iemn

Institute of Electronics, Microelectronics and Nanotechnology

UMR CNRS 8520

Multi-Physics Characterization Platform

PCMP Plateforme de Caractérisation Multi-Physique

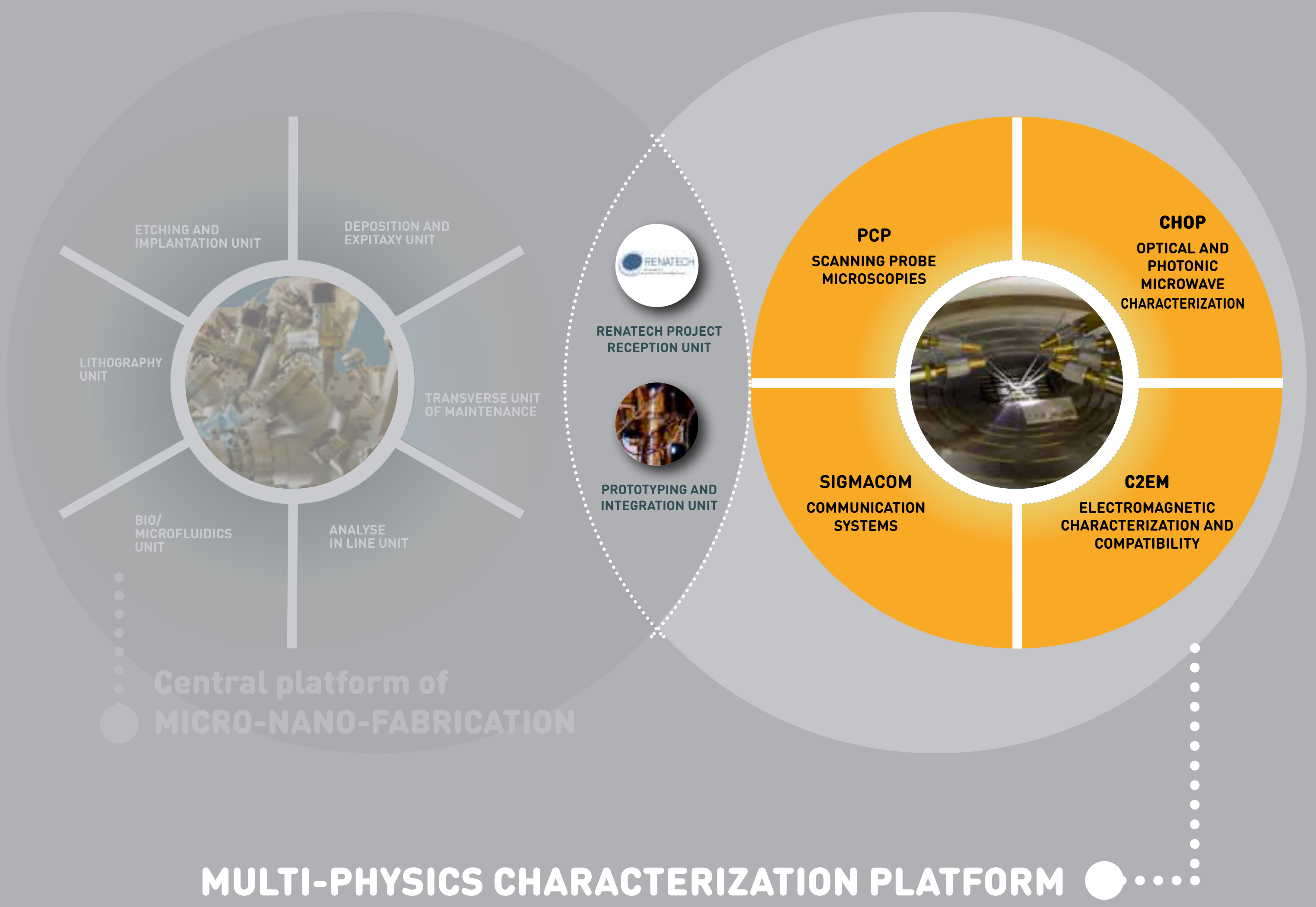
iemn
Institute of Electronics, Microelectronics and Nanotechnology
UMR CNRS 8520

IEMN stands for Institute of Electronics, Microelectronics and Nanotechnology, a laboratory created in 1992 as a joint research unit of five institutions: Lille University, CNRS, Polytechnic University Hauts-de-France, JUNIA/ ISEN, Ecole Centrale Lille. The Institute's scientific policy is based on flagship application projects of societal interest (Transport, Energy, Health, Internet of Objects, Neuromorphic Technologies, UHD Telecommunication) and three transverse scientific and technological axes (Materials, Devices, Nano-Characterization).
IEMN's research is performed based on a strong connection between its 22 research groups and its technlological (Micro Nanofabrication and Multi Physics Characterization) platforms in which cutting-edge equipment is operated by a highly qualified technical staff.

