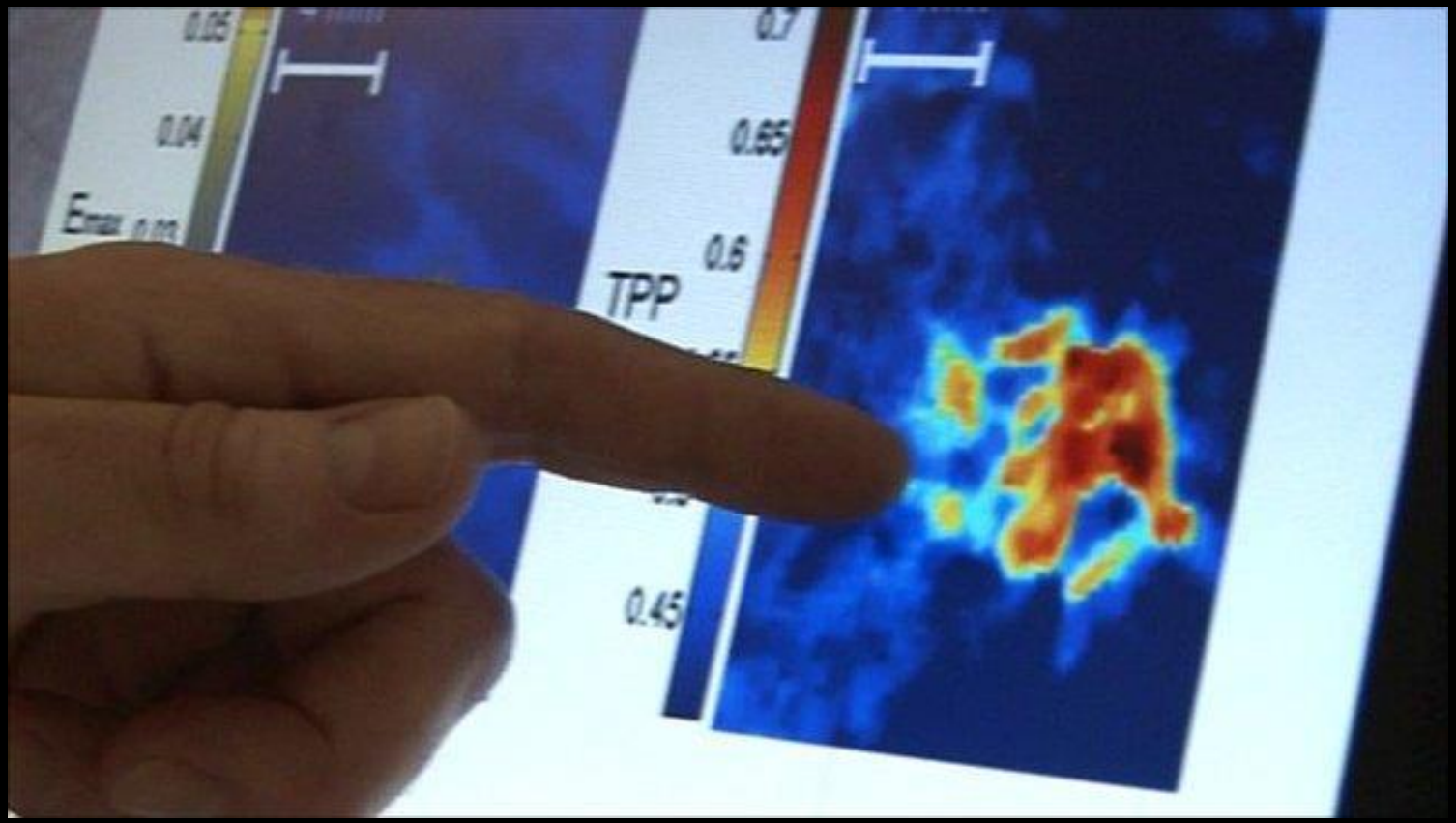
## A GLIMPSE INTO

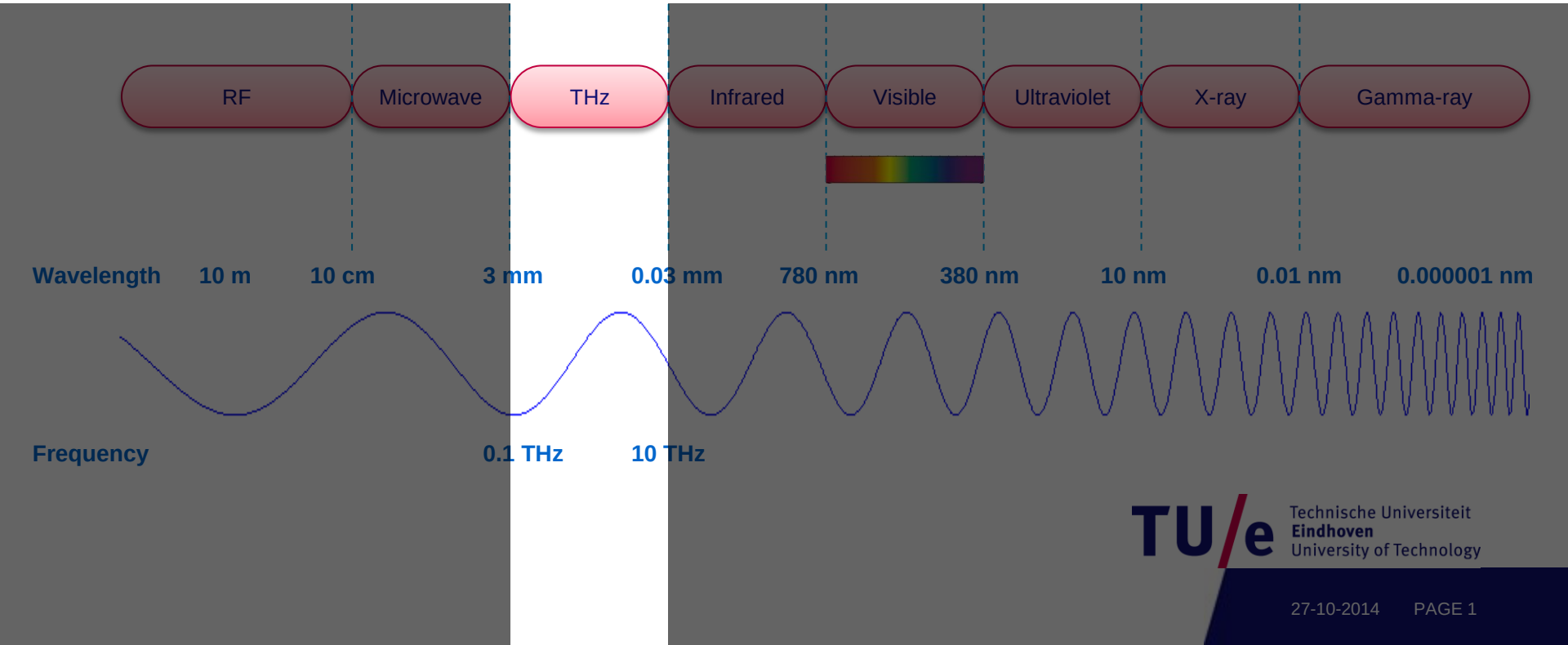
# THE WORLD OF TERAHERTZ




**By Juan Alfaro**

# Terahertz (THz)

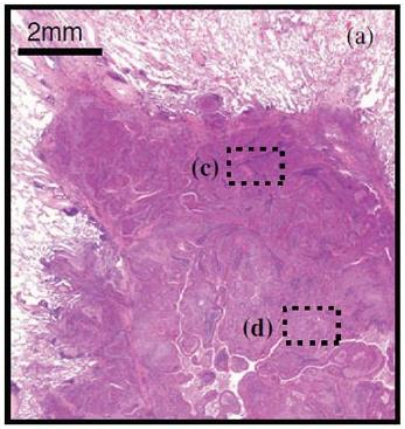
- “See” through non-polar, non-metallic materials
- Strongly absorbed by water
- Non-ionizing



# THz images of tumorous tissue

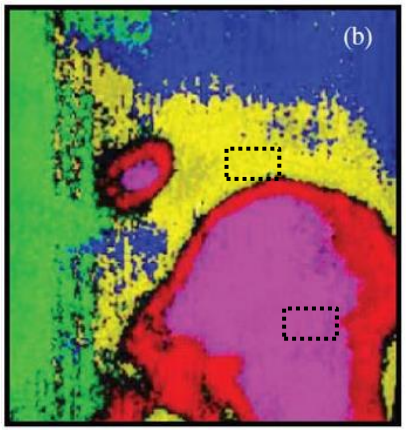
- **Cancer**: 2nd leading cause of death in Europe (1 out of 5 deaths)
- Cancer detection and diagnosis tools:
  X-rays, MRI, ultrasound, …, T-rays (THz rays)?

Lung-cancer sample visible image




*2010 Phys. Med. Biol. 55 4615*

Segmented THz image




- Obtained from refractive index data at each pixel.
- Healthy:
  - Blue
  - Green
- Tumor:
  - Yellow
  - Magenta
  - Red

# Contrast of THz images

**Lack of understanding**

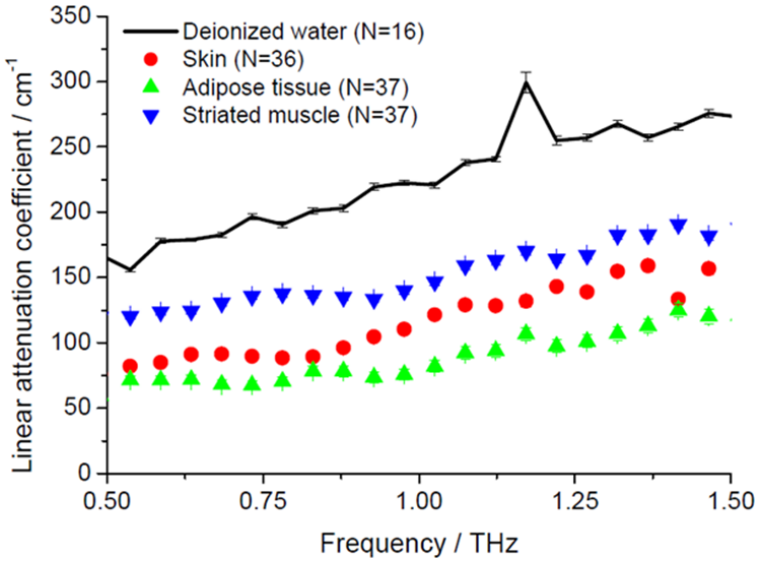
Contrast

- **Water** content?
- Cells' sizes?
- Cell arrangement?
- Protein content?
- DNA content?

