Terahertz Program CWTe

Research Retreat 2017

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Center for Wireless Technology Eindhoven

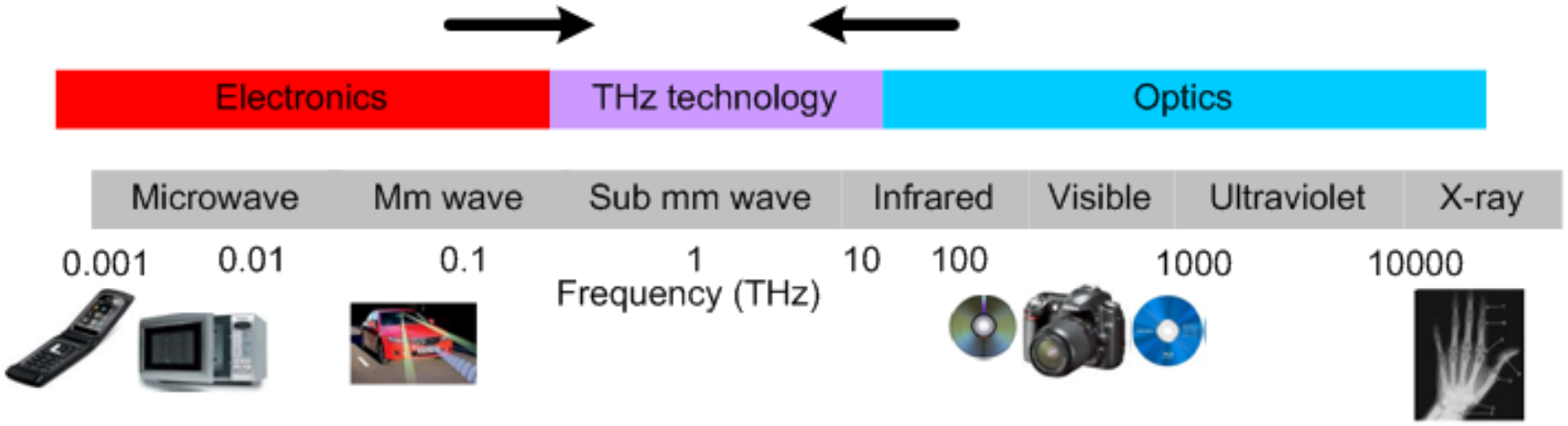
Technische Universiteit
Eindhoven
University of Technology

Where innovation starts

- THz research at TU/e
- THz opportunities and research strategy
- THz application domains
- Miniaturized THz systems
- Material characterization
- Conclusions

THz radiation: Unique properties

1 THz = 1000 GHz



- THz radiation can **penetrate** through non-polar materials (e.g. plastics, wood, clothing)
- THz imaging has sub-mm **resolution**
- THz spectroscopy **identifies** specific materials (e.g. explosives)
- THz radiation is **non-ionizing** (and therefore safer than X-ray)
- THz radiation is **strongly absorbed polar materials** (e.g water)
- Enabler for extreme high data rate communication
- Applications in the THz range continue to increase rapidly

Intensive terahertz research in NL

SRON : Superconducting terahertz technology & applications (Baryshev, Gao, Baselmans)
SRON: Valorization lab

TU/e EE: IC integrated terahertz sensors (Prof. Marion Matters)
TU/e TN : Terahertz plasmonics and metasurfaces (Prof. Jaime Gomez-Rivas)
TU/e EE: THz photonics (Prof. Idelfonso Tafur Monroy)

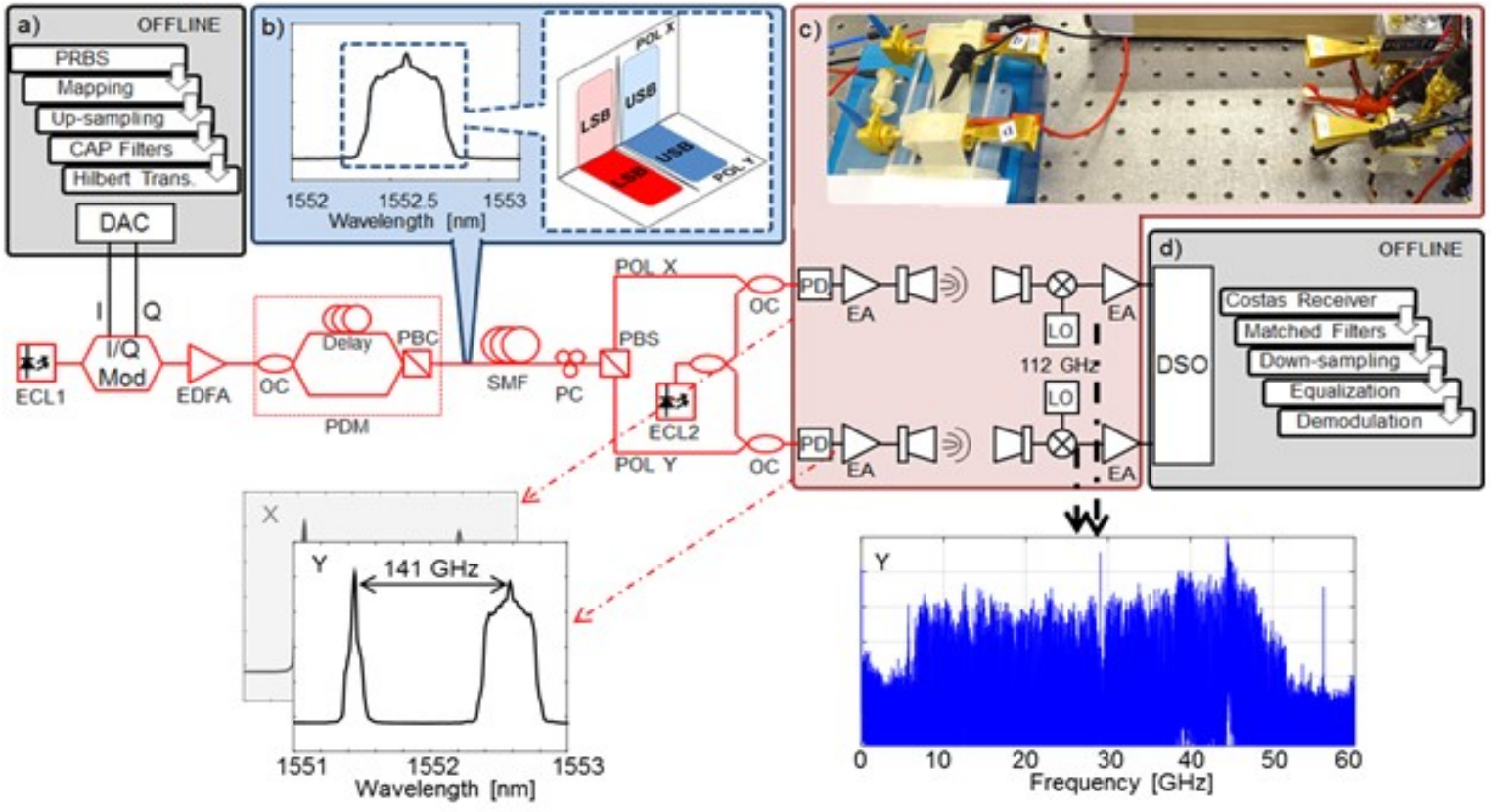
3 THz professors at TU/e

TU/e EE: IC photonics circuits for mm-wave applications (Kevin Williams/Meint Smit)
TU/e EE: Mm-wave antenna arrays (Electromagnetics group)

TU Delft EWI: Terahertz antennas (Prof. Andrea Neto)
TU Delft EWI: Millimeter wave measurement techniques (Dr. Marco Spirito)

RU Groningen: Superconducting terahertz sensors
Nijmegen: Free electron laser research facility (broadband high power terahertz source)
ESA: Terahertz sensors for space (Peter de Maagt)

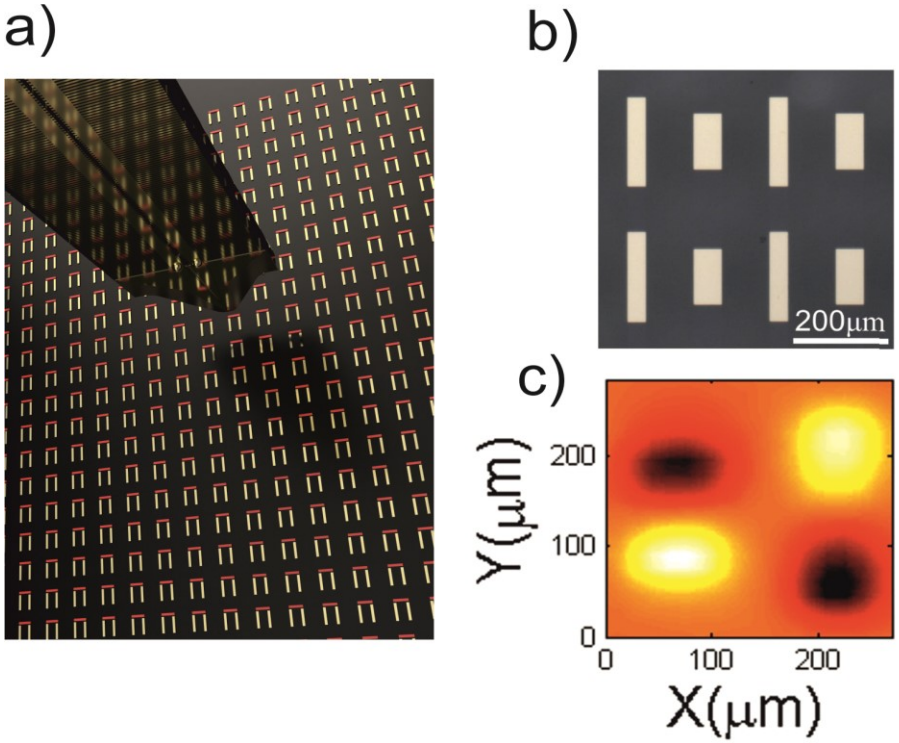
THz photonics for communication and sensing



352 Gbps wireless data transmission link at 141 GHz

R. Puerta, J. Yu, J J Vegas Olmos, I. Tafur Monroy, "Single Carrier PDM Radio-over-Fiber 328 Gb/s Wireless Transmission in a D-band Millimeter Wave 2×2 MU-MIMO System, IEEE/OSA J. Lightwave Technol. 10.1109/JLT.2017.2756089, 20 sept. 2017.