The research groups make up the five research departments of the laboratory:

- Materials, nanostructures and devices
- Micro/nano/bio-systems, waves and microfluidics
- Micro, nano and optoelectronics
- Technologies for telecommunications and intelligent systems
- Acoustics and integrated systems

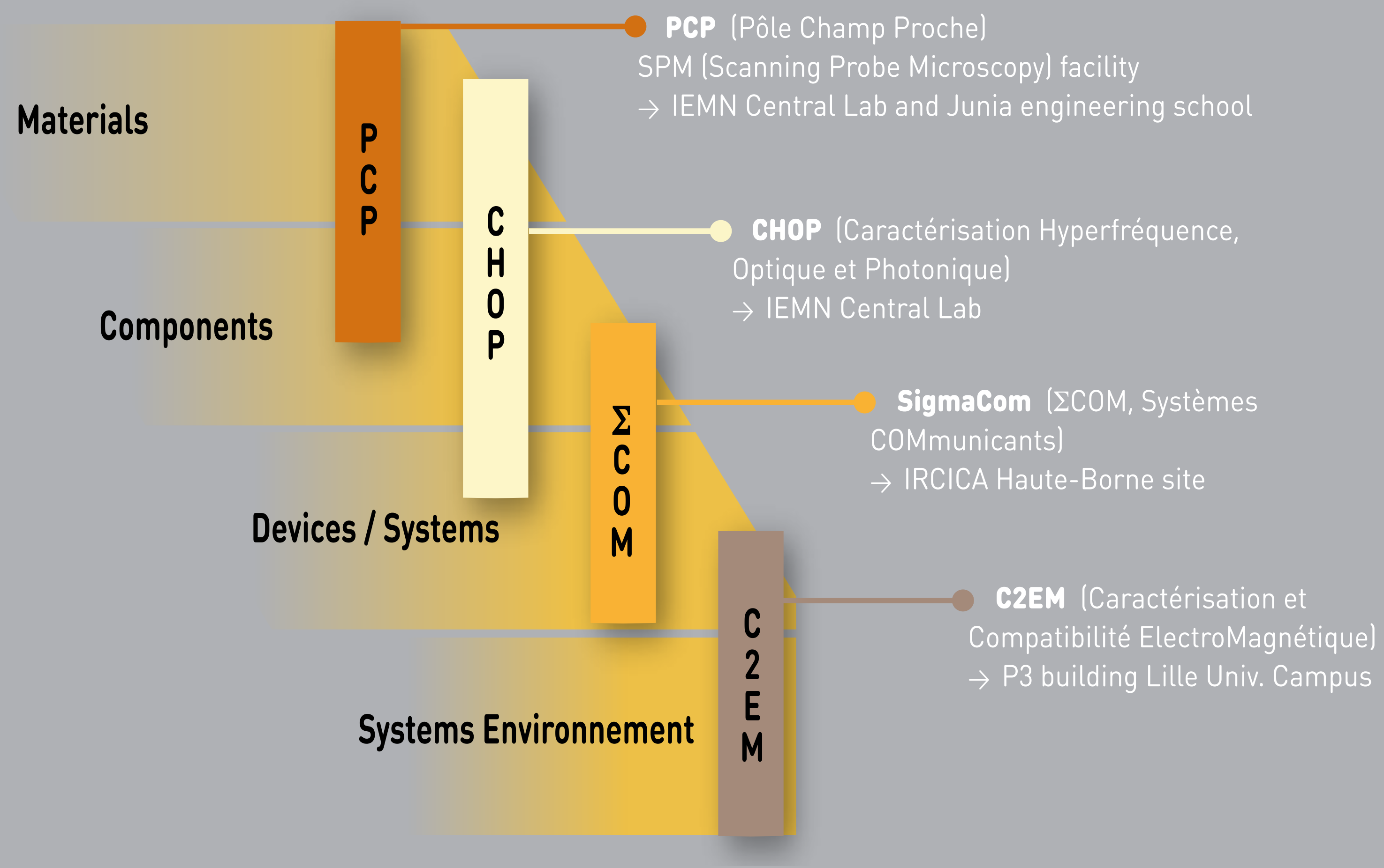
470 people work at IEMN, in research groups, platforms, and administrative services. At the forefront of education and technological research, and owing to numerous dynamic international collaborations, IEMN hosts PhD and graduate students coming from 30 different countries. IEMN designs, manufactures and characterizes devices and systems for Electronics, Photonics, Energy Storage and Harvesting, Bio-micro-technologies, Sensors, Integrated Systems and Instrumentation. Moreover, as evidenced by numerous patents plus spin-off's creations, IEMN demonstrates its effectiveness in promoting and facilitating technology transfer of innovations emanating from its research groups.