**Need for a database**

THz spectroscopic information ⟷ Link ⟷ Different types of tissues

Tissue characterization




Better diagnose of disease

*E. Berry, et al., Proceedings of SPIE: Medical Imaging 2003: Physics of Medical Imaging.*

# TU/e THz Program

## TU/e - CWTe

Terahertz Imaging Spectroscopy Program

Mixed-signal Microelectronics group


Long term goal

Portable and low cost THz systems

Develop know-how

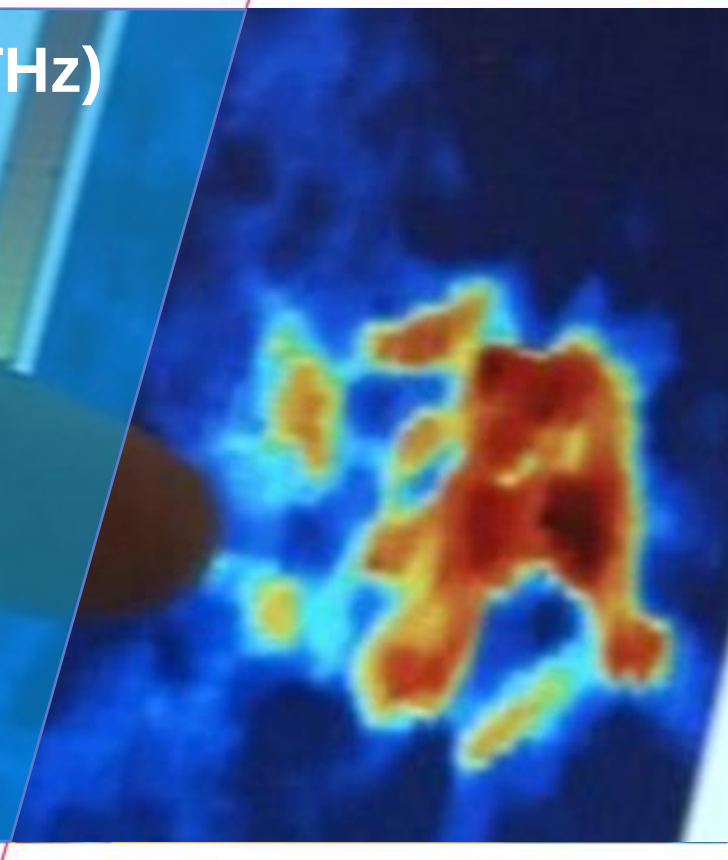
Develop experimental capability

**To better understand:**

- **THz generation**
- **THz detection**
- **THz manipulation**
- **THz system's building blocks**

Technische Universiteit Eindhoven University of Technology

# Laboratory System for Terahertz (THz) Imaging Spectroscopy of Tissue Samples




Juan Alfaro

PDEng - Healthcare Systems Design

**Supervisor**

dr. M. K. Matters-Kammerer

**Design Coach**

ing. A. R. van Dommele

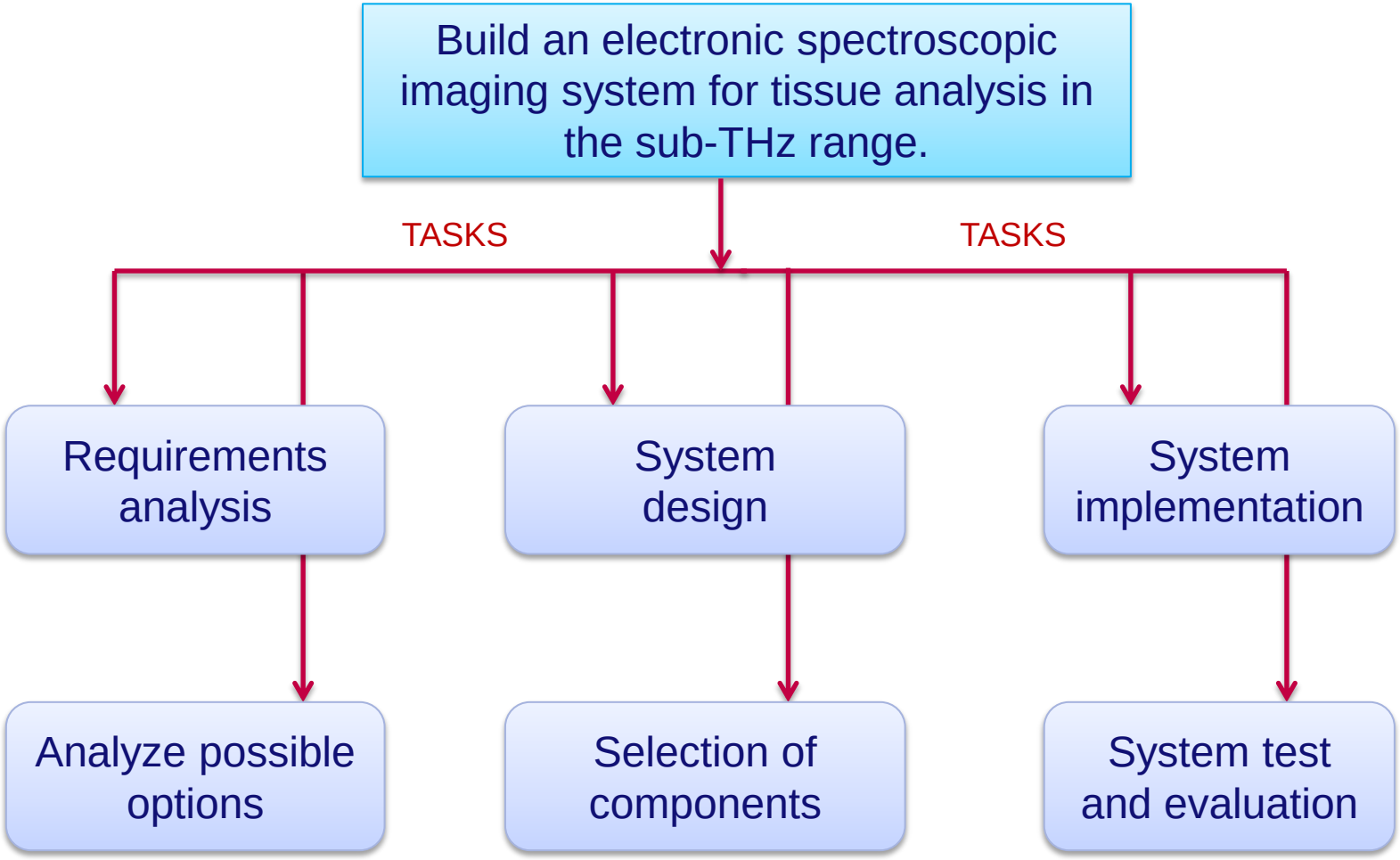

CWTe
Centre for Wireless Technology Eindhoven

MSM
Mixed-signal Microelectronics group

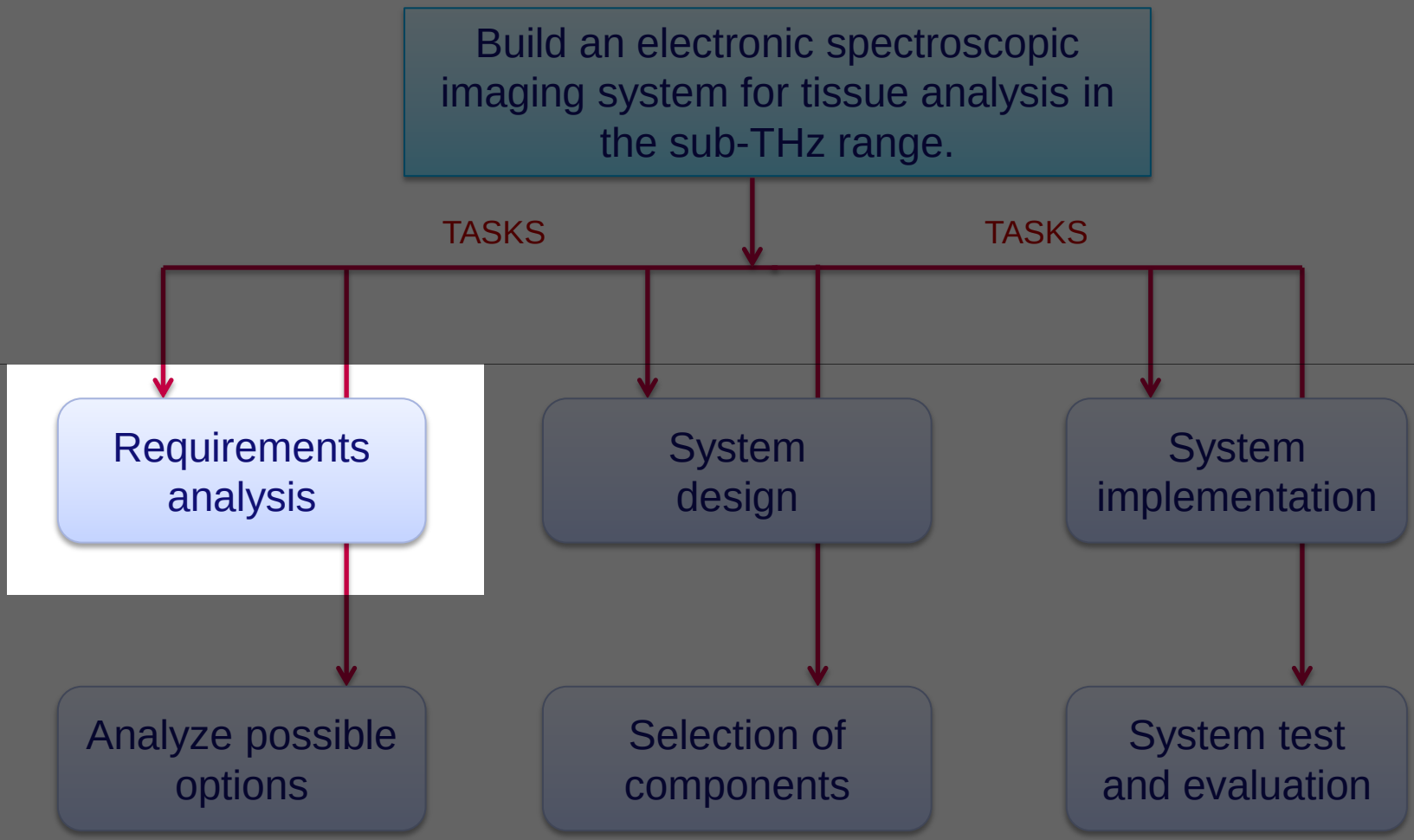
TU/e
Technische Universiteit Eindhoven University of Technology

Where innovation starts

# Project Overview



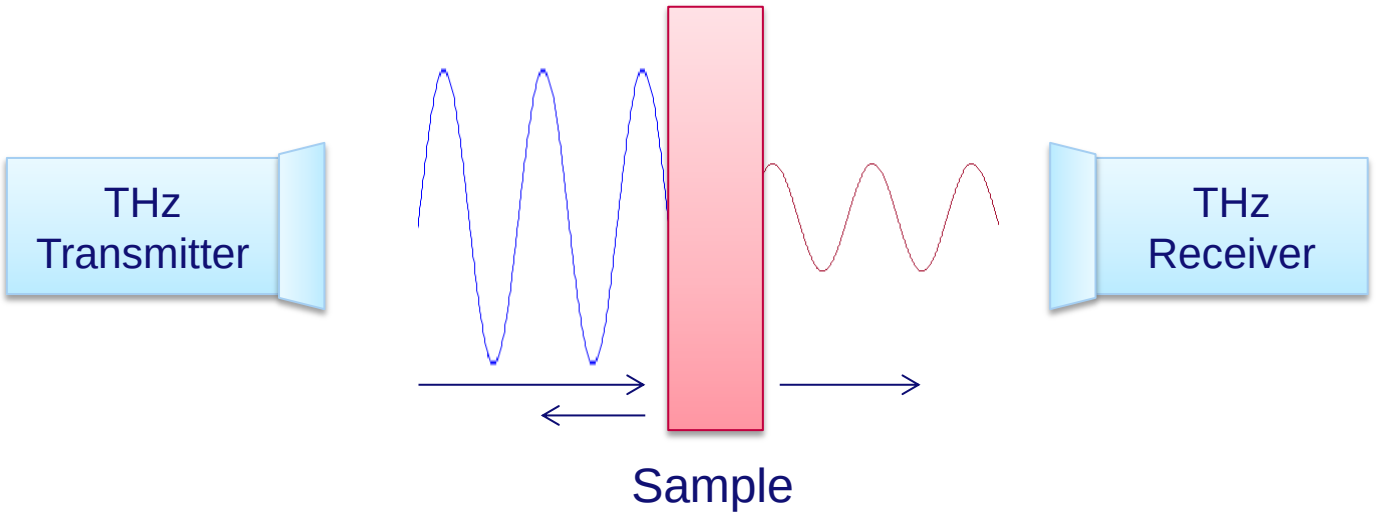
# Project Overview

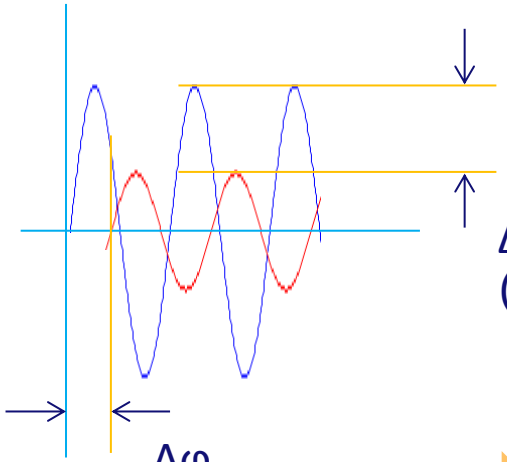


# Analysis of requirements

- **Main requirements:**
  - **THz generation from microwaves**
  - **Frequency range: 100 GHz to 500 GHz (eventually focus on certain bands)**
  - **Diffraction-limited resolution**
  - **Coherent detection (magnitude and phase)**