THz plasmonics and metasurfaces



THz near field microscopy

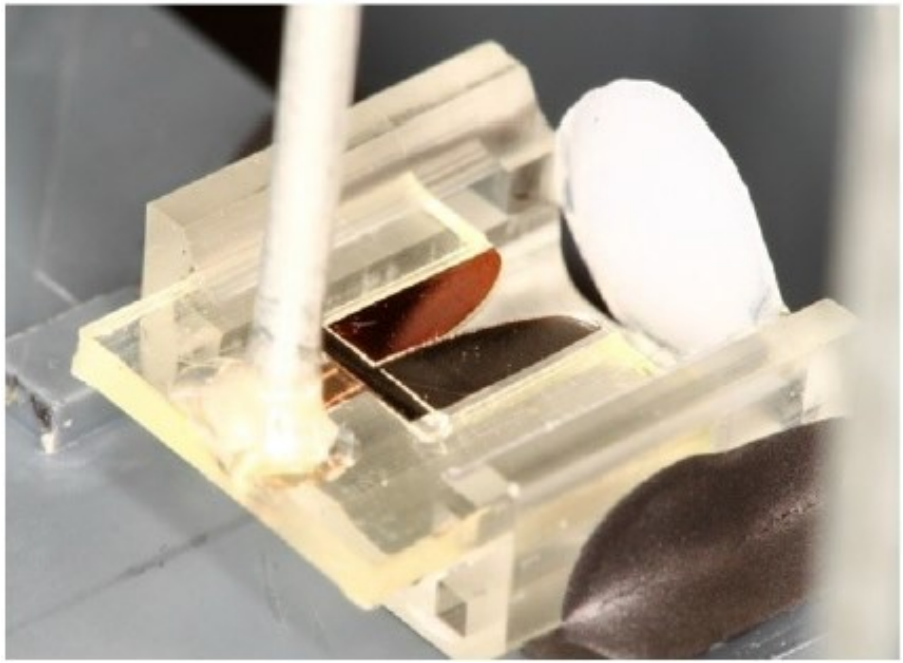
a) THz near-field probe scanning a metasurface

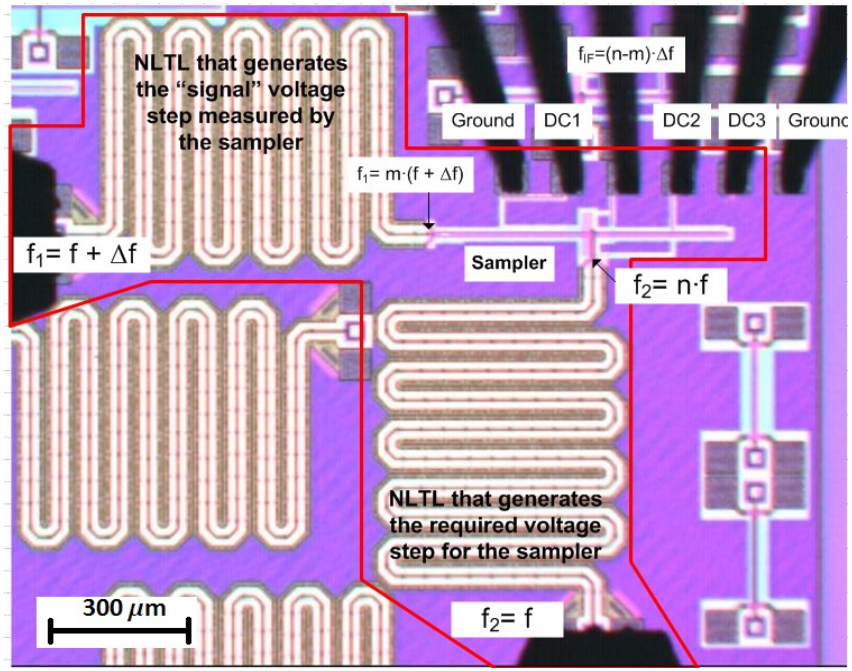
b) Scanning electron microscope image of an array of detuned resonantors

c) THz electric near-field amplitude measured on two of the resonators. The oposite phase in each of the resonantors renders the array transparent at a resonant frequency

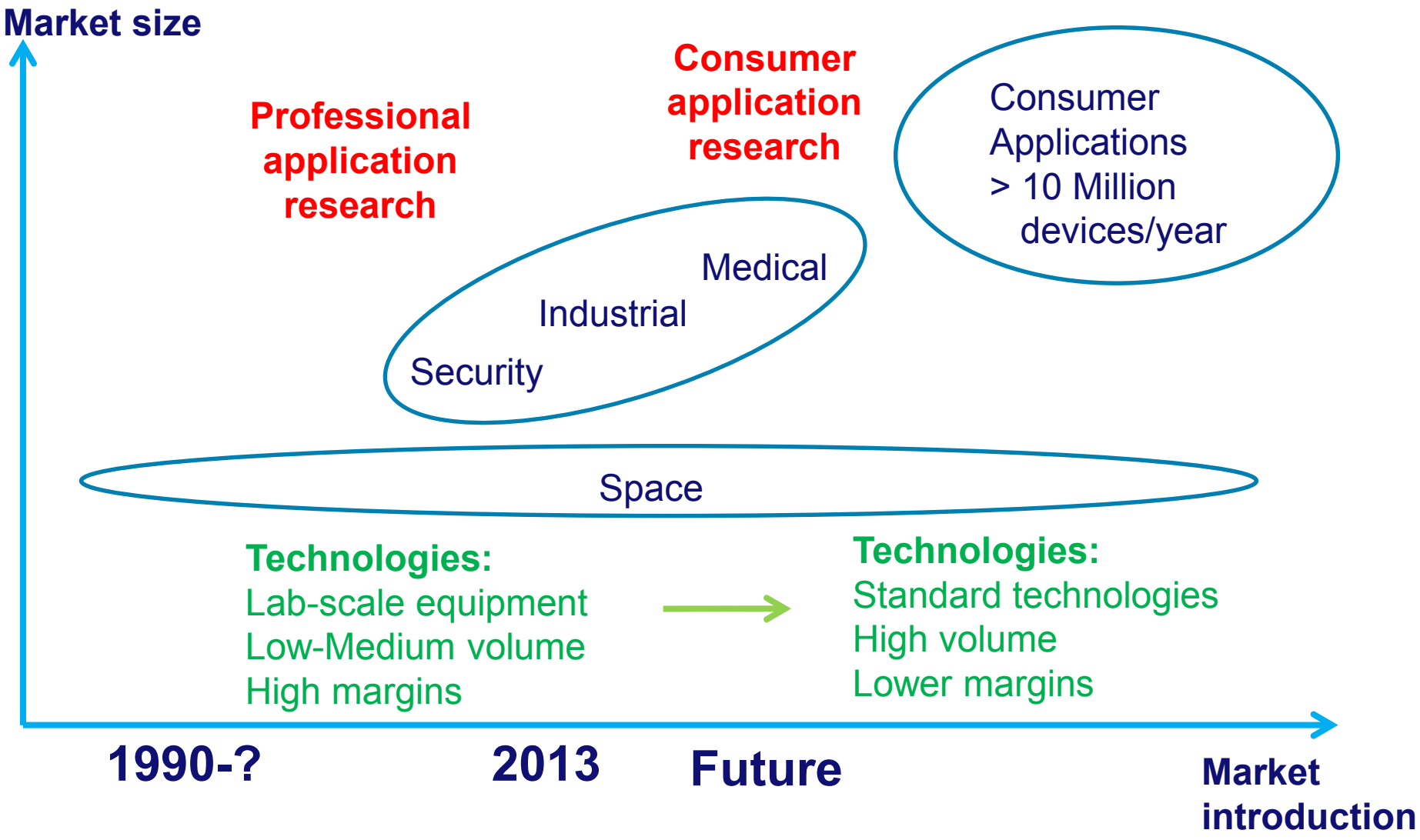
IC integrated THz systems

20-480 GHz broadband spectrometer CMOS and chip-scale packaged





What problem do we solve for whom?



