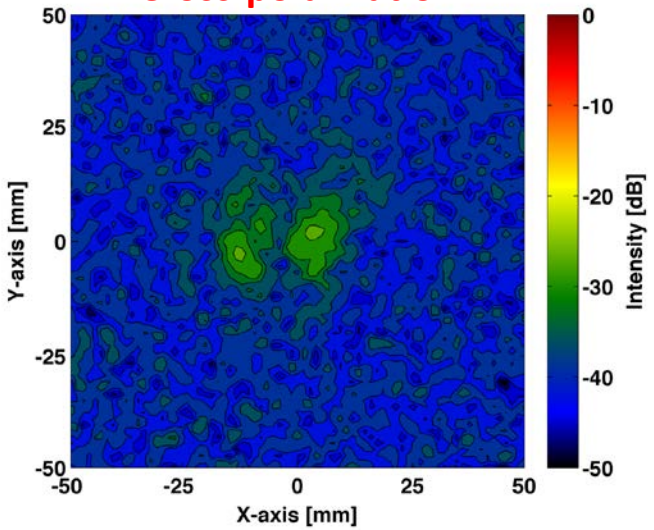
500 GHz

Co-polarization



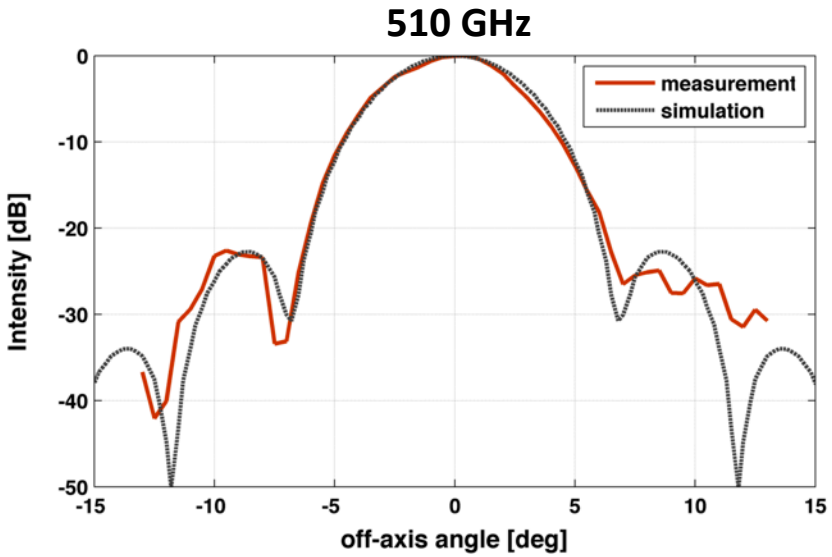
500 GHz

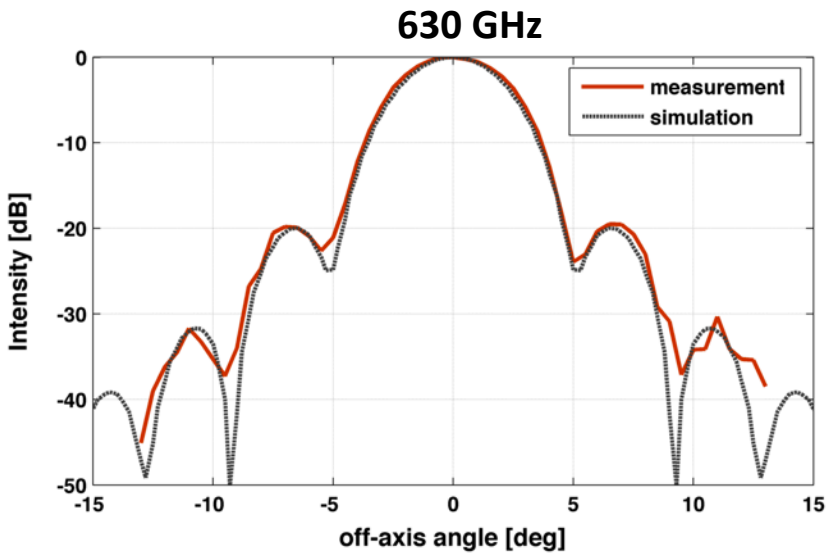
Cross-polarization



SWISSto12 corrugated antennas

Radiation Patterns: Agreement with simulations





Focal plane arrays

Corrugated horn antenna Arrays for the QUBIC experiment

- Operating at 150 GHz
- Leightweight material: Aluninium
- High mechanical accuracy

