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)?

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

Lung-cancer sample visible image

Segmented THz image

Contrast of THz images

Lack of understanding

- Water content?
- Cells’ sizes?
- Cell arrangement?
- Protein content?
- DNA content?

Need for a database

THz spectroscopic information

Different types of tissues

Tissue characterization

better diagnose of disease

TU/e THz Program

TU/e - CWTe

Terahertz Imaging Spectroscopy Program

Challenge

To better understand:

• THz generation
• THz detection
• THz manipulation
• THz system’s building blocks

Long term goal

Portable and low cost THz systems

Develop know-how

Develop experimental capability

Mixed-signal Microelectronics group
Laboratory System for Terahertz (THz) Imaging Spectroscopy of Tissue Samples

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Project Overview

Build an electronic spectroscopic imaging system for tissue analysis in the sub-THz range.

Tasks:
- Requirements analysis
  - Analyze possible options
- System design
  - Selection of components
- System implementation
  - System test and evaluation
Build an electronic spectroscopic imaging system for tissue analysis in the sub-THz range.

**TASKS**

- **Requirements analysis**
  - Analyze possible options

- **System design**
  - Selection of components

- **System implementation**
  - System test and evaluation
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

THz Transmitter

Sample

THz Receiver

$\Delta M$ (Magnitude)

$\alpha$: attenuation coefficient

$n$: refractive index

$\Delta \varphi$ (Phase)
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Requirements analysis

System design

System implementation

Analyze possible options

Selection of components

System test and evaluation
Pre-design phase

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

![Diagram]

- Up to 67 GHz
- Up to 1 THz

VNA extender

Horn antenna

PC

PNA-X

VNA extender

Horn antenna

VNA extender

Up to 1 THz
Pre-design phase

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

[Diagram showing the setup with PC, PNA-X, Horn antennas, VNA extender, and frequency ranges up to 1 THz.]

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
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  - Analyze possible options
Base design (90-125 GHz)
Extended design (270-375 GHz)
Frequency and power performance

Frequency Plan and Output Power

\[ f_{in} \text{ (GHz)} = 10-13.9 \ , \ P_{in} = 10 \text{ dBm} \]
Optics setup

\[ \frac{f}{D} = 1 \]

- **Base design @ 115 GHz** \( \text{spot size} = 3.31 \, \text{mm} \)

- **Extended design @ 345 GHz**: \( \text{spot size} = 1.104 \, \text{mm} \)

\( f \) : focal length  
\( D \) : Diameter

\[ \text{spot size} = 1.27 \lambda \frac{f}{D} \]
Component selection process

- Compare specifications from different manufacturers for each component
- Choose best performance, lower cost
Build an electronic spectroscopic imaging system for tissue analysis in the sub-THz range.

**Requirements analysis**

**System design**

**Analyze possible options**

**Selection of components**

**System implementation**

**System test and evaluation**
Frequency and power testing

Signal Generator 1

Amplifier Multiplier Chain (x9)

9*f_in

f_LO

Signal Generator 2

Optical components, stage, and sample

9*f_in

f_LO

Vector Network Analyzer
Amplifier’s output (90-125 GHz)

VDI AMC 408 - WR9.0 Performance

VDI AMC 408 - WR9.0 Measured Performance

Signal Generator 1

Even Harmonics Mixer

9*f_in

f_in = 10 GHz - 13.9 GHz

f_\text{LO} can be calculated

\text{IF}_{\text{ref}} = 9*f_{\text{in}} - 8*f_{\text{LO}}
Tripler’s output (270-375 GHz)

**Signal Generator 1**

- **Amplifier Multiplier Chain (x9)**
- **Tripler (x3)**

\[ f_{in} \]
\[ 9f_{in} \]
\[ 27f_{in} \]

**Efficiency (%)**

**Output Frequency (GHz)**

\[ f_{LO} \]
\[ IF_{ref} = 3(9f_{in} - 8f_{LO}) \]
\[ f_1 = 10 \text{ GHz} - 13.9 \text{ GHz} \]
\[ f_{LO} \text{ can be calculated if chosen to be 1 GHz} \]
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

40 dB
Imaging through plastic

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

40 dB
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

40 dB
Magnitude and phase images

Visible image

Freq. = 110 GHz
Spot size = 3.5 mm
Sample thickness = 3.35 mm
Magnitude and phase images

Phase image

\[ n = 1 + \frac{\lambda_0}{d} \left( \frac{\Delta \varphi}{360^\circ} \right) \]

- \( n \): refractive index
- \( d \): sample thickness

Experimental:
\[ n_{\text{ruler}} = 1.6 \]

Literature:
\[ n_{\text{acrylic glass}} = 1.49 \]
\[ n_{\text{polycarbonate}} = 1.58 \]
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 ?