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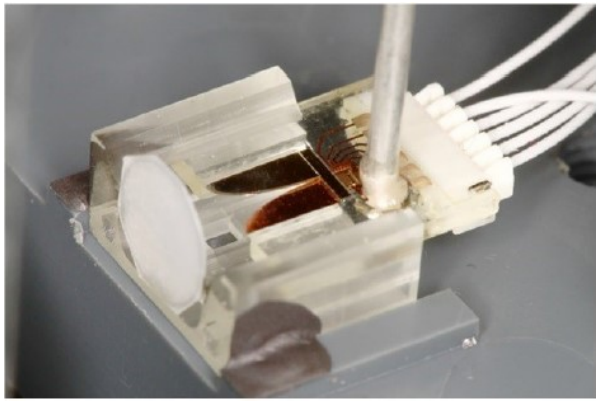
Miniaturized THz systems

THE WORLD NEEDS "REAL-WORLD" THZ TECHNOLOGY
to enable many new applications

From Lab-scale:

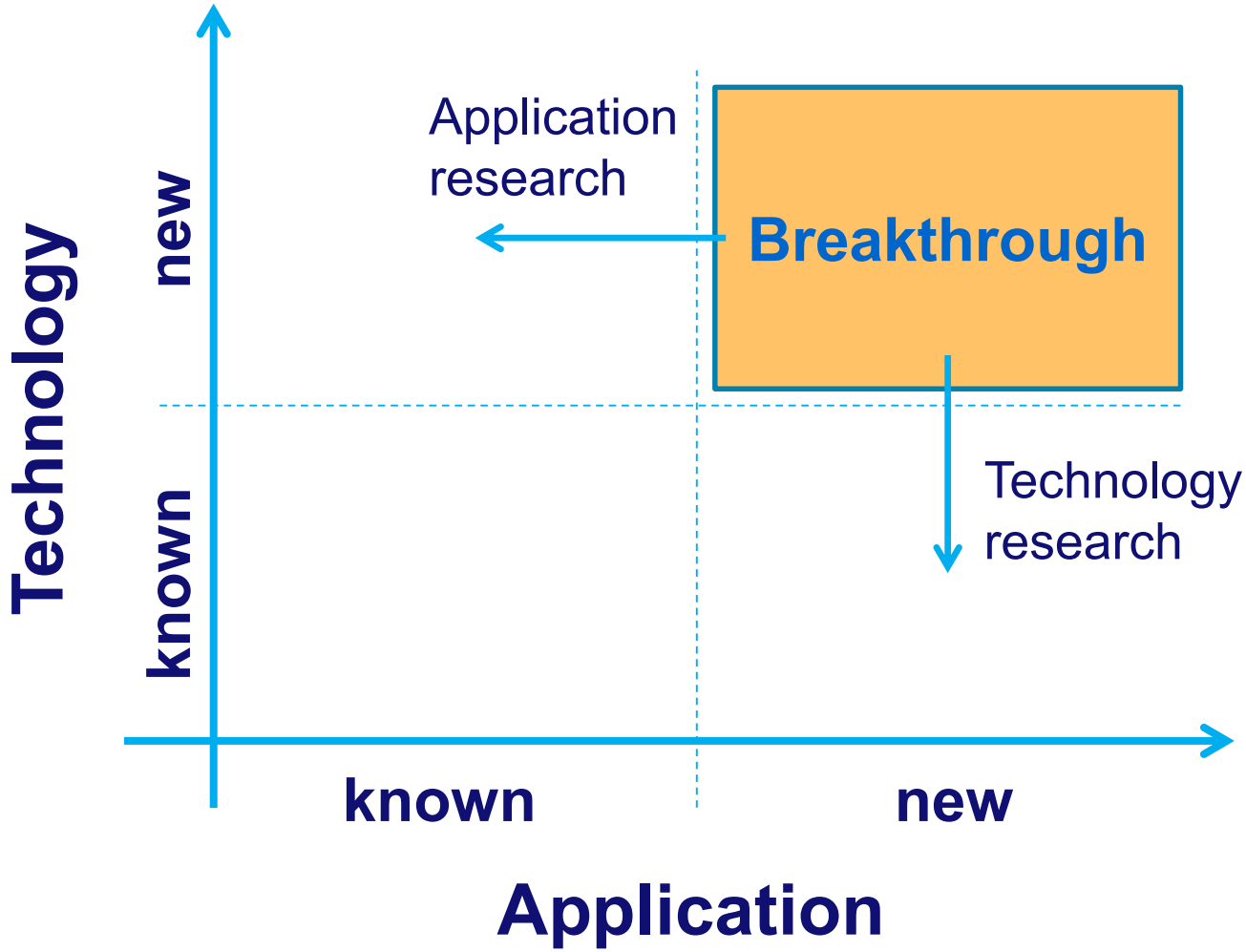
To miniature, affordable "real-world" technology



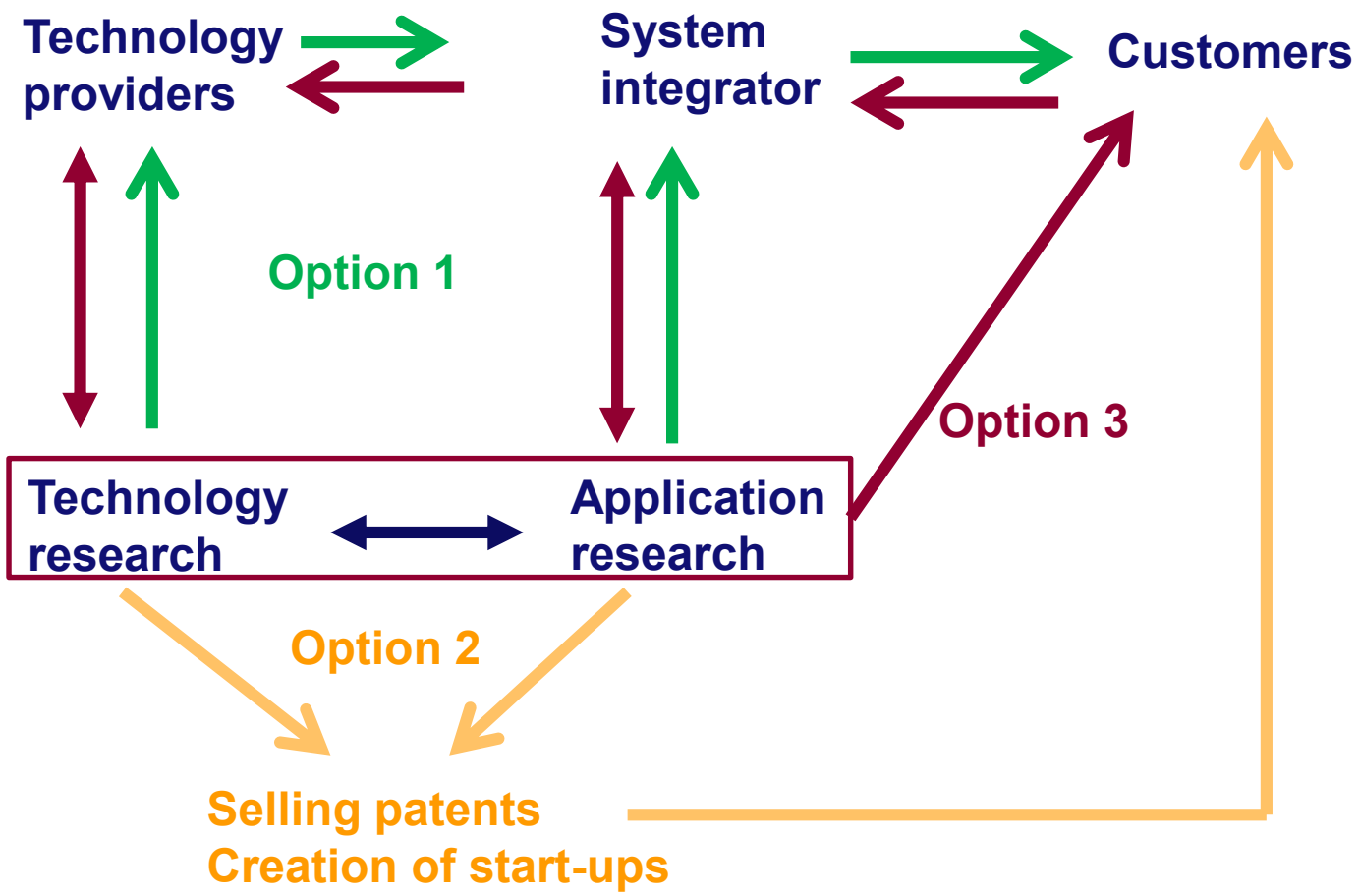
For:

- **Spectroscopic imaging**
- **Ultra high data rate communication**

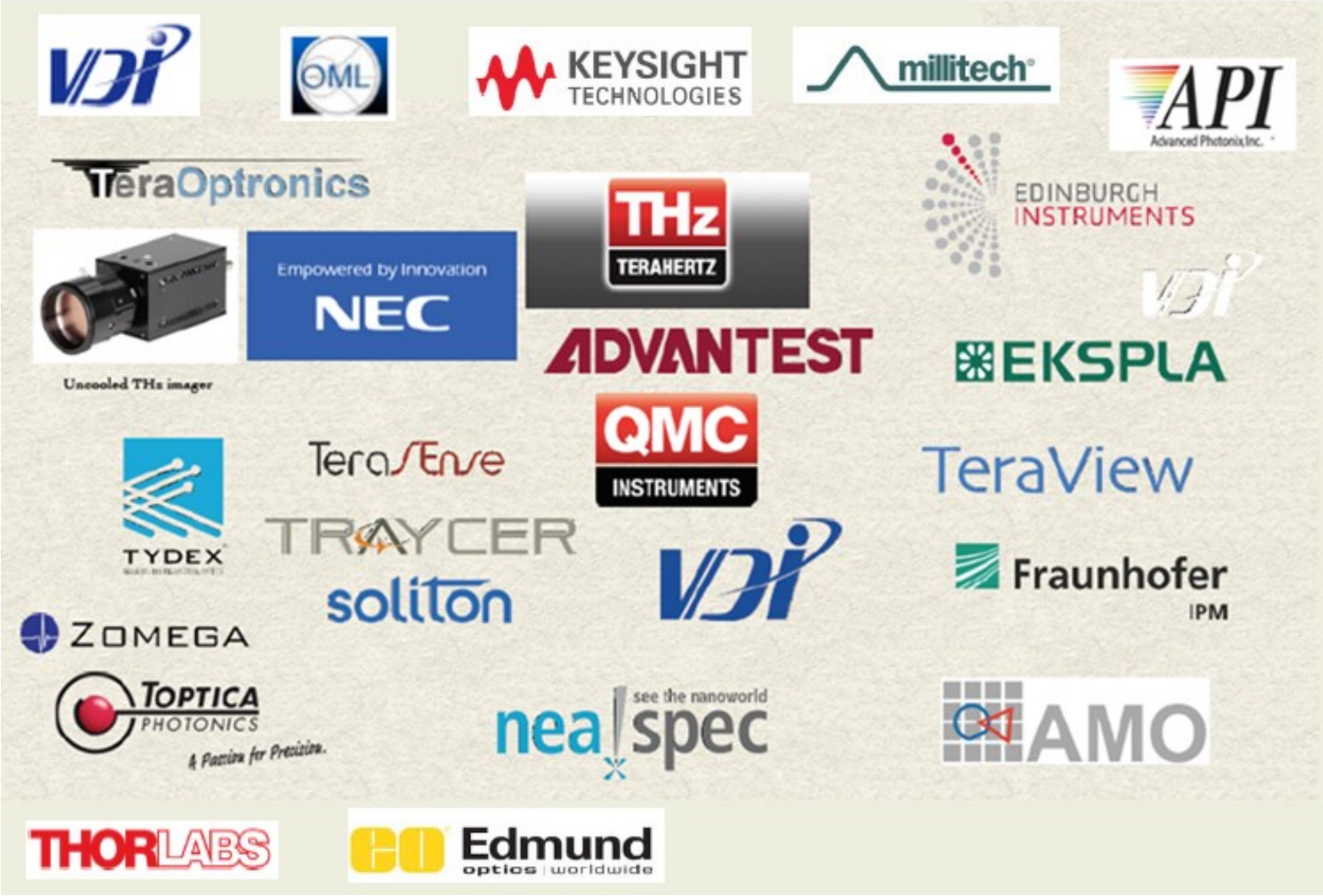
The Terahertz challenge



Ecosystems for successful THz valorization



Companies active in the THz field



Build a THz ecosystem

Exploring new collaborations

SKF

DSM
BRIGHT SCIENCE. BRIGHTER LIVING.

KLM

KEYSIGHT TECHNOLOGIES

océ

PHILIPS

Holst Centre
Open Innovation by imec and TNO

ABB

Roadmaps

Spectroscopic imaging roadmap
- Dutch THz roadmap
- CWTe THz roadmap
- URSI THz roadmap

Lab-building

- **Excellent lab facilities**
- **Measurements up to 370 GHz**
- **NWO groot proposal 2017**
- **Extend lab with cooperations and projects**

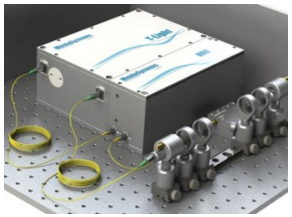
Drivers in THz sensing

Expert lab equipment → **Professional equipment** → **Consumer**

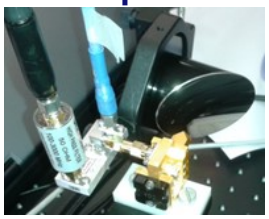
THz Analysis ↓

THz manipulation ↓

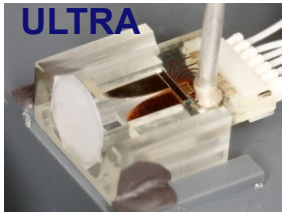
THz-TDS



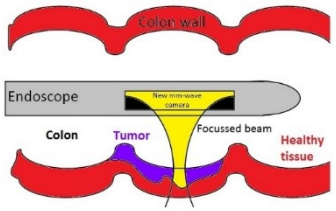
Free-space



Integrated ULTRA

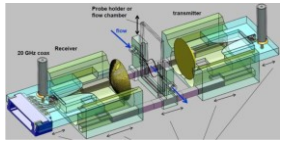


THz-endoscope

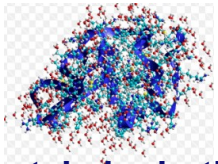


Integrated into other equipment
Implanted into the body
Non-expert use enabled
Integrated signal processing

Company: Swissto12



Micro-fluidics



Protein hydration sensing

THz enabled medication?

Performance, Miniaturization ↓

Accessibility : Ease of use / Price →

Lab Analysis

Solid material analysis

Contaminant detection

Gas analysis

Microfluidics

Living cells/bacteria

Molecular interaction (e.g. drug-protein, antibiotic-bacteria)

Medical Analysis

Pathology

THz endoscopes, catheters, guidewires

Implantable sensors

THz sensor surface

Body fluid analysis (e.g. blood)

Breath analyser

Process control

Layer integrity, paint/coating

Contamination detection: e.g. metal particles

Food control

Solvation dynamics

Humidity + drying process control: paint/powders/food/ wood/paper

Medication testing

Consumer

Air-quality

Spectroscopy on mobile devices

Home healthcare

Food quality

Cosmetics

Skin cancer

Electronic pills

Lab and infrastructure

- **Extend frequency range:**
  Continusously extend NA, SA and antenna setups to higher frequencies for IC and antenna measurements as well as more diverse application/material testing

- **Material characterization:**
  Make it **very accessible** for application research groups and companies

- **Multiplication factor:**
  Use results from research projects to enable measurements at other location (e.g. in companies, bio-medical labs, hospitals)

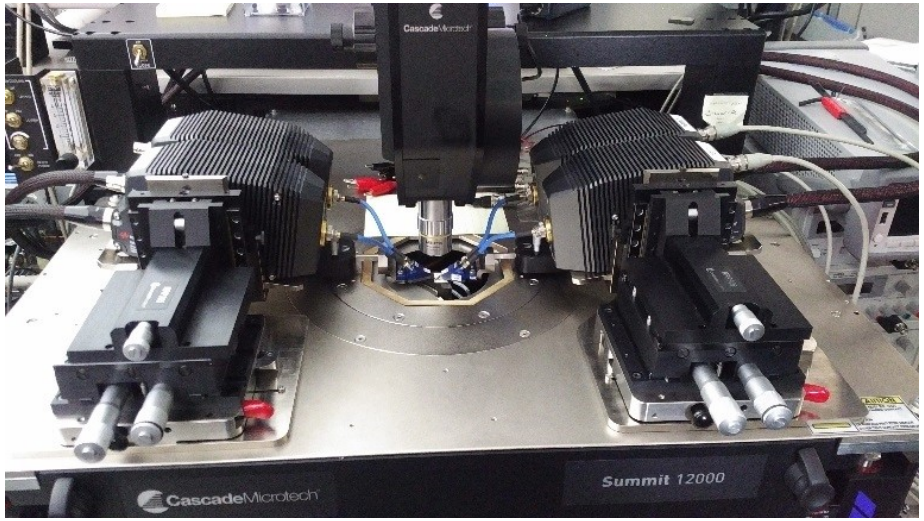
NWO large grant submitted in October 2017: 4 million Euro
Keeping fingers crossed!