Technology also applicable to phased arrays:

- Point to point telecom
- Radar front ends

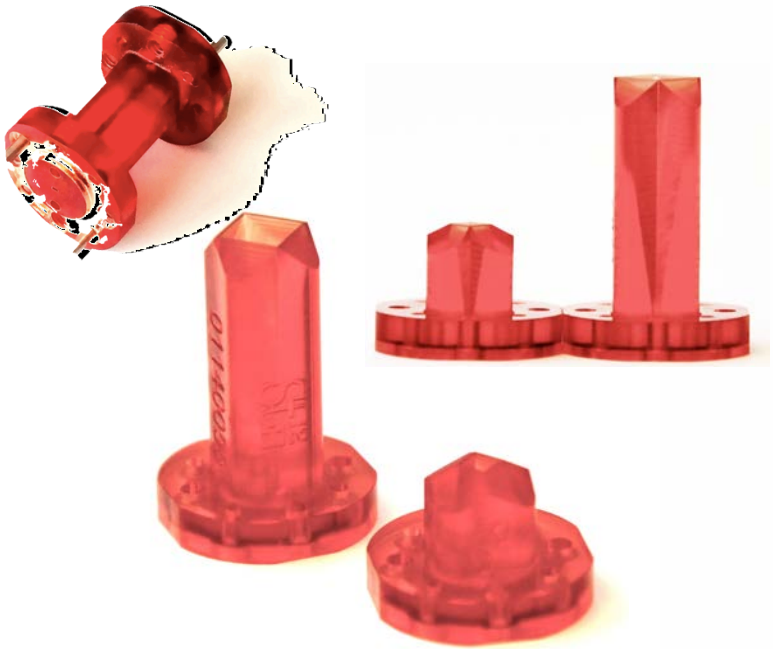
Outline

- About SWISSto12
- Modular Corrugated wave-guiding components & technology
- Outlook: application platforms based on SWISSto12 components:
  - Material characterization
  - On wafer probing
  - Gas spectroscopy
- Sub-mm wave and THz Antennas
- **Additive manufacturing for low-cost wave-guiding components**