# Coherent detection



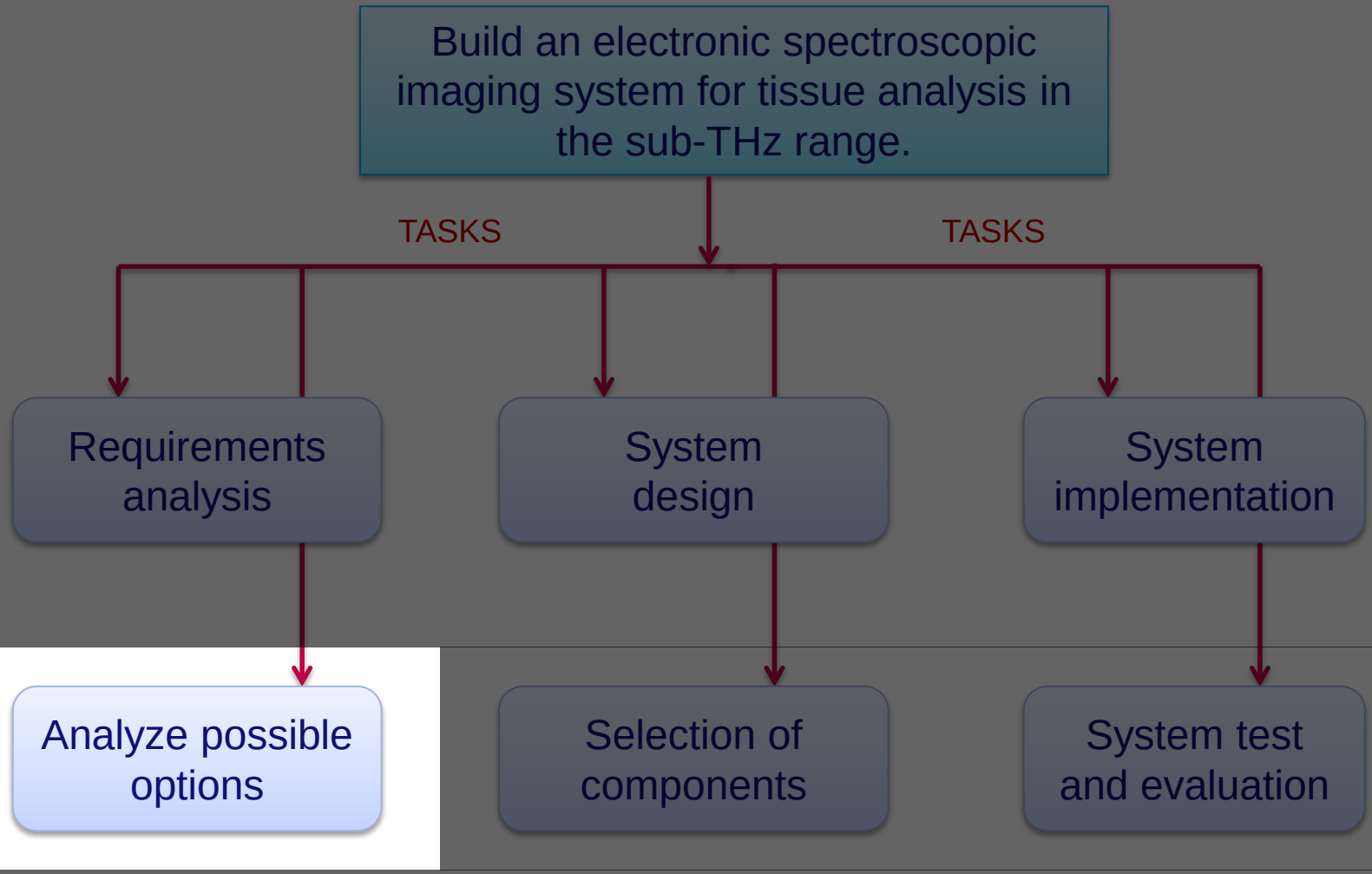
ΔM
(Magnitude)

→ *α*: attenuation coefficient

Δφ
(Phase)

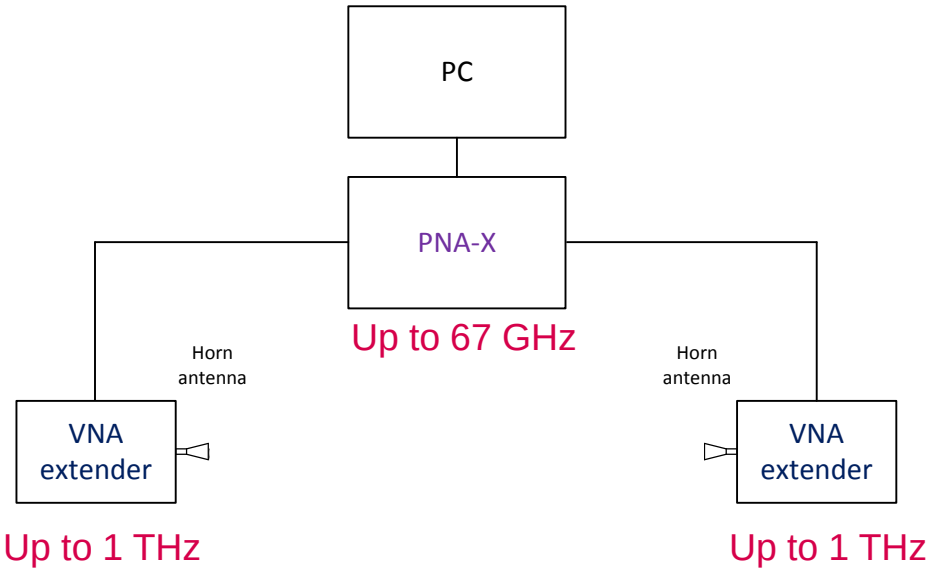
→ *n*: refractive index

# Project Overview



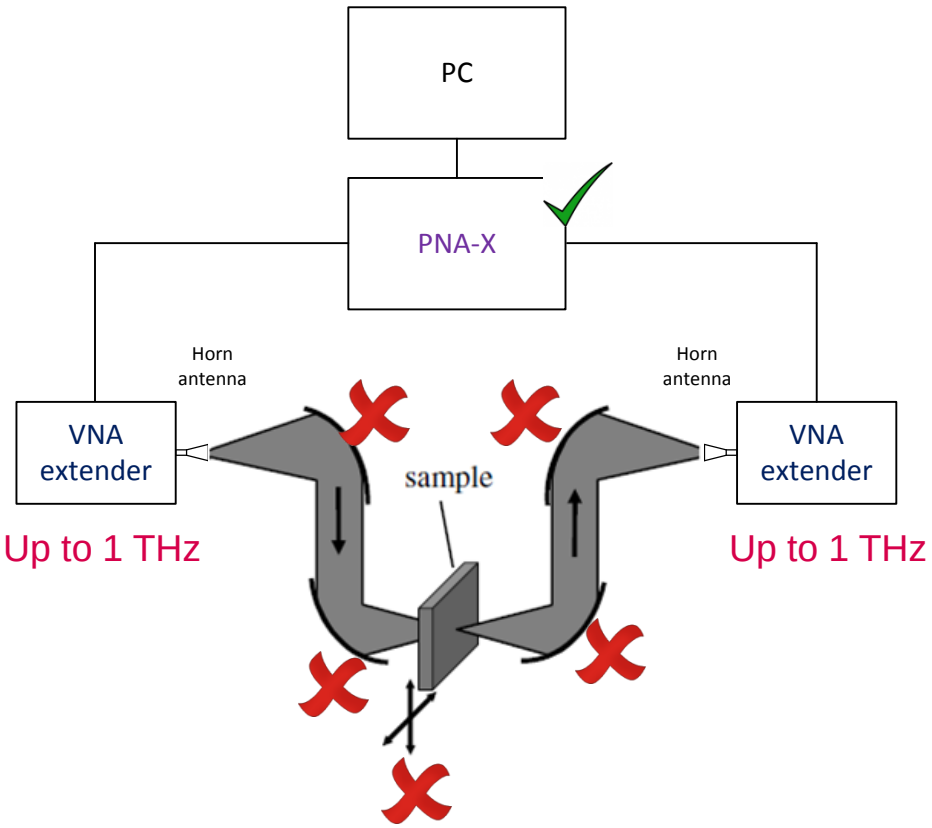
# Pre-design phase

- **Original approach:**
  **Use Vector Network Analyzer (PNA-X) + extenders**



# Pre-design phase

- **Original approach:**
  **Use Vector Network Analyzer (PNA-X) + extenders**




✓ Available in Lab.
✗ Purchase required

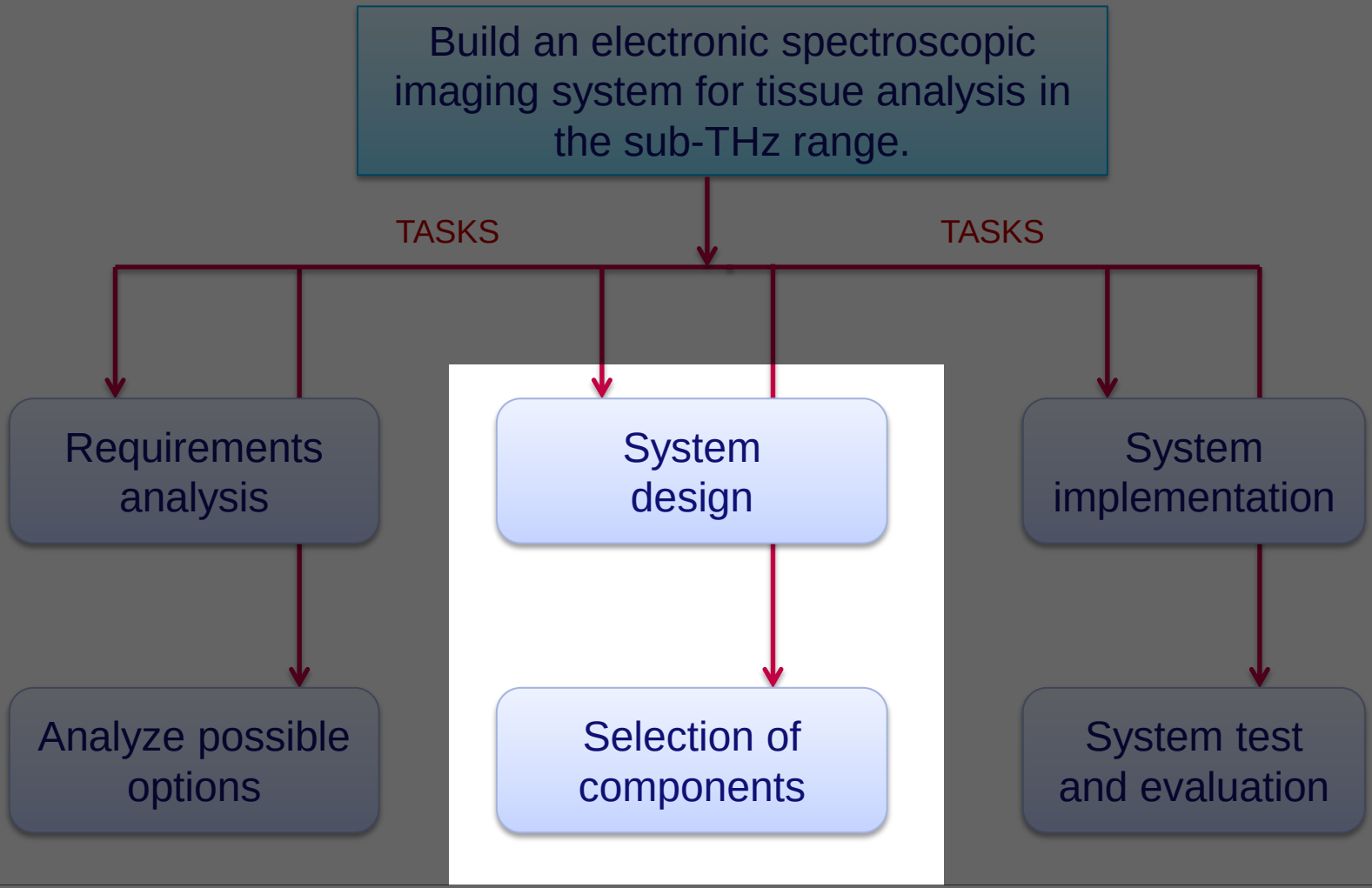
- Up to 140 GHz ✓
- 140 – 220 GHz ✗
- 220 – 325 GHz ✗
- 325 – 500 GHz ✗
- 500 – 750 GHz ✗
- 750 – 1100 GHz ✗