Goal: Extend frequency range

1) IC characterization up to 1.5 THz

2) High resolution near-field THz time-domain microscope up to 2 THz

3) Optical fibre coupled THz transmitter and receiver system up to 5 THz



Keysight VNA with
VDI extenders

Images: Keysight, Rob Streeder

WR 1.0 measurement probes

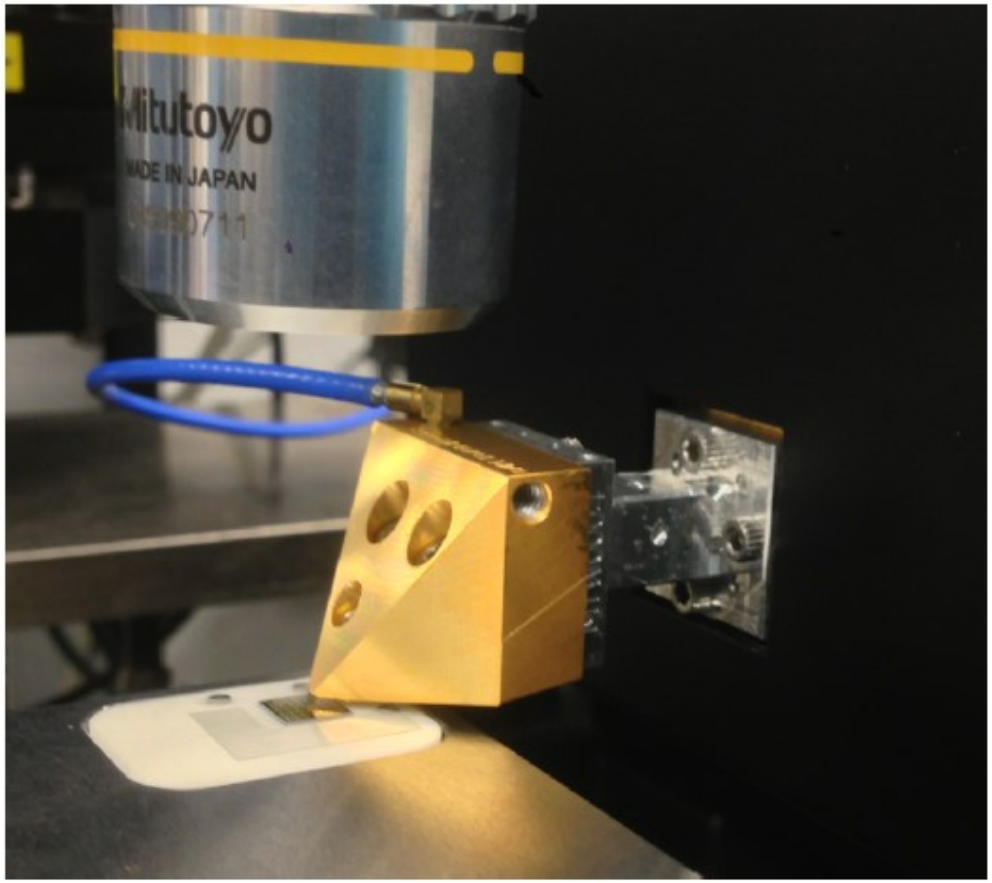


Fig. 4. One-port measurement setup on PA200 probe station. The probe is connected to the frequency extender through a 1-inch, split-block 90 degree waveguide twist.

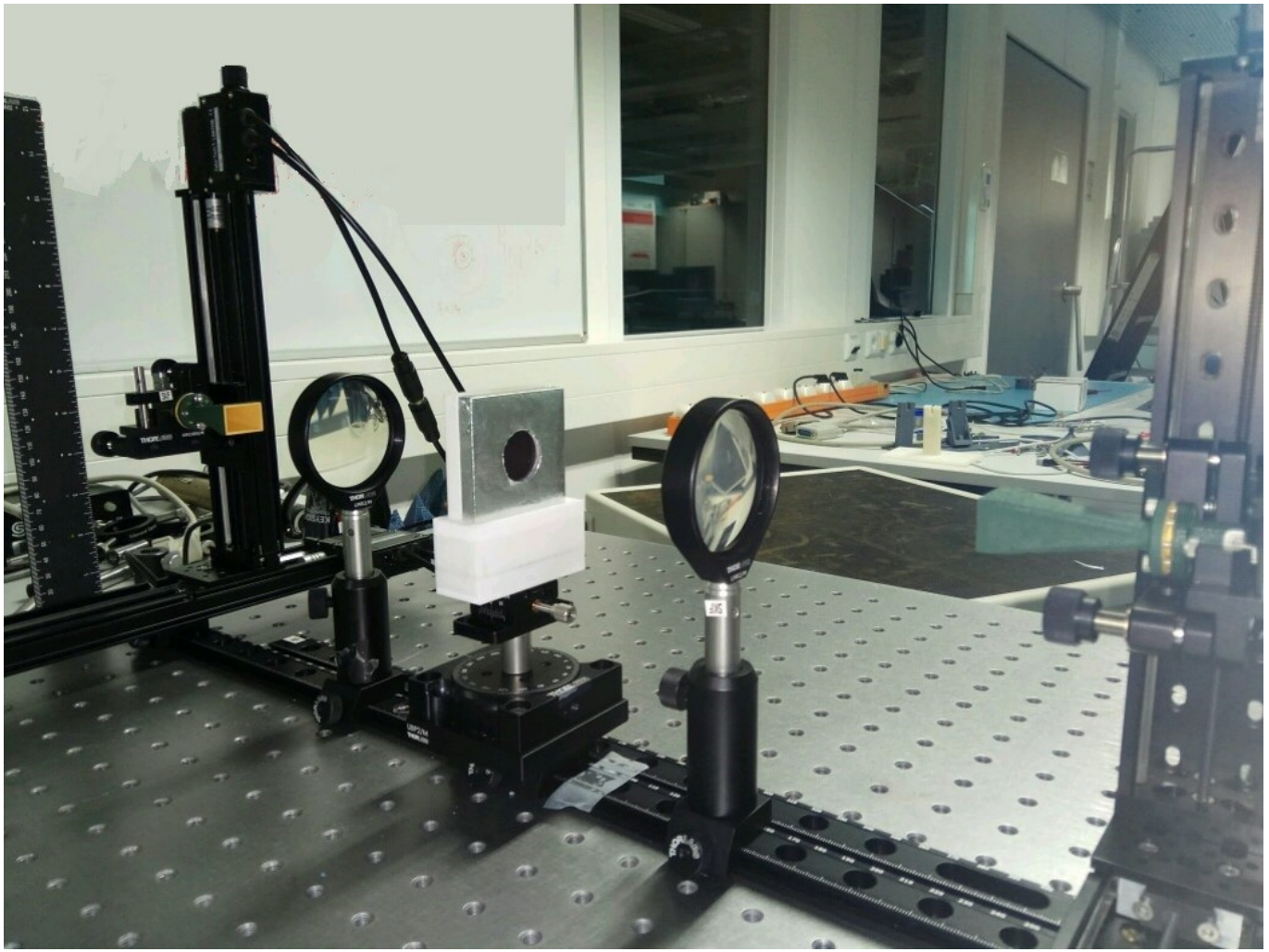
- WR-1.0: 750 GHz – 1.1 THz
- Micromachined probe
- Internal transitions:
  1) waveguide to rectangular coaxial transmission line
  2) rectangual coaxial transmission line to coplanar waveguide
- 25 µm CPW pitch

Matthew F. Bauwens et al., A 1.1 THz Micromachined On-Wafer Probe, IMS 2014

50 kEuro per piece!