The Multi-Physics Characterization Plateform

The Multi-Physics Characterization Plateform is the instrumental facility of IEMN dedicated to characterization of materials, devices and electronic systems, from materials at the nanoscale to electronic systems in their environment. It gathers 4 services localized on Lille University campus «Cité Scientifique», Haute-Borne site and Junia engineering school (Lille center town)

→ **Access to the PCMP Platform is regulated.**
Please contact the head of each PCMP Service to request access.



CONTENTS

iemn Institute of Electronics, Microelectronics and Nanotechnology UMR CNRS 8520

pcmp-contact@iemn.fr

IEMN / PCMP

PCP

The Scanning Probe Microscopy service named **"Pole Champ Proche"** supplies premium tools, to observe and manipulate atoms, molecules or nanoscale objects on the micro to subnanometer scale, making these instruments essentials to Nanoscience and Nanotechnology. The PCP facility is organised into 2 domains depending on the measurement environment:

- AIR domain for microscopes operating in air ambient, liquid or controlled gas atmosphere
- UHV domain for microscopes operating under Ultra High Vacuum

With 8 instruments and 400m² of area in a ISO8-certified environment localized on the ground floor of IEMN, the facility hosts about 30 expert users. Part of the instruments are on free access and can be booked online. One day training for beginners is provided in request. The team is composed of 3 permanent engineers providing internal, external academic and industrial services in the framework of the RENATECH national network. Their mission concern also the development of new instruments and experimental techniques in collaboration with users, Start-up and SPM companies.

Head of PCP
M. Berthe

@

- **Air domain SPM's** — I. 1-4

→ Louis Thomas

ICON
DIMENSION
MULTIMODE
BIOSCOPE

- **UHV domain SPM's** — I. 5-8

→ Maxime Berthe → Sylvie Godey

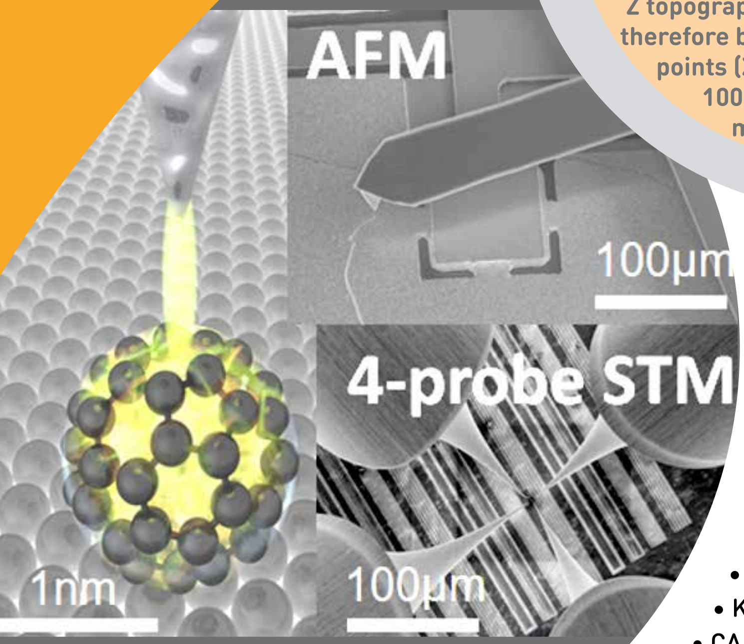
VTAFM
JT-SPM
LT-STM
NANOPROBE

pcp-contact@iemn.fr

PCP

AIR DOMAIN SPM's

The Scanning Probe Microscopes use a recent technique (Nobel prize in Physics 1986) of microscopy where a probe (tip) interacts with the surface of the sample at a very short distance (Angstrom to 100nm). This interaction is based on tunneling current or atomic force that is kept constant thanks to a feedback loop which controls the distance between tip and surface with an actuator. Z topography (Angstrom to 10µm) can therefore be saved for each coordinate points (X,Y) ranging from 5nm to 100µm depending of the microscope model.