# New approach

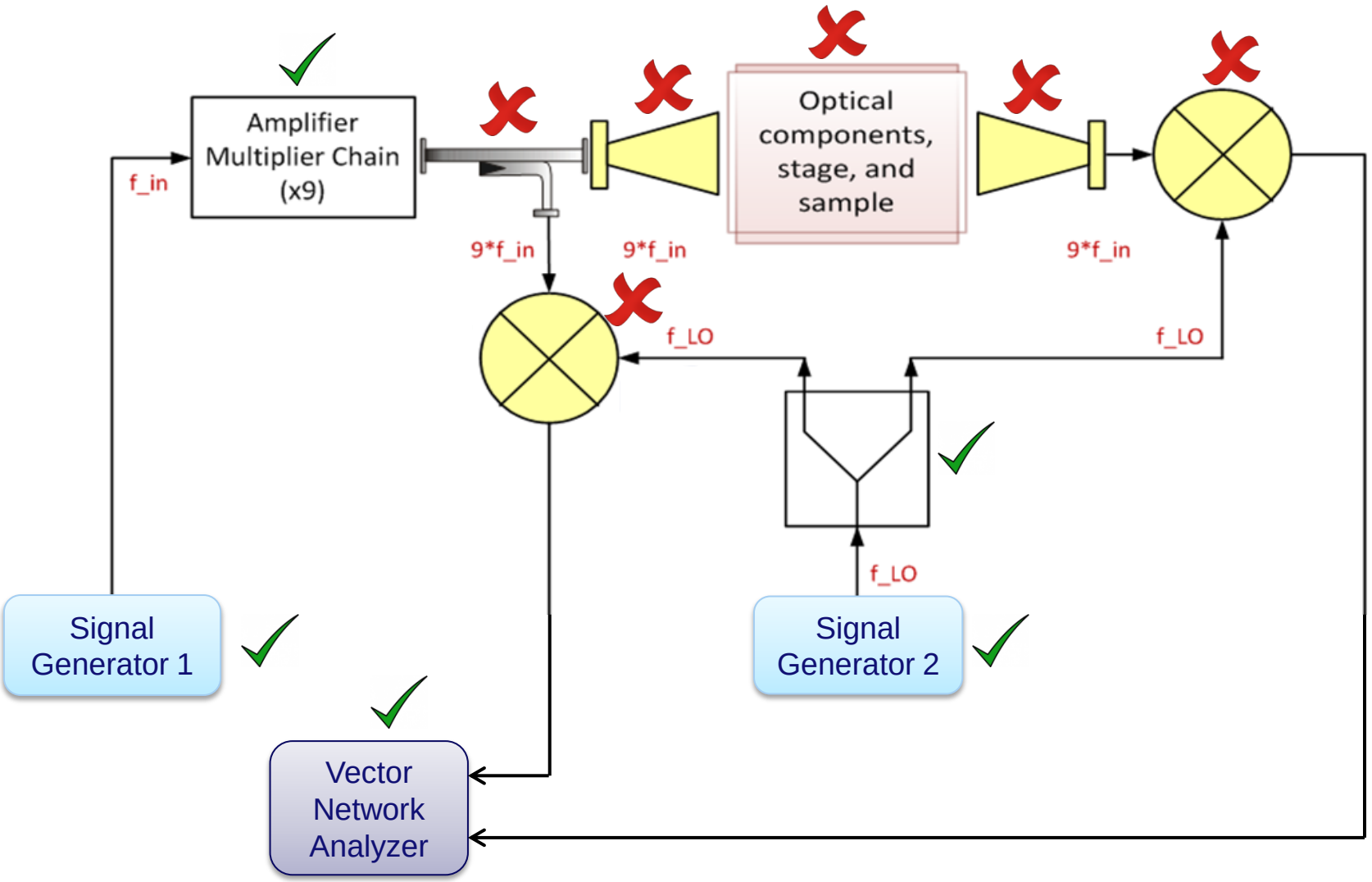
- **Build our own modules**
- **Magnitude and phase**
- **Discussion meetings with experts**



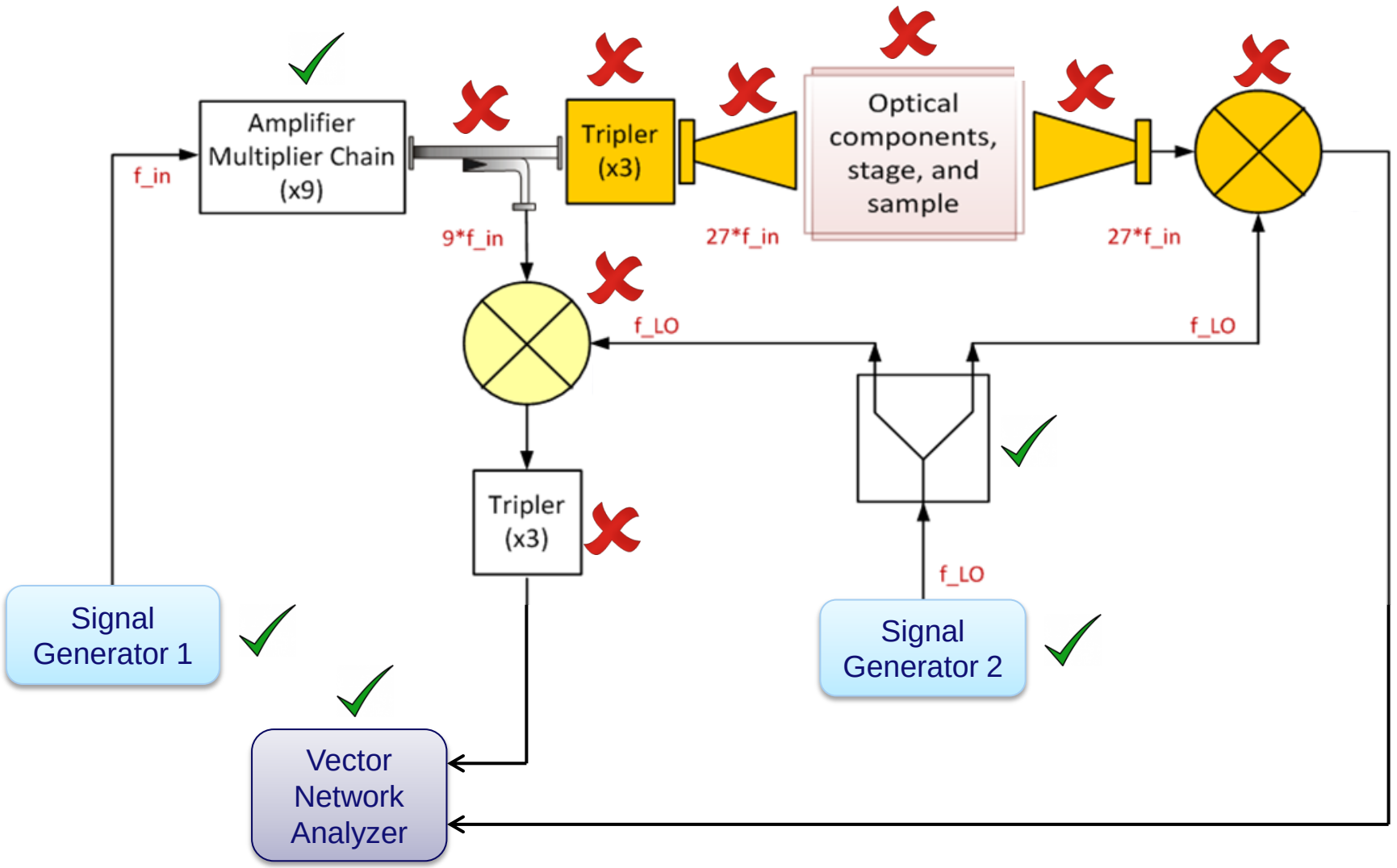
# Project Overview



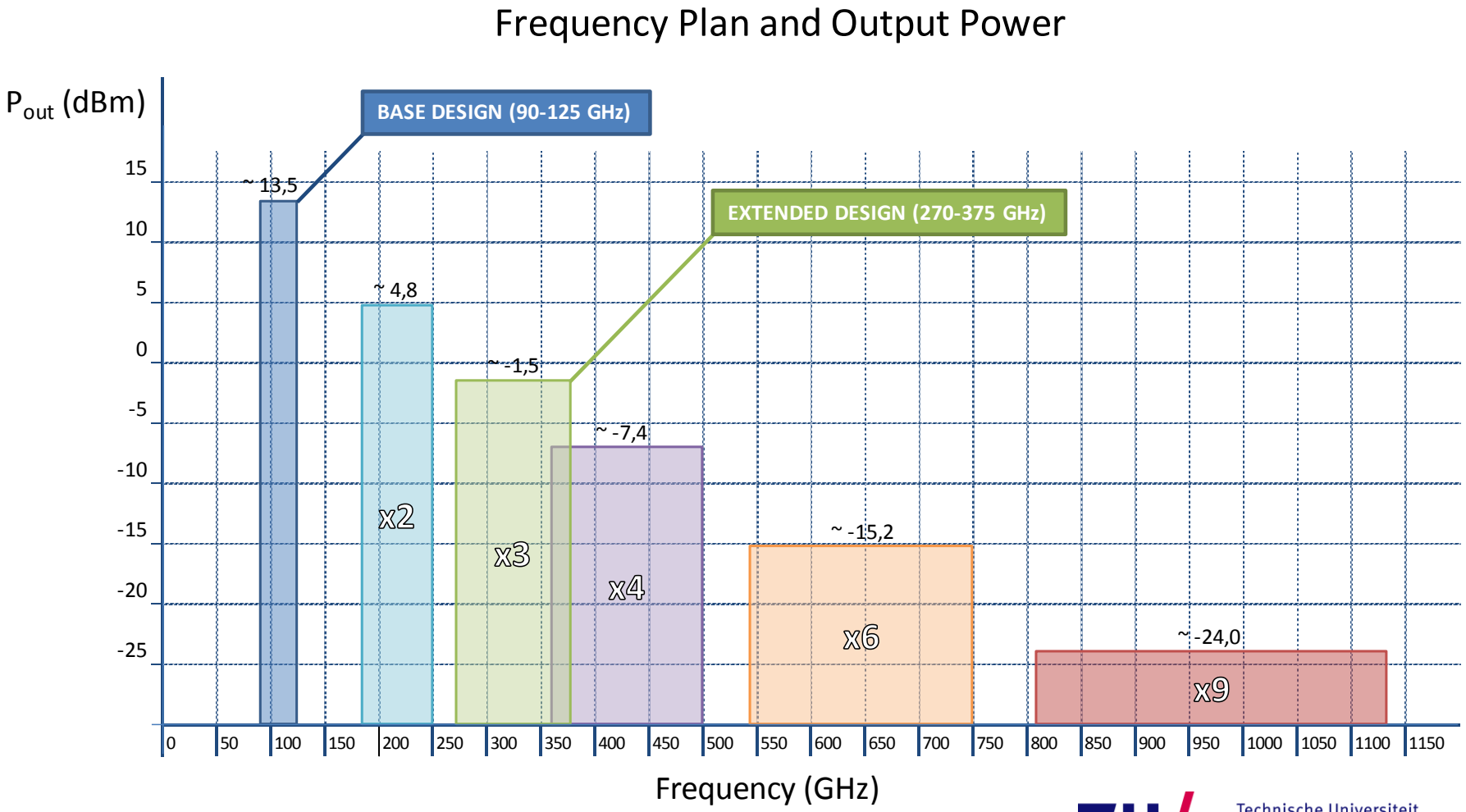
# Base design (90-125 GHz)