Material characterization at mm-wave and THz

Dielectric constant: Repeatibility and accuracy better than 1%



Sample holder for semi-fluid samples

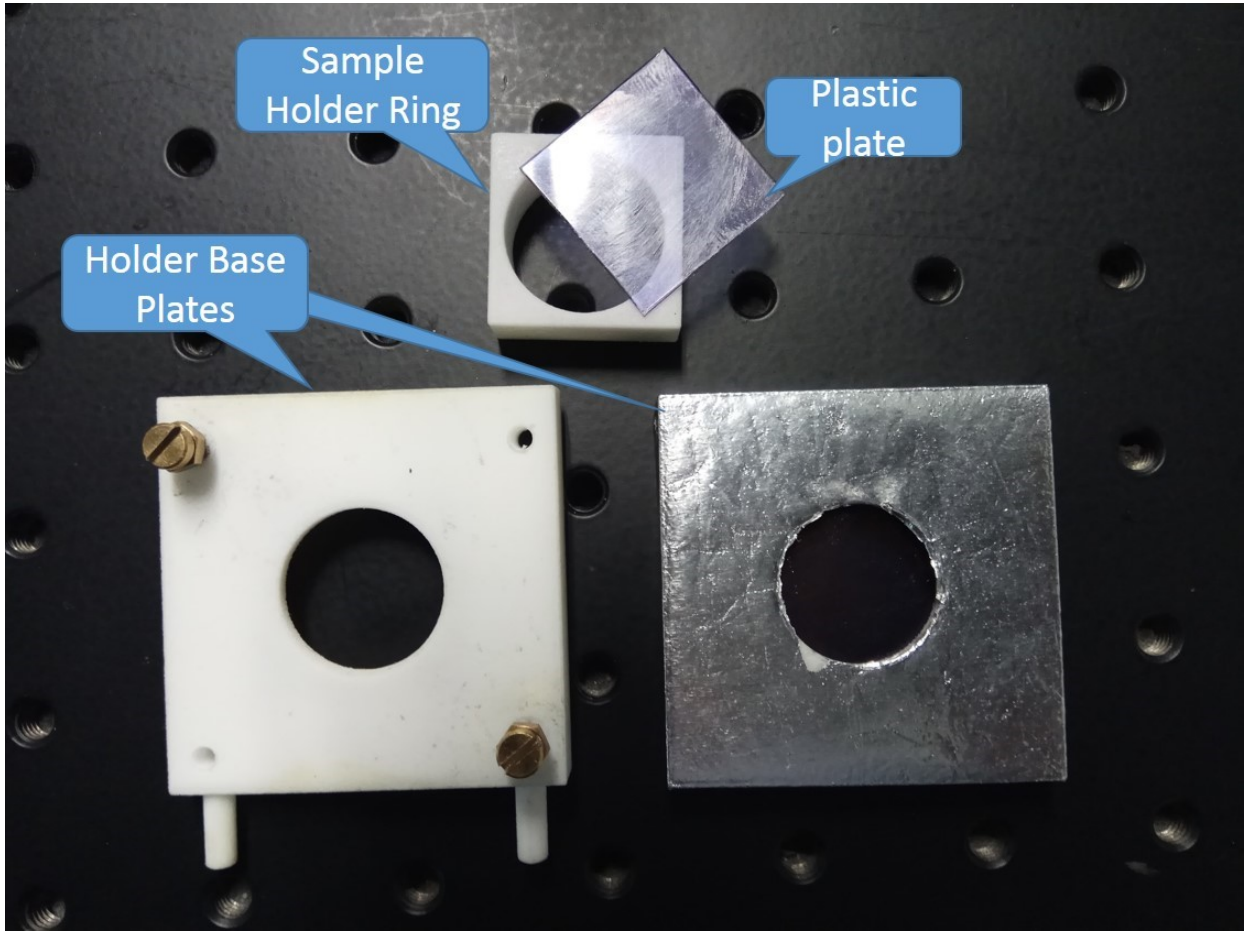


Fig. 17. Photograph of the 3D printed sample holder

Sample Holder Design

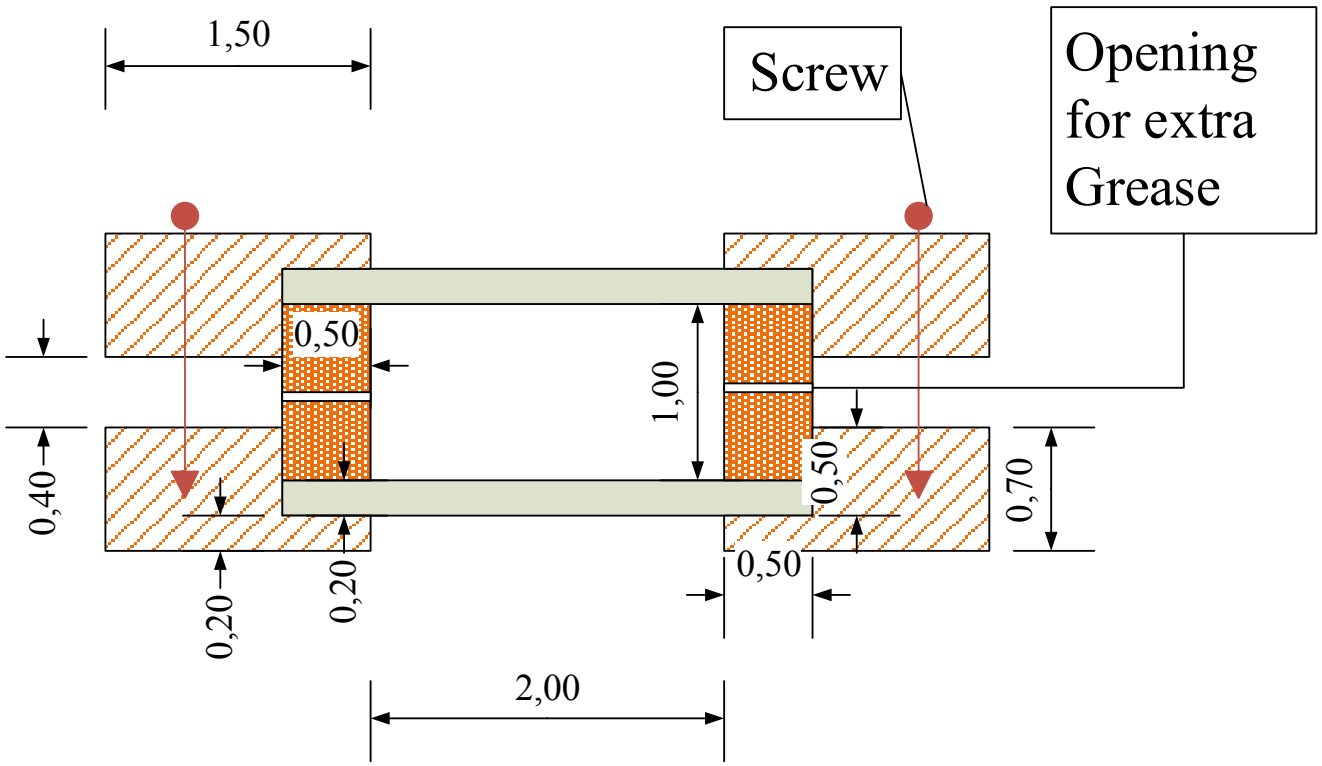
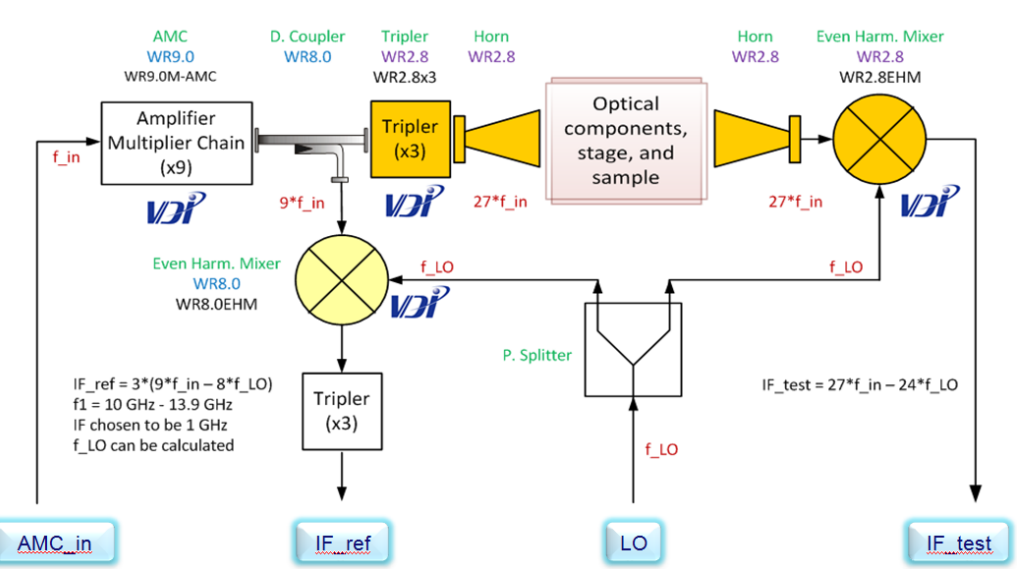
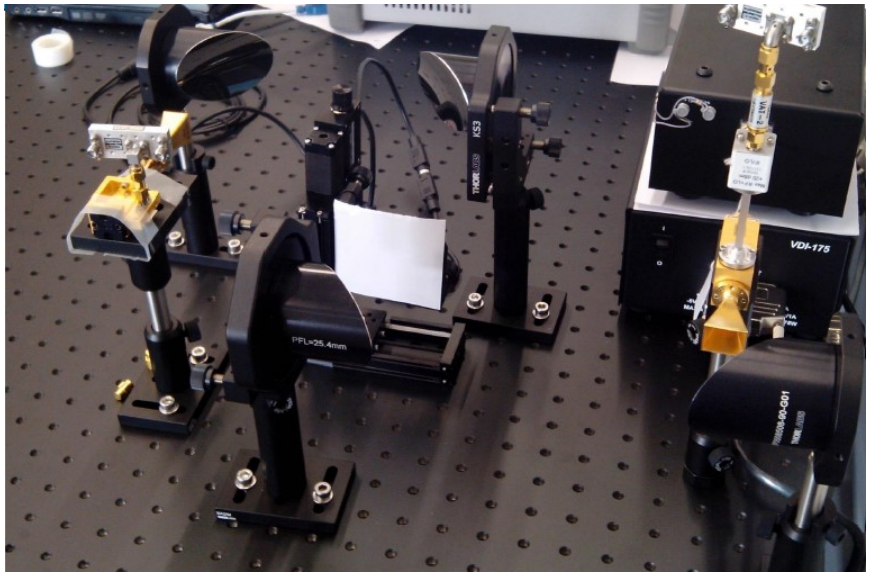


Fig. 16. Sample holder – cross sectional view

Millimeter wave network analyzer



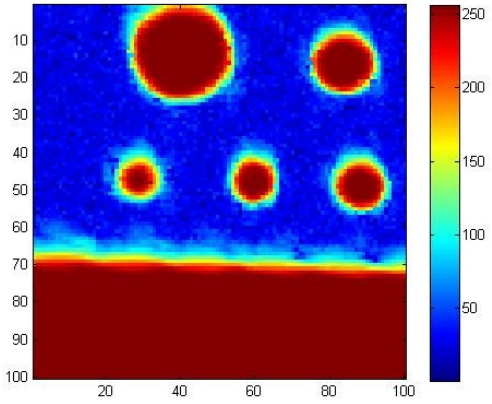


SNR:
60 dB @ 115 GHz
40 dB @ 345 GHz

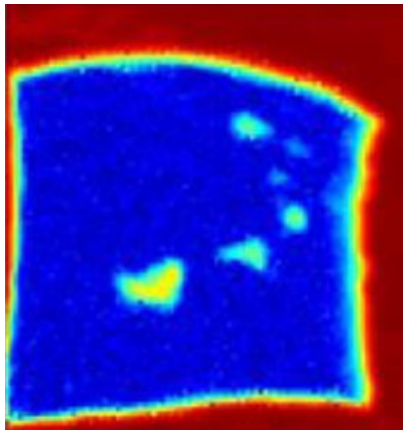
Image resolution:
3.3 mm @ 115 GHz
1.1 mm @ 345 GHz