The probe interacts in contact (C) or non-contact (NC) mode and can work in static or dynamic mode. Various physical characteristics of the surface can be adressed through differents modes of measurement:

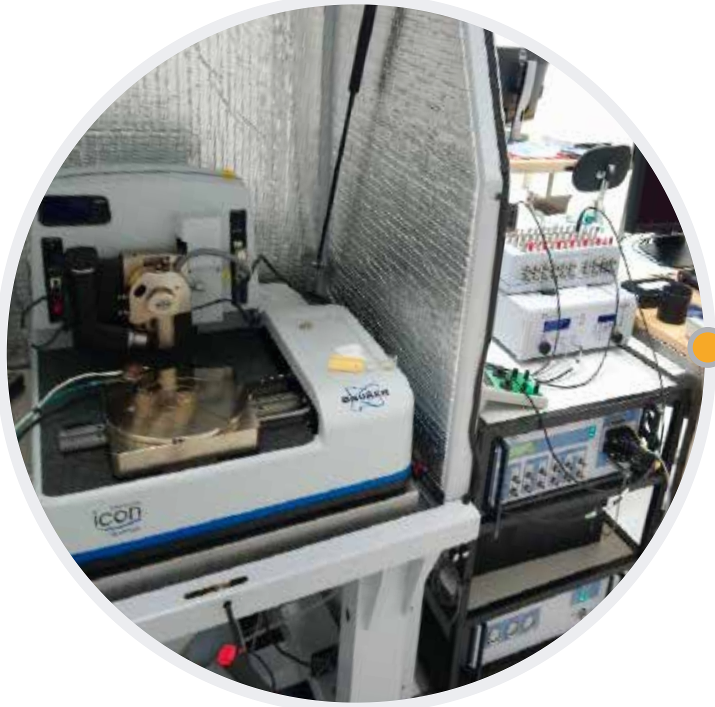
- STM: Scanning Tunneling Microscopy (NC),
- LDOS: Local Density of Electronic States (NC)
- AFM: Atomic Force Microscopy (C, NC), Force Spectroscopy (C)
- EFM: Electrostatic Force Microscopy (NC)
- MFM: Magnetic Force Microscopy (NC)
- KPFM: Kelvin Probe Force Microscopy (NC)
- CAFM: Conductive Atomic Force Microscopy (C)
- PFM: Piezoelectric Force Microscopy (C)
- SCM: Scanning Capacitance Microscopy (C)
- SThM: Scanning Thermal Microscopy (C)

→ APPLICATION EXAMPLES

- Topographic monitoring of technological processes and material growth: Molecular beam epitaxy, Etching, Film deposition, lithography
- Local characterization in contact mode of the physical properties of the material: Electrical conductivity by CAFM or thermal by SThM, Piezoelectric response by PFM, Measurement of adhesion force and mechanical property by force spectroscopy
- Local characterization in non-contact mode of the physical properties of the surface: Measurement of electrostatic and magnetic forces (EFM, MFM), measurement of charges , measurement of surface potential (KPFM), Density of states (STM)

→ ADVANTAGES & LIMITATIONS

(+) 3D nanometric topography measurement , sub nanometric roughness measurement
(+) Simultaneous local physical imaging and characterization
(−) Tip Convolution (−) Low scan speed



ICON

Louis Thomas

- **Sample dimension :** 5mm square to 20cm diameter
- **Scan range :** 10nm to 100µm (X and Y linearization feedback: close loop) - Max. Z range: 10µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM Tapping, AFM Peakforce, EFM, KPFM, CAFM, PeakForce TUNA, PFM, SThM, Force spectroscopy
- **Environnement :** Ambient air, Nitrogen gas
- **Temperature :** -25°C to 250°C

→ APPLICATIONS

- PeakForce
- Thermal chuck for small sample

→ ADVANTAGES & LIMITATIONS

(+) Large sample, large coarse displacement of the chuck (2µm resolution)
(−) Acoustic and vibrational Noise sensitive

DIMENSION Bruker

Louis Thomas