# Extended design (270-375 GHz)

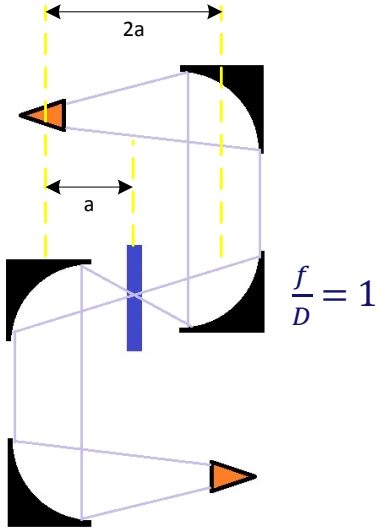


# Frequency and power performance




$f_{in}$ (GHz) = 10-13.9 , $P_{in}$ = 10 dBm

# Optics setup




SETUP 2

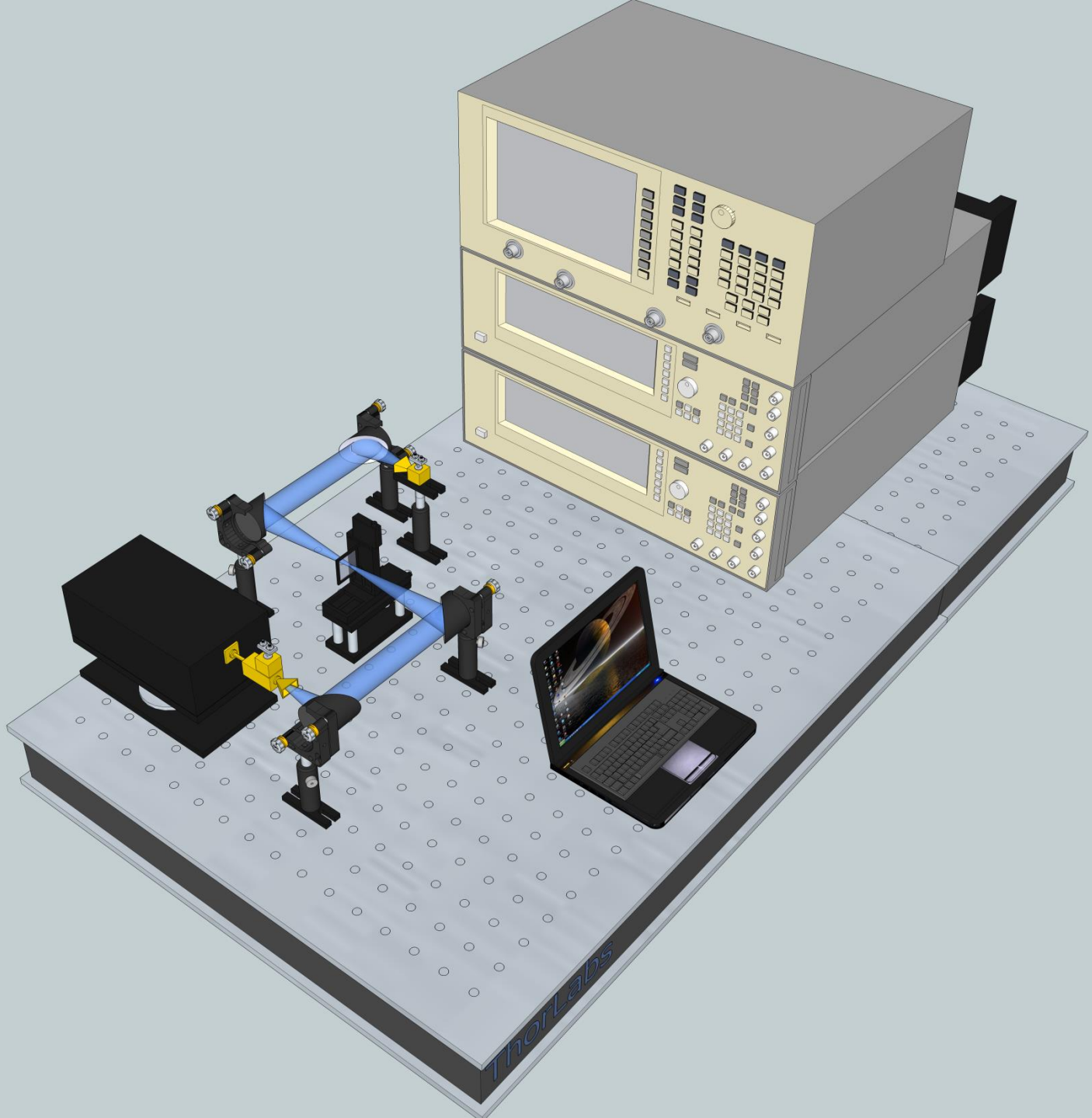
$f$ : focal length
$D$ : Diameter

$$spot\ size = 1{,}27\ \lambda\ \frac{f}{D}$$

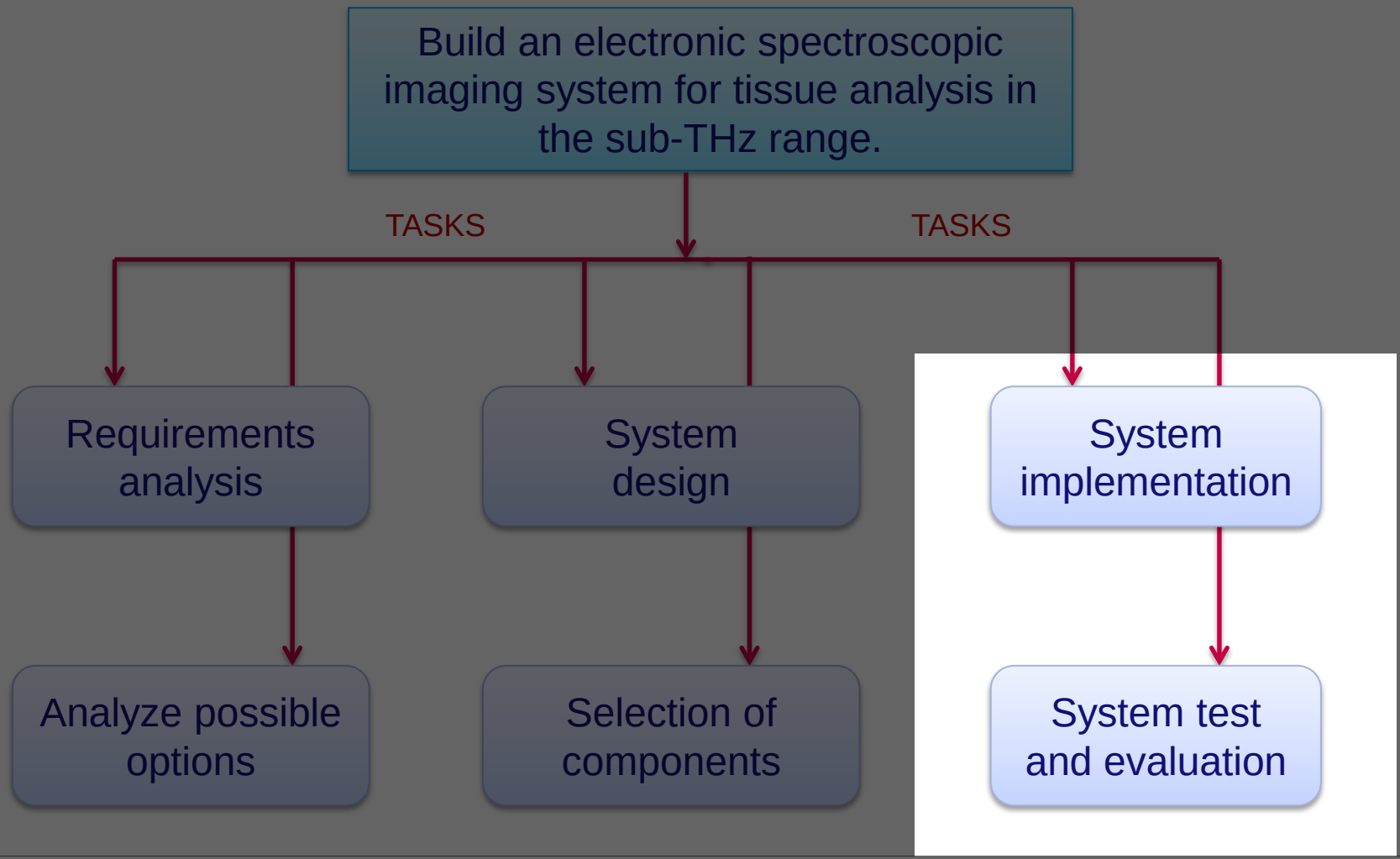
- Base design @ 115 GHz $spot\ size = 3.31\ mm$
- Extended design @ 345 GHz: $spot\ size = 1.104\ mm$

# Component selection process

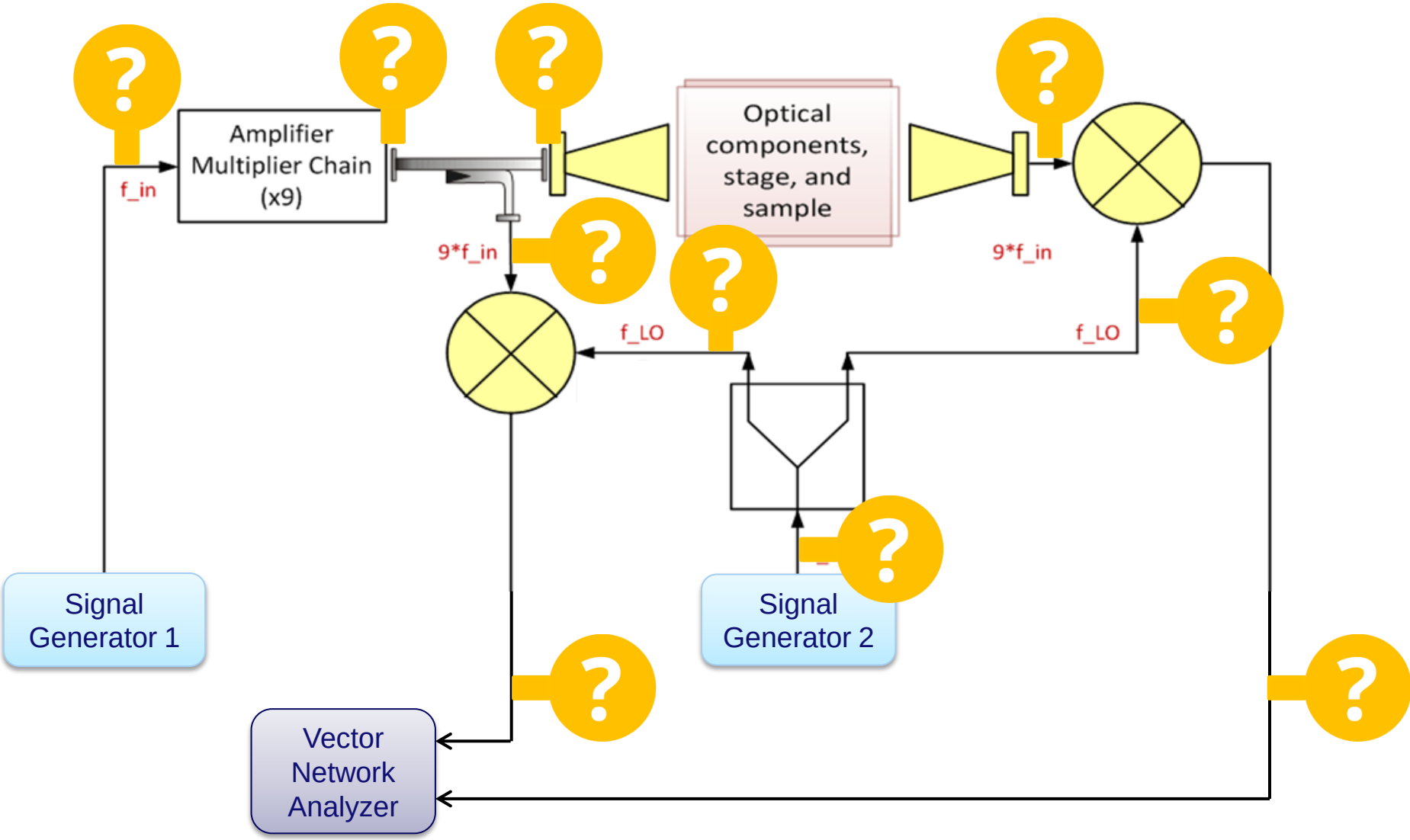
- **Compare specifications from different manufacturers for each component**
- **Choose best performance, lower cost**