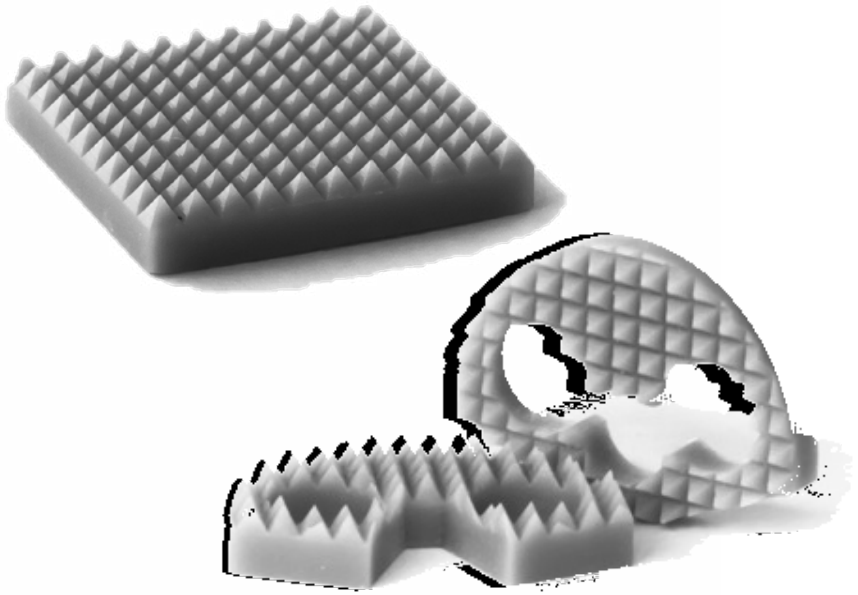
Plastic components

Unprecedented Design Capabilities

Metal-coated components



Customized microwave absorbers

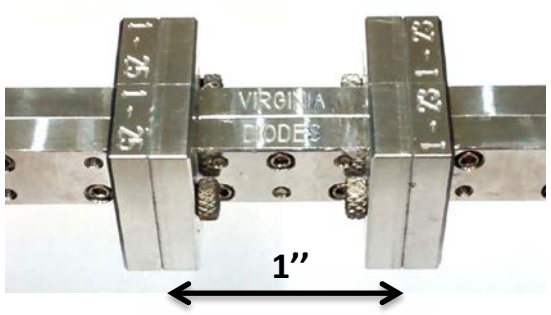


- Highly customizable
- Low cost
- Performance comparable with conventional (metallic) components
- Very short delivery times (~ 1-2 weeks)

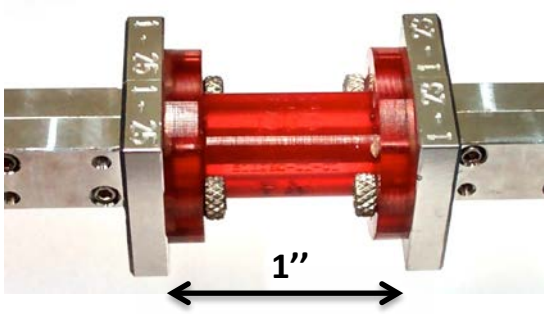
Plastic components

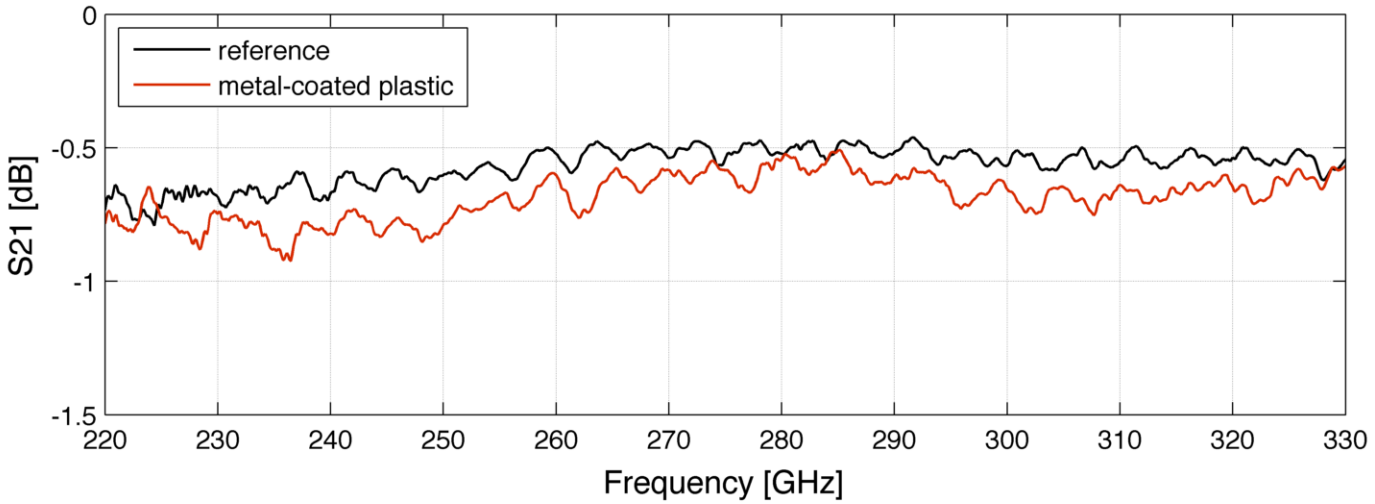
S21 parameter - WR-3.4 (220-330 GHz)