Output power:
10 dBm @ 115 GHz
-2 dBm @ 345 GHz

System ready for application testing with biomedical or other samples



345 GHz: **Metal plate with holes**



Smoked ham

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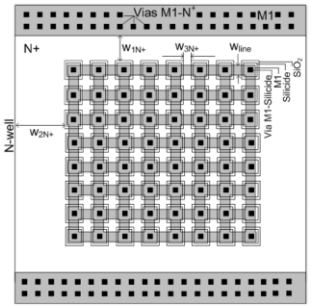
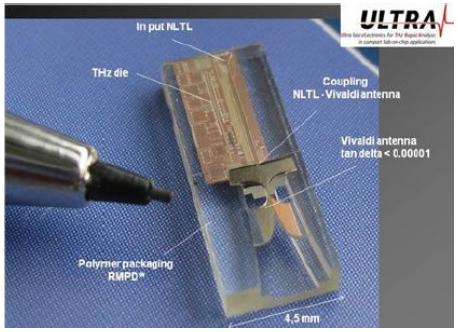
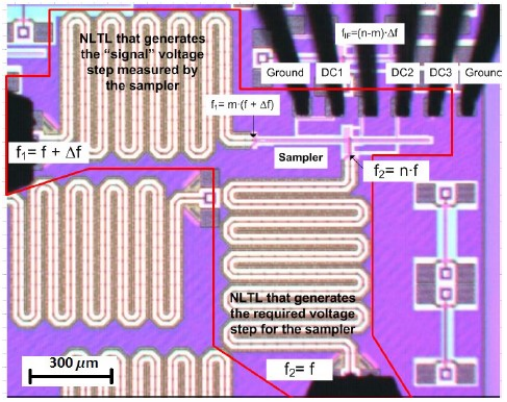
Spectroscopic Imaging: research results



Ultra high speed Schottky diodes in CMOS, IEEE Trans. Elec.Dev.



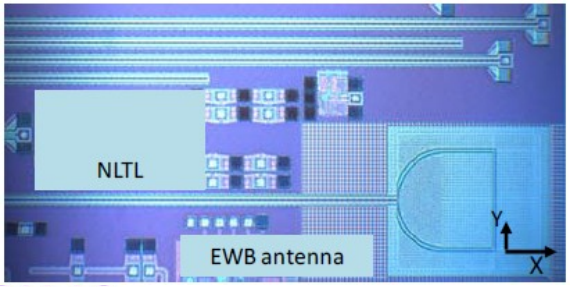
Hybrid sub-mm-wave broadband transmitter IEEE Trans. MTT



20-480 GHz on-chip spectrometer, EuMW conference, 2016

2010 2011 2012 2015 2016 2017

On-chip sub-mm-wave broadband transmitter, IEEE Electron Device letters



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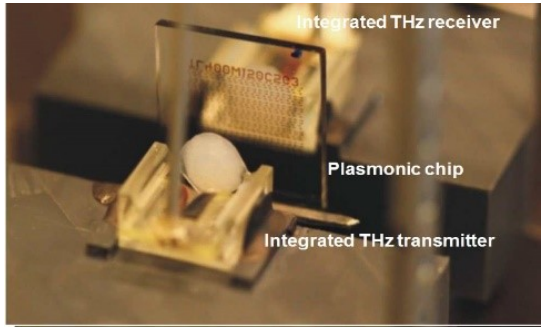
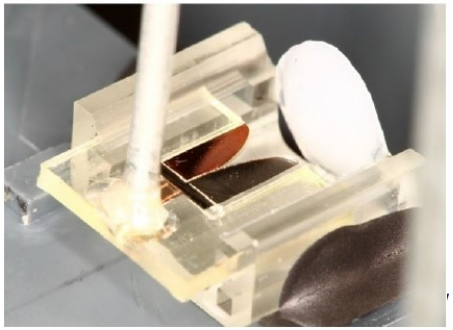
Plasmonic enhanced all-electronic thin layer detection EuMW conference, 2015

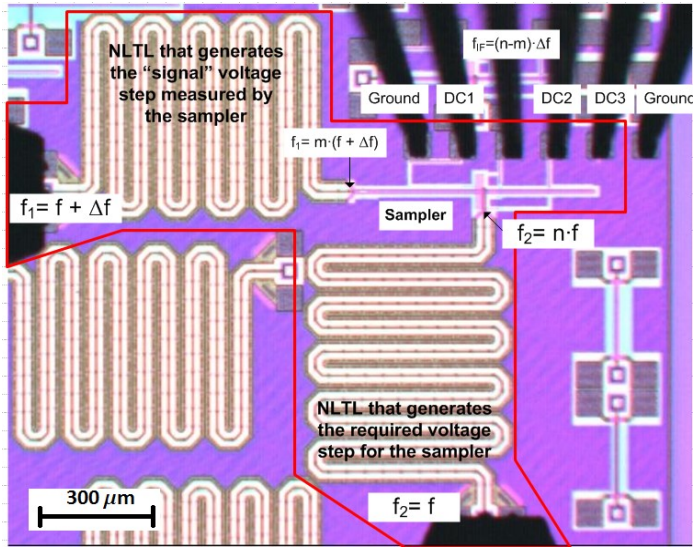


Invited overview paper, International Journal on Microwave Technology

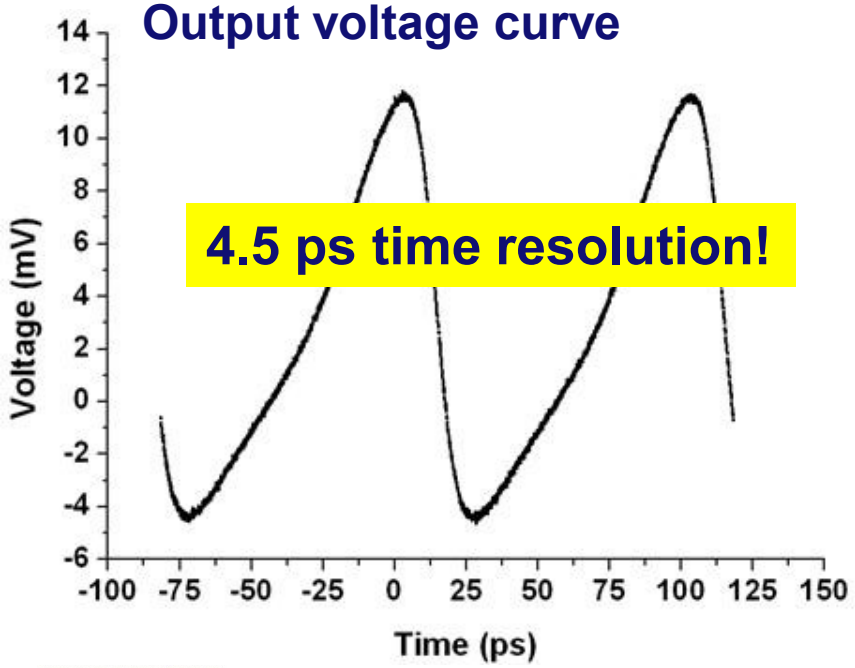


World-record bandwidth spectrometer

Time domain spectroscopy in CMOS

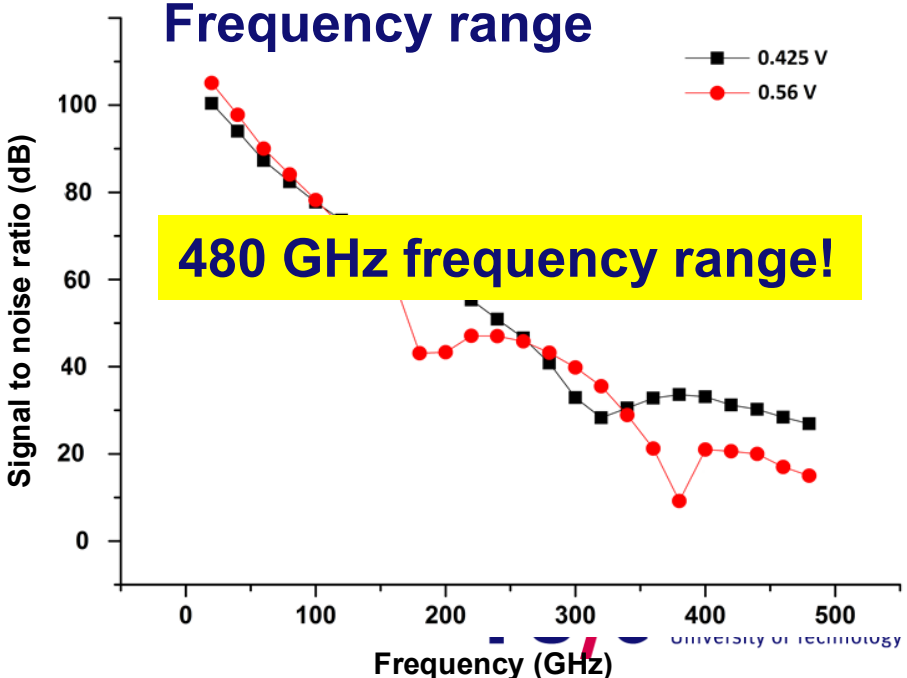


Output voltage curve



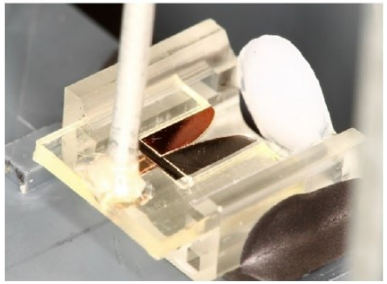
4.5 ps time resolution!