ThorLabs

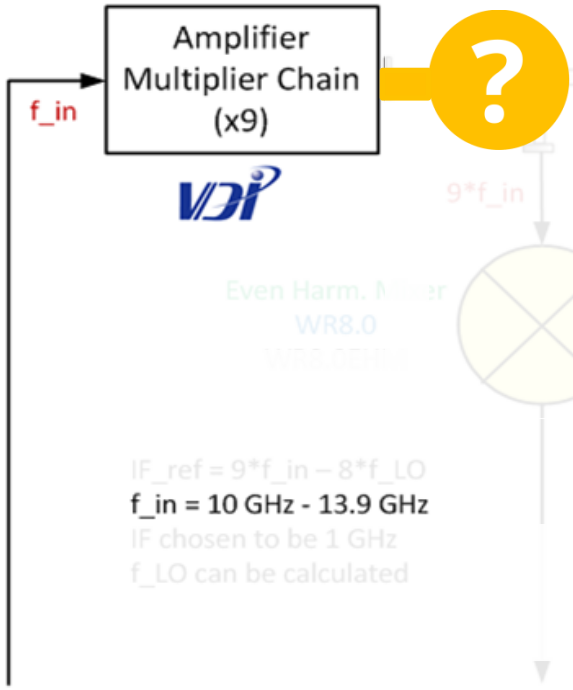
# Project Overview

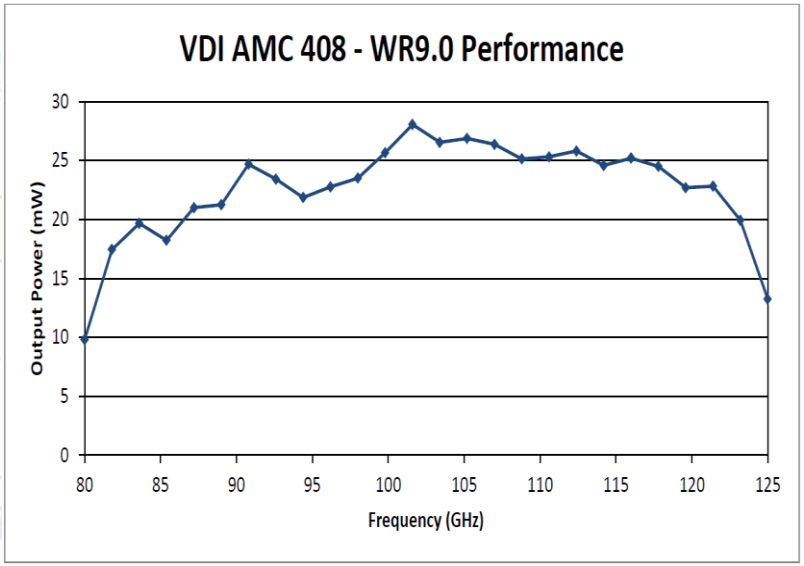


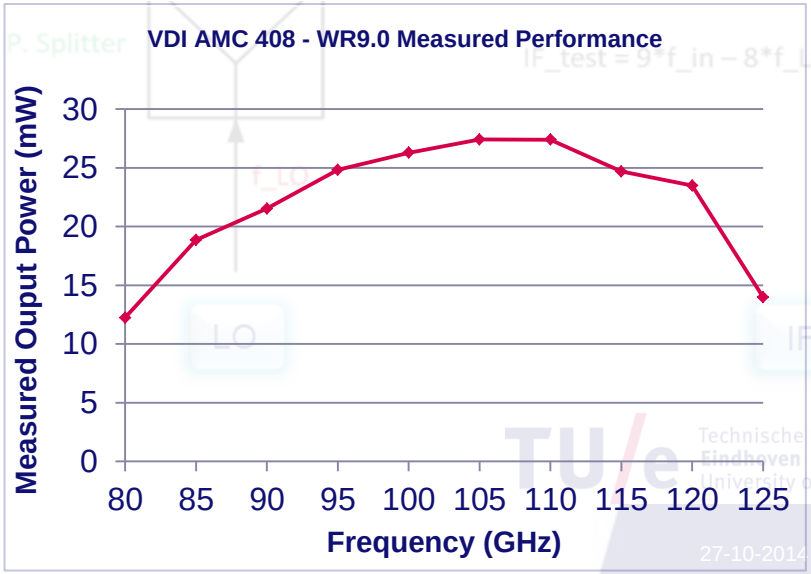
# Frequency and power testing



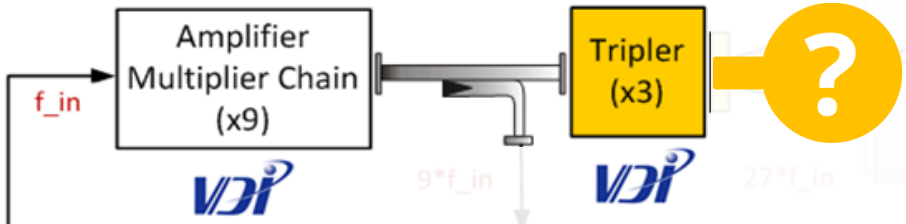
# Amplifier's output (90-125 GHz)



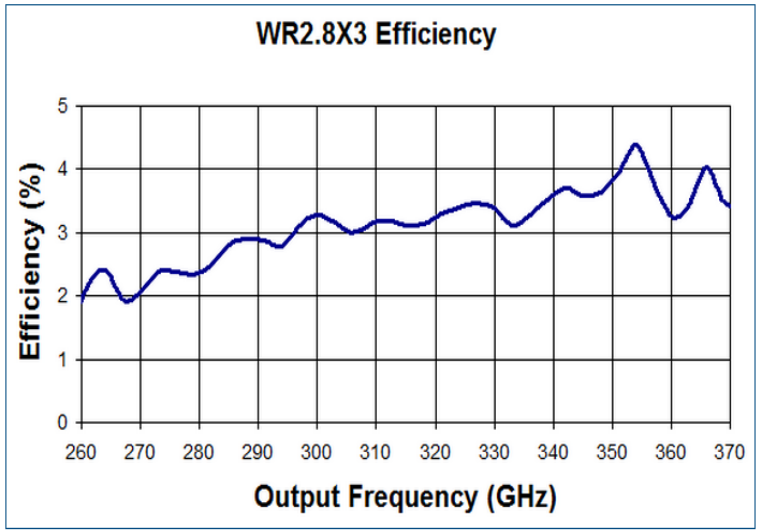



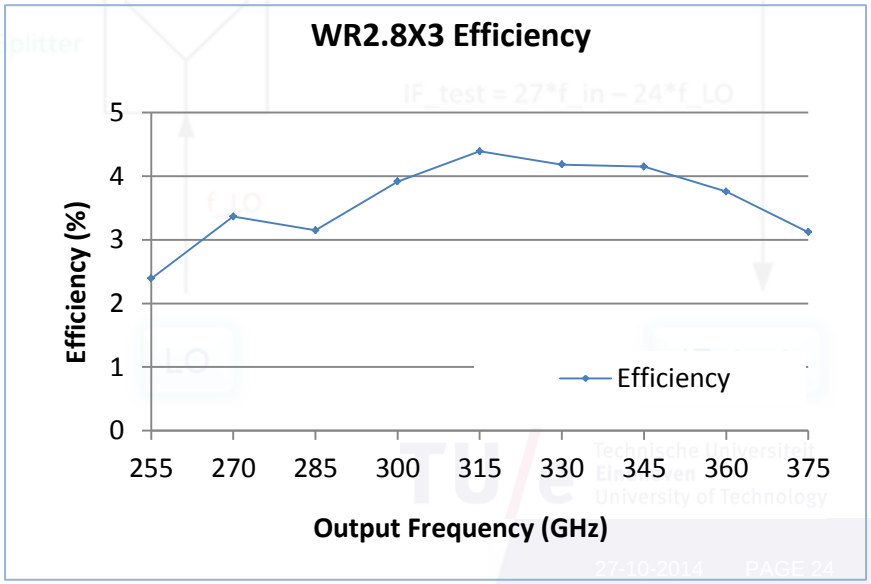



# Tripler's output (270-375 GHz)



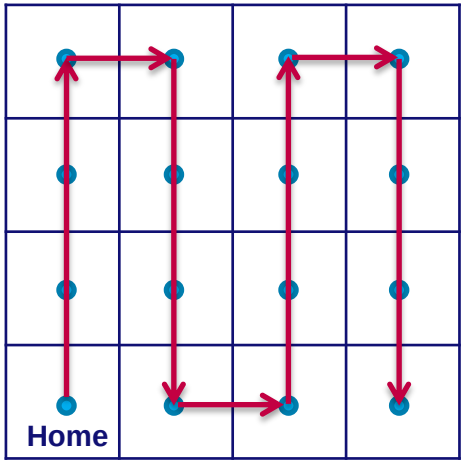

Signal Generator 1

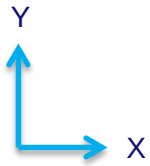


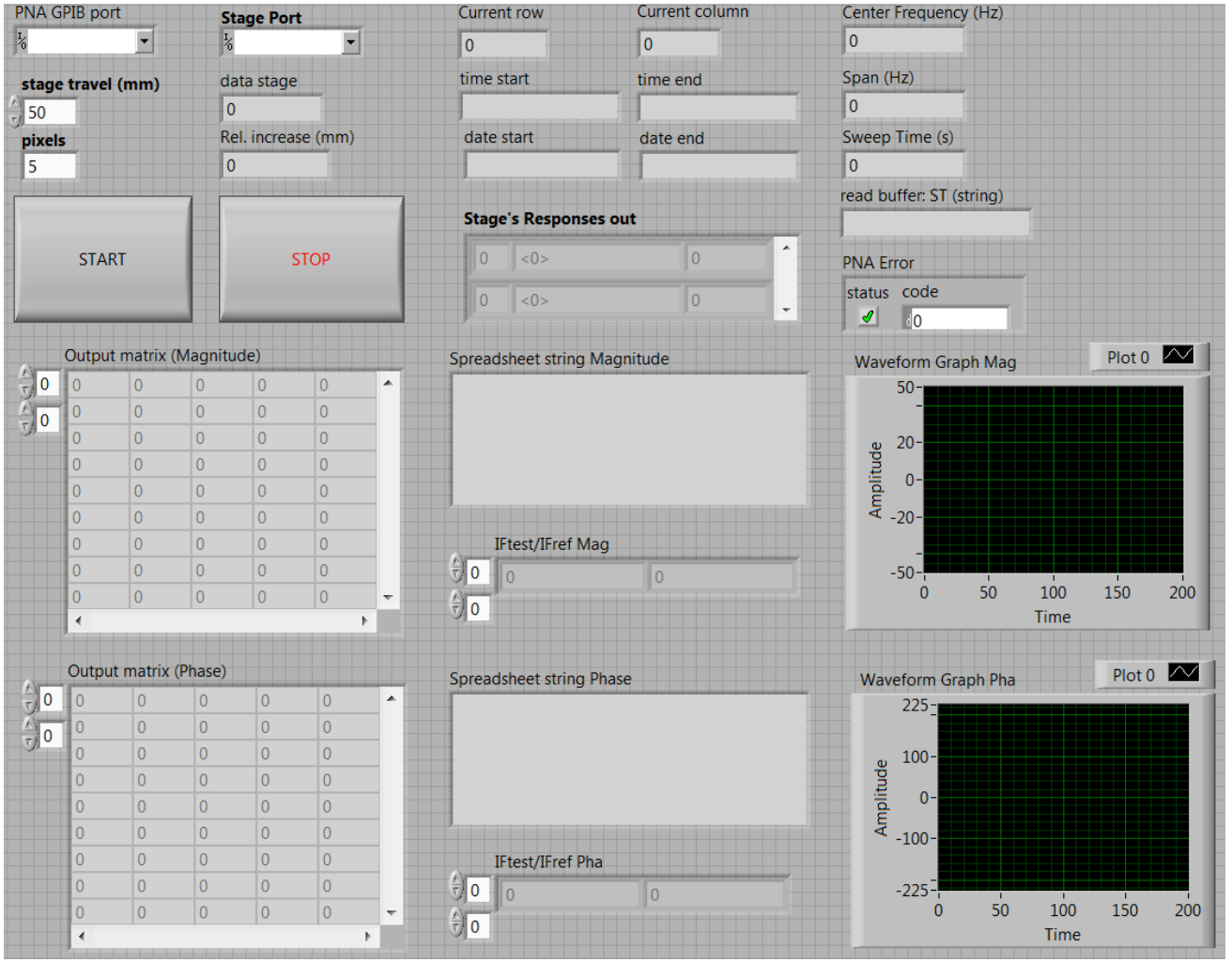



# Image scanning and data acquisition

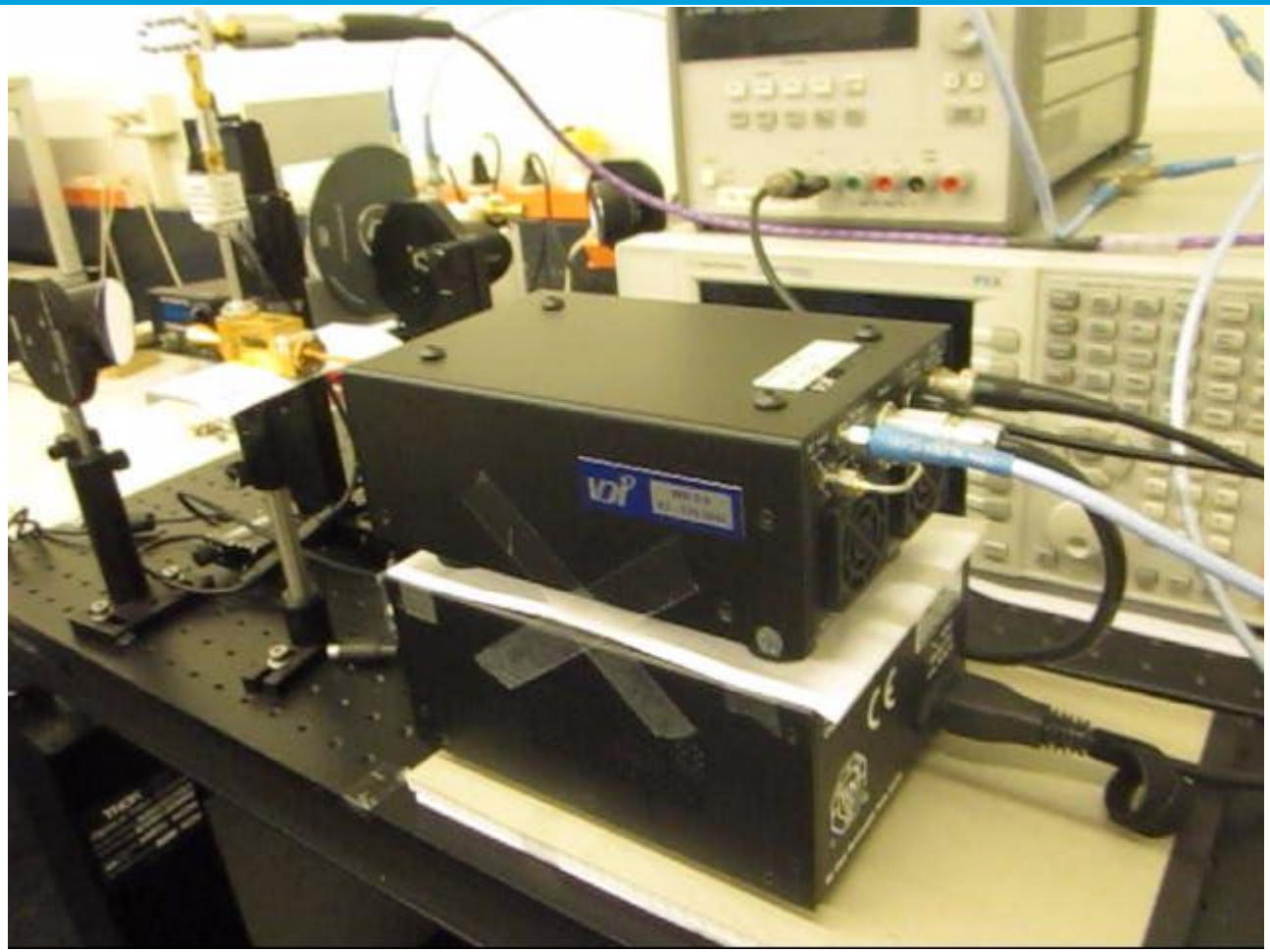
## Sample XY scanning



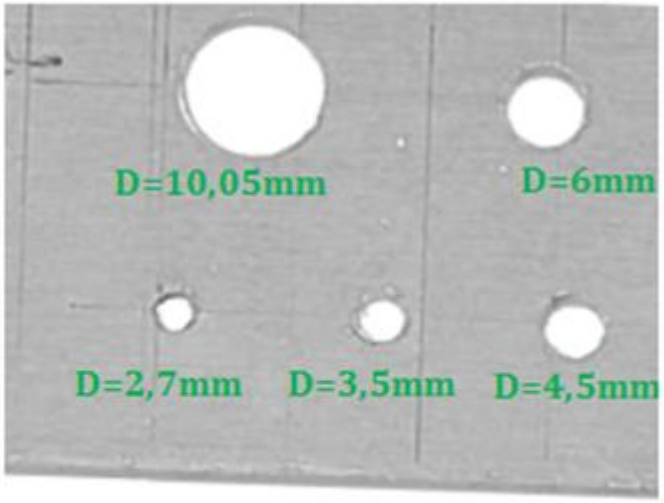



# System Integration



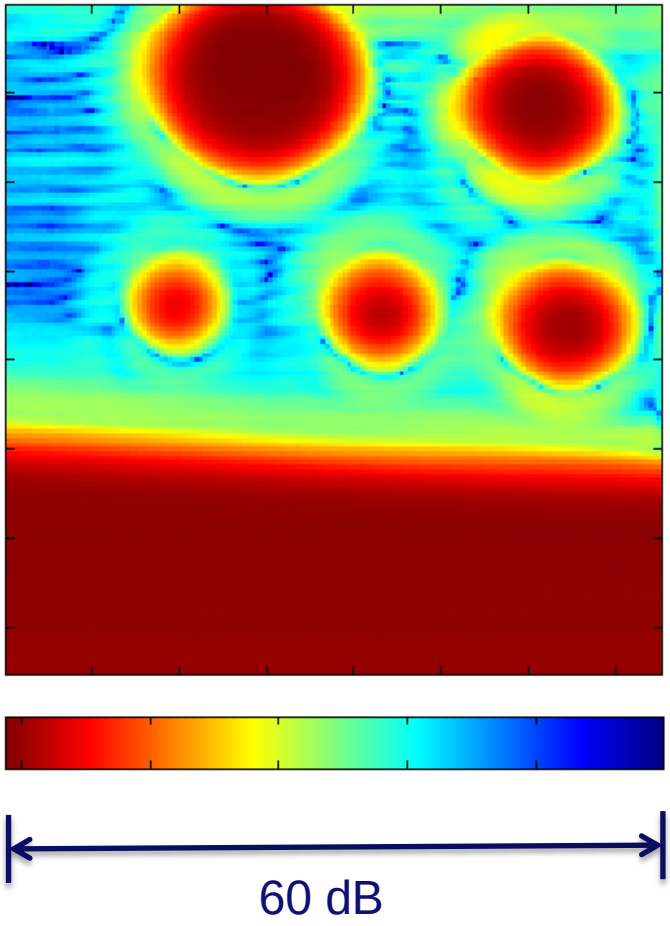
# Testing base and extended designs

Sample 1: metal sheet with holes



# Base design @ 115 GHz

Sample 1: metal sheet with holes




Base design @ 115 GHz

Spot size: 3.3 mm

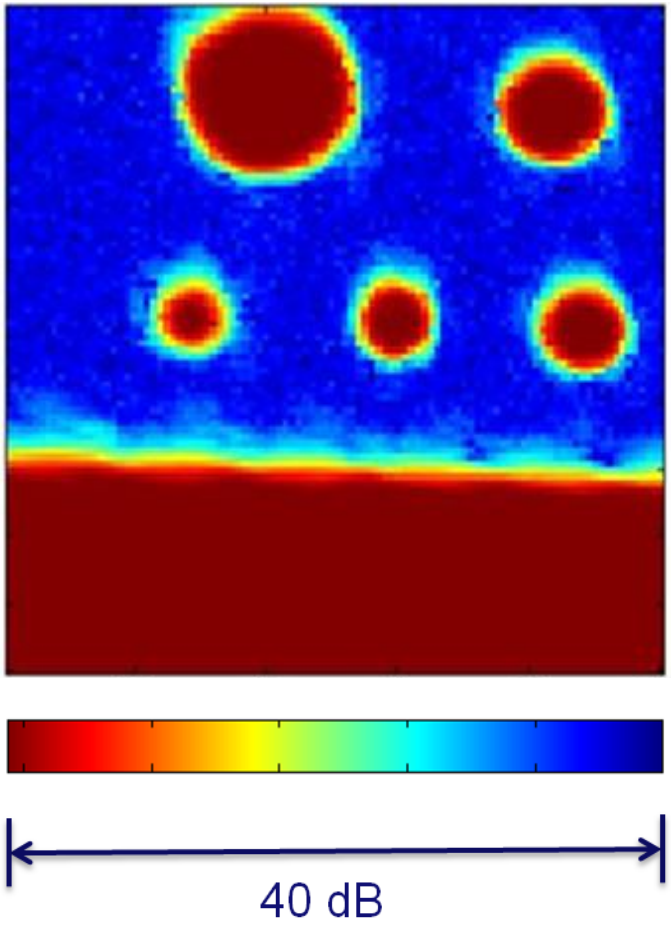
150 x 150 pixels

50mm x 50mm

Acquisition time = 3 hours

# Extended design @ 345 GHz

Sample 1: metal sheet with holes




Extended design @ 345 GHz

Spot size: 1.1 mm

250 x 250 pixels

50mm x 50mm

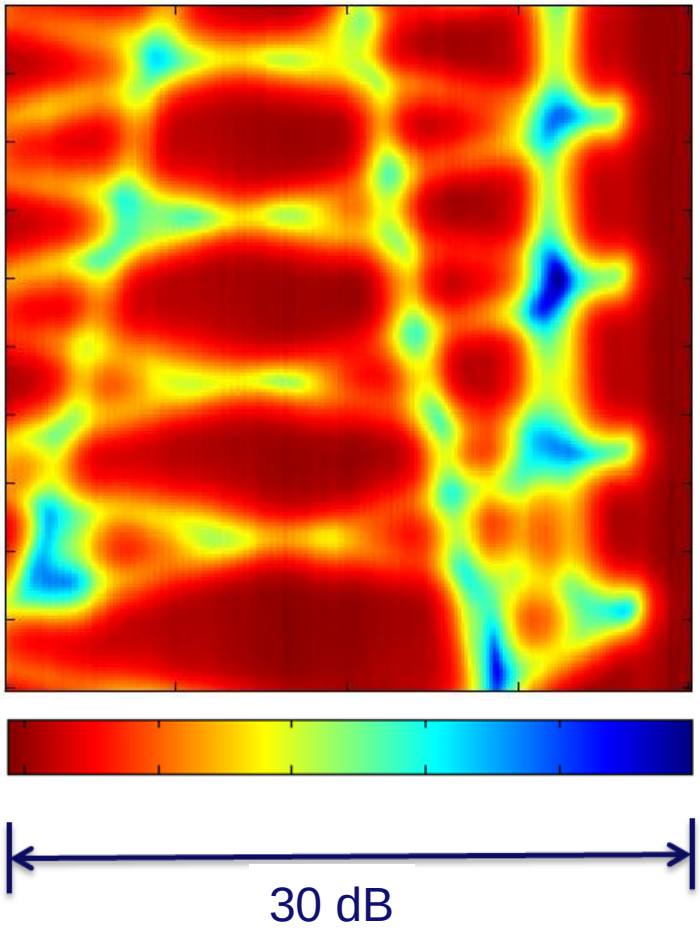
Acquisition time = 5 hours

# Imaging through plastic

Sample 2: TU/e card wounded with a 3-mm wide flat braided copper wire

# Base design @ 115 GHz

Sample 2: TU/e card wounded with a 3-mm wide flat braided copper wire




Base design @ 115 GHz

Spot size: 3.3 mm

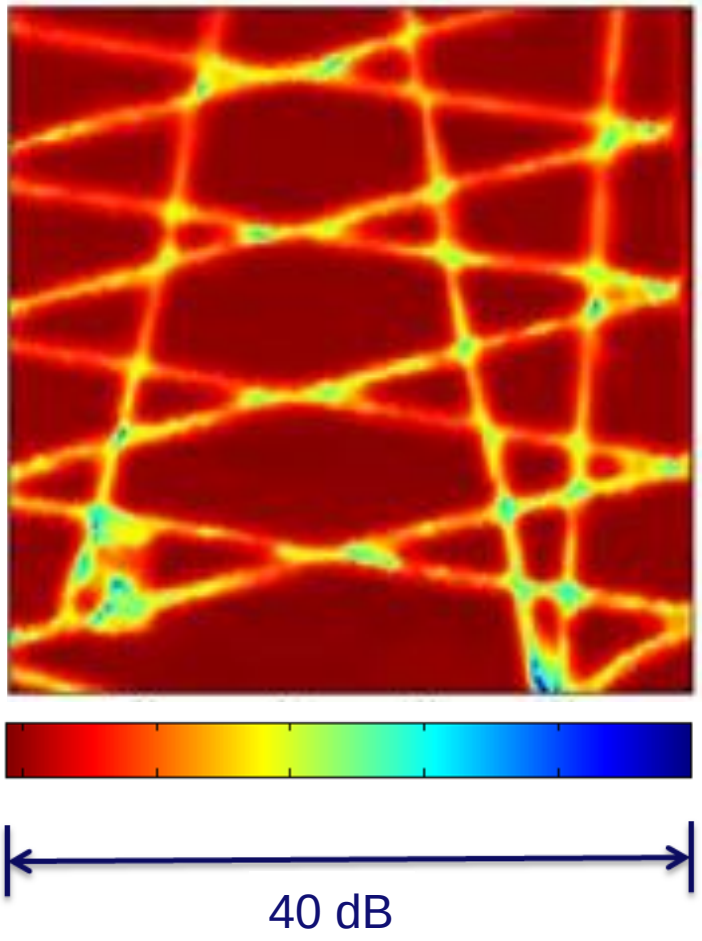
250 x 250 pixels

50mm x 50mm

Acquisition time = 5 hours

# Extended design @ 345 GHz

Sample 2: TU/e card wounded with a 3-mm wide flat braided copper wire




Extended design @ 345 GHz

Spot size: 1.1 mm

250 x 250 pixels

50mm x 50mm

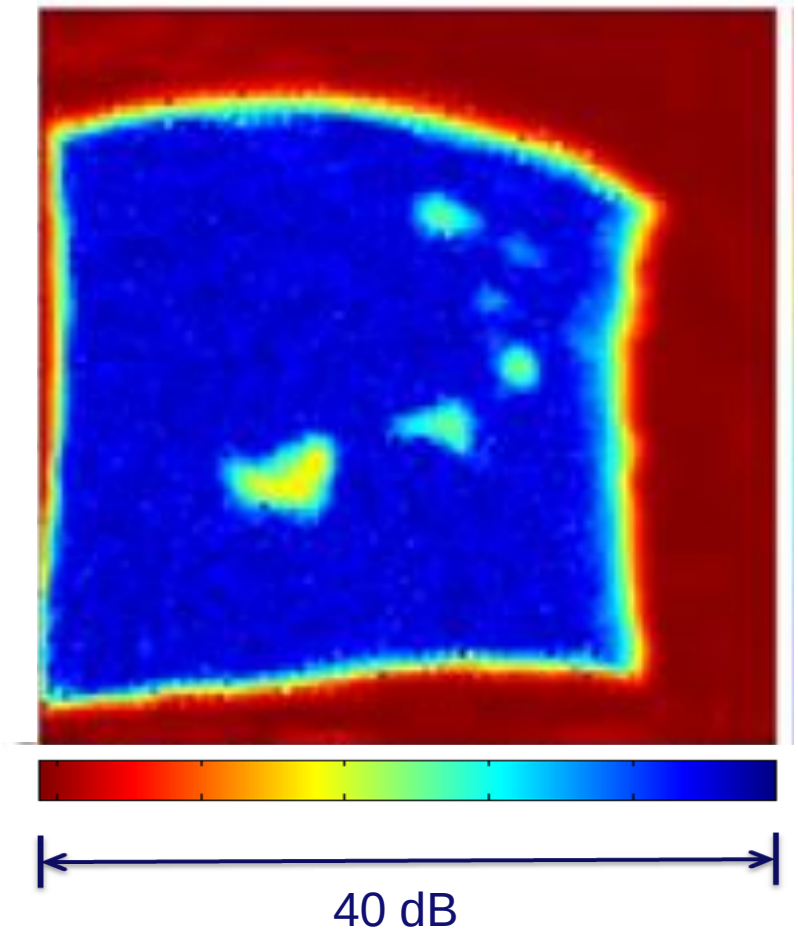
Acquisition time = 5 hours

# Towards tissue

Sample 3: piece of smoked ham

# Extended design @ 345 GHz

Sample 3: piece of smoked ham




Extended design @ 345 GHz

Spot size: 1.1 mm

250 x 250 pixels

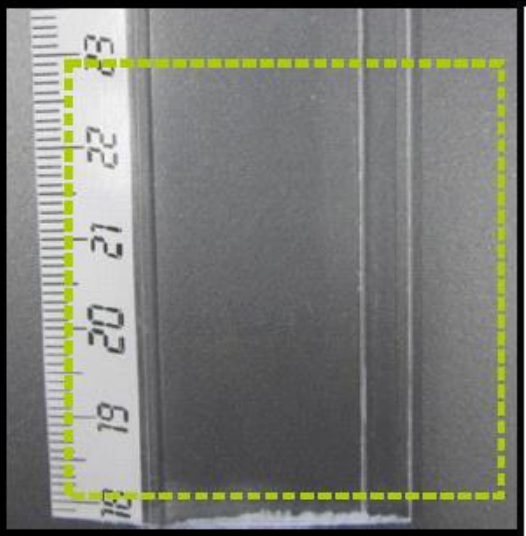
50mm x 50mm

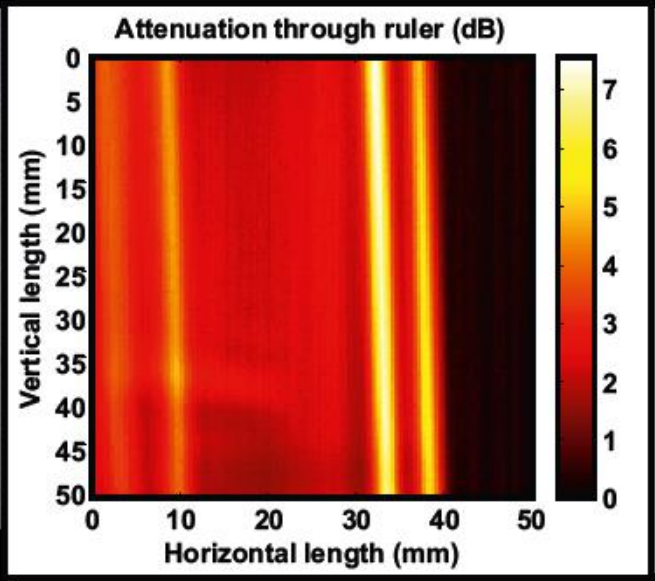
Acquisition time = 5 hours

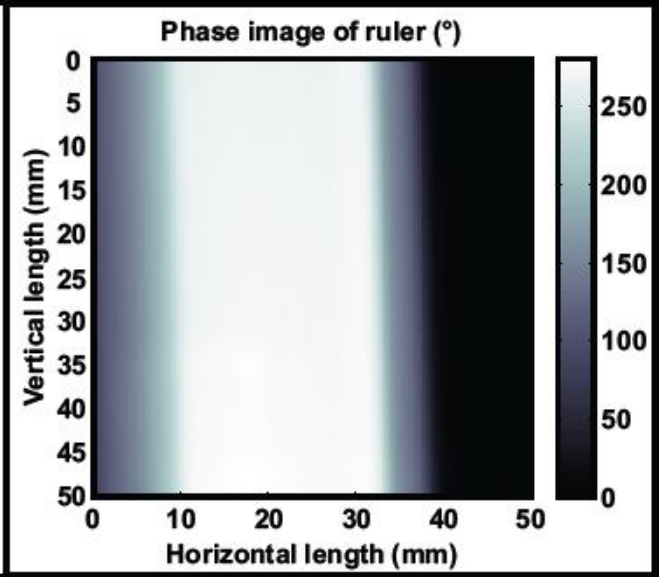
# Magnitude and phase images

Magnitude image

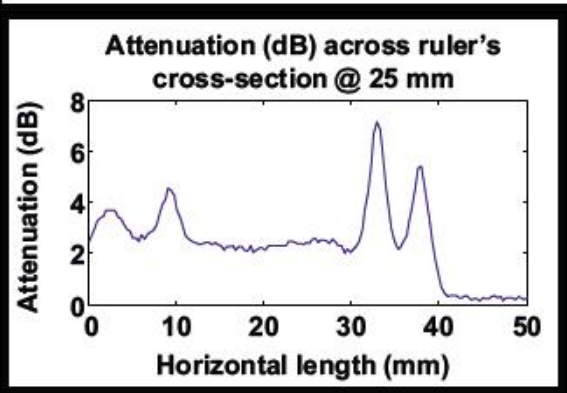
Phase image

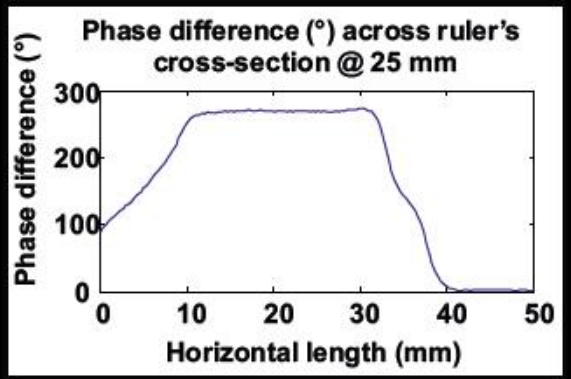





Visible image

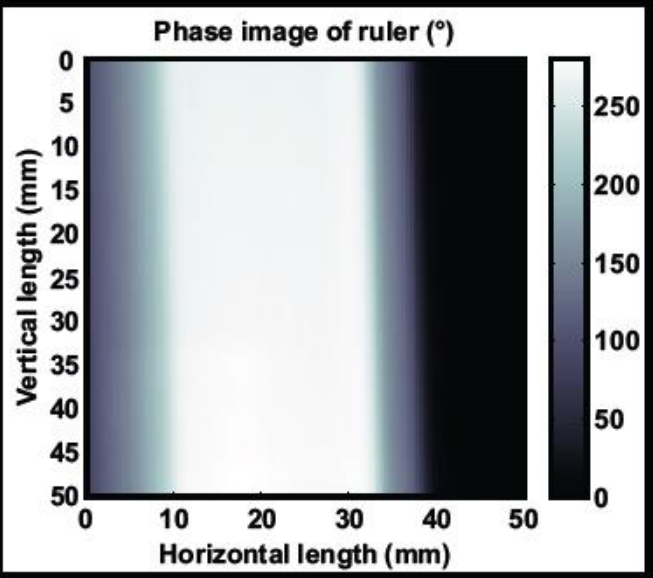


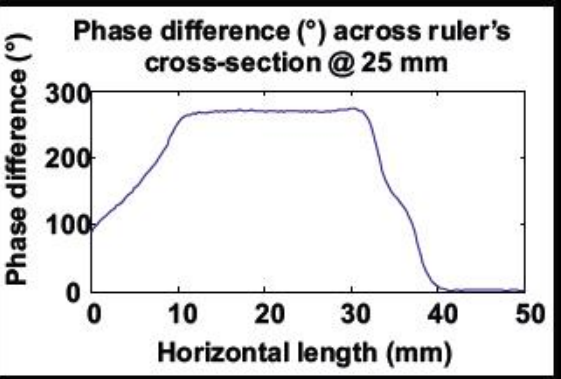




Freq. = 110 GHz
Spot size = 3.5 mm
Sample thickness = 3.35 mm

# Magnitude and phase images

Phase image




$n$: refractive index
$d$: sample thickness

$$n = 1 + \frac{\lambda_0}{d}\left(\frac{\Delta\varphi}{360°}\right)$$

Experimental:
$n_{ruler} = 1.6$

Literature:
$n_{acrylic\ glass} = 1.49$
$n_{polycarbonate} = 1.58$

# System performance

- **SNR:**
  - **60 dB @ 115 GHz**
  - **40 dB @ 345 GHz**
- **Output power:**
  - **10 dBm @ 115 GHz**
  - **-2 dBm @ 345 GHz**
- **Image resolution:**
  - **3.3 mm @ 115 GHz**
  - **1.1 mm @ 345 GHz**
- **System ready for application testing with biomedical or other samples**

# Summary

- **What can be done with current system:**
  - **Magnitude images @ 110 GHz with ~30% bandwidth**
  - **Magnitude images @ 330 GHz with ~30% bandwidth**
  - **Phase images (refractive index) @ 110 GHz with ~30% bandwidth**
  - **Phase images @ 330 GHz require additional IF amplifiers and an IF multiplier (x3)**

- **Base design scalable up to 1 THz, it requires additional multipliers and harmonic mixers**
- **Optical alignment: Improvements on methods need to be developed**
- **VNA to be replaced with ADC modules**
- **Cooperation with Faculty of Biomedical Technology**

# Questions ?