Reference waveguide
Aluminum, split-block type

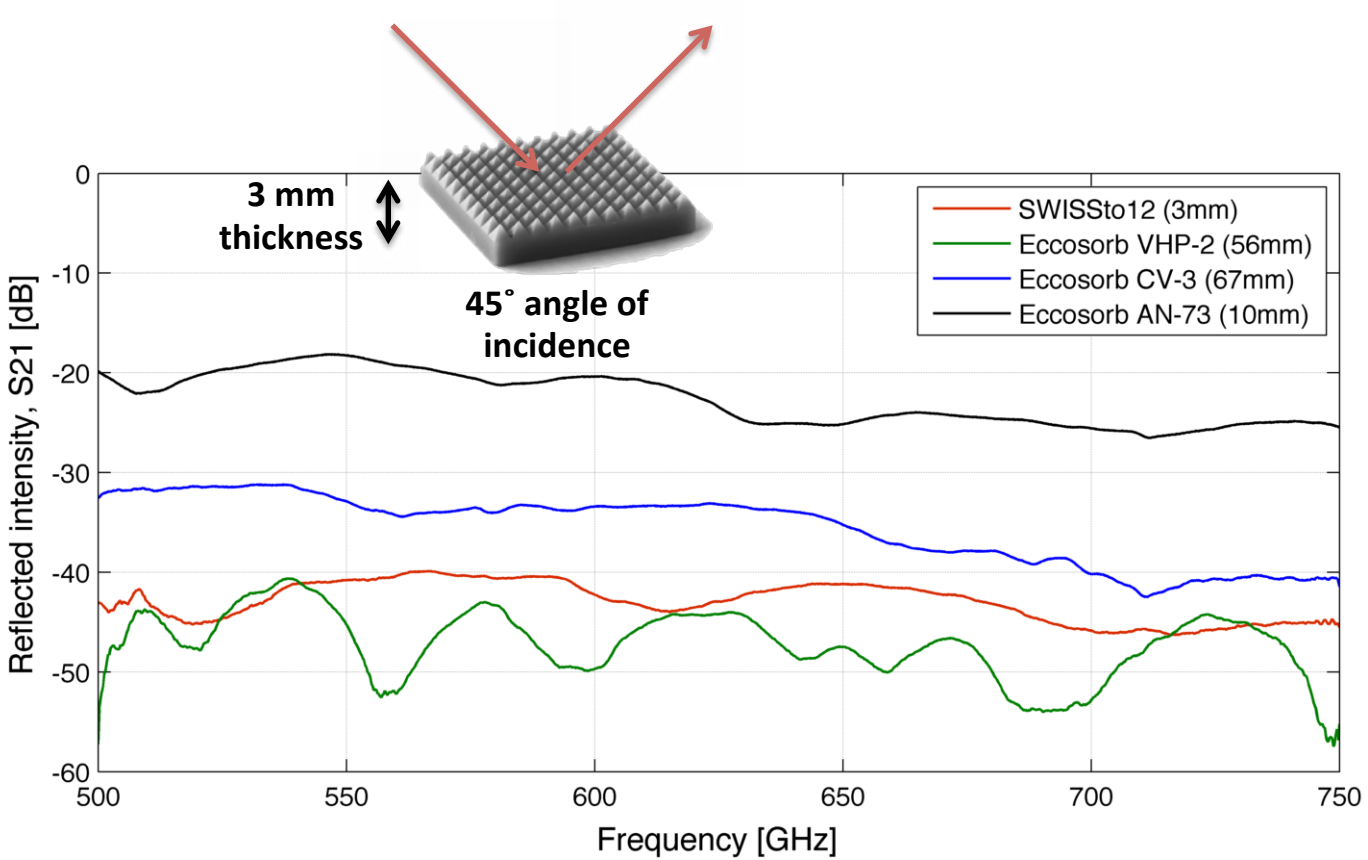


Plastic waveguide
Metalized 3D-printed plastic





Customized plastic absorbers



- Performance in reflection similar to competitor absorbers at much lower thickness
- Absorbers can be designed and printed to perfectly match any surface

Feed antennas

Metalized plastic diagonal horn

Ongoing studies in the:

- WR 3.4 band (220 – 330 GHz)
- WR 1.5 band (500 – 750 GHz)

Low-cost phased antenna arrays in applications such as:

- **Radar front ends**
- **Point to point Telecom**

SWISSto12 Contacts

Meet us at:

- Swedish Microwave Days, March 2014, Göteborg, Swe
- European Conference on Antennas and Propagation, April 2014, The Hague, NL
- International Symposium on Space Terahertz Technology, April 2014, Moscow, Ru
- International Microwave Symposium, June 2014, Tampa, USA
- ARFTG, June 2014, Tampa, USA
- COST DNP meeting, June 2014, Zürich, CH
- IRMMW-THz, September 2014, Tucson, USA
- European Microwave Week, October 2014, Rome, I

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Summary