Frequency range



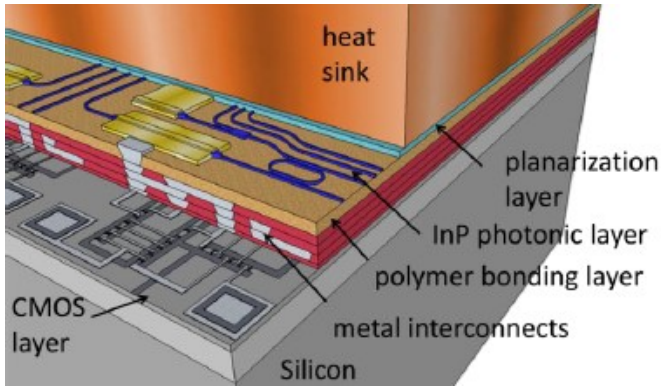
480 GHz frequency range!

THz spectroscopy up to several THz



CMOS:
up to 480 GHz

FUTURE:
New front-ends in non-CMOS technologies



EU H2020: WIPE

STW: Photronics

Sensor applications:
Typically lower volume than communication devices

↕

Room for non-conventional technologies

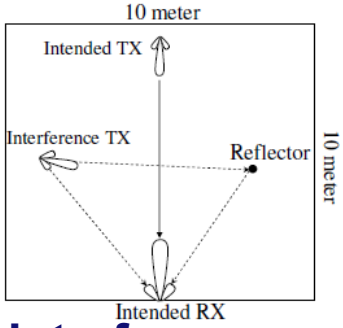
InP technology
Fraunhofer IAF
III-V-labs in Paris
GSC (US)
PHI group:
InP photonics

Graphene
Dr. A. Bol, TU/e
Philips PINS
U Manchester

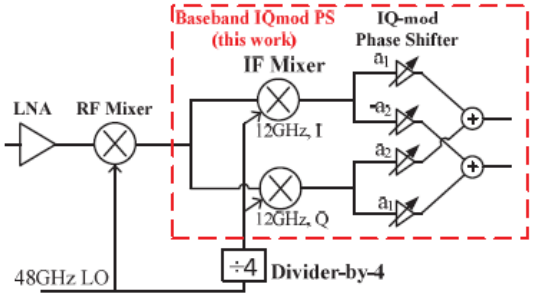
Nanowires
Prof. E. Bakkers

Microplasmas
Prof. G. Kroessen

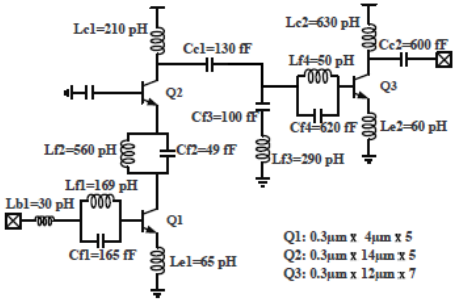
Ultrahigh data rate communication



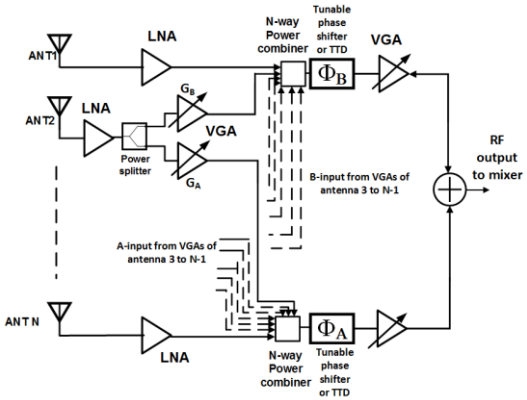
Interference cancellation with genetic algorithms ISCAS 2012



Baseband phaseshifter ISCAS 2014



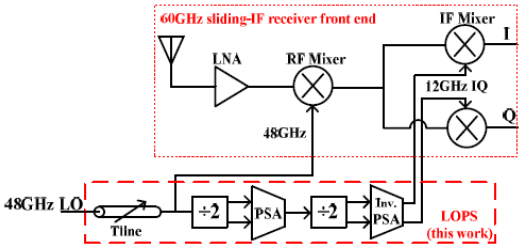
VSAT filtering LNA, IMS 2014, MTT 2016



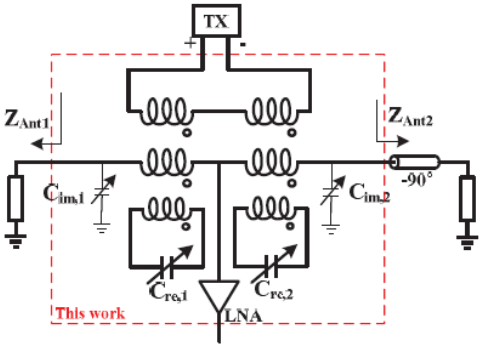
Interpolation based phased array ISCAS 2017

2012 **2013** **2014** **2015** **2016** **2017**

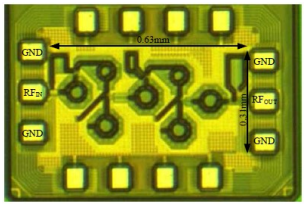
60 GHz sliding IF mixer ESSCIRC 2013



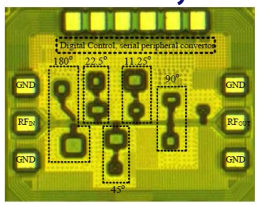
Tunable transformer based duplexer, CICC 2014, MTT 2016



LNA with lowest NF RFIC 2016



Digital phase shifter Electronics Letters, 2016



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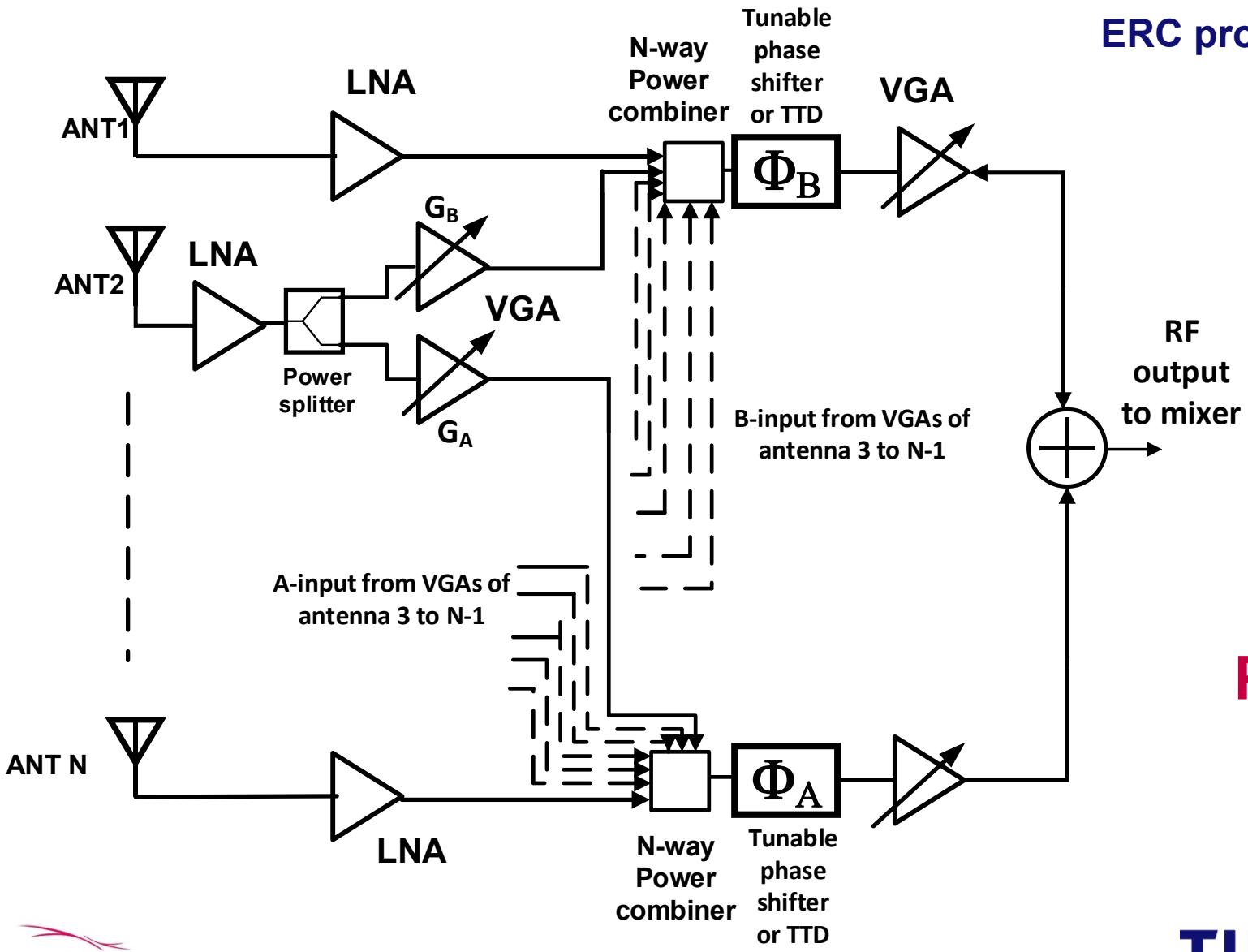
Interpolation based phased array



ERC project: BROWSE

B. Wang et al. ISCAS 2017

Poster!

Conclusions

- THz field is growing, 3 full professors at TU/e
- THz sensing: rich application field
  New valorization routes will be explored
- Lab-building: Ecosystem for THz cooperation
- Roadmap under development
- Partnering with industry: contact us!
- Incubator for new THz network and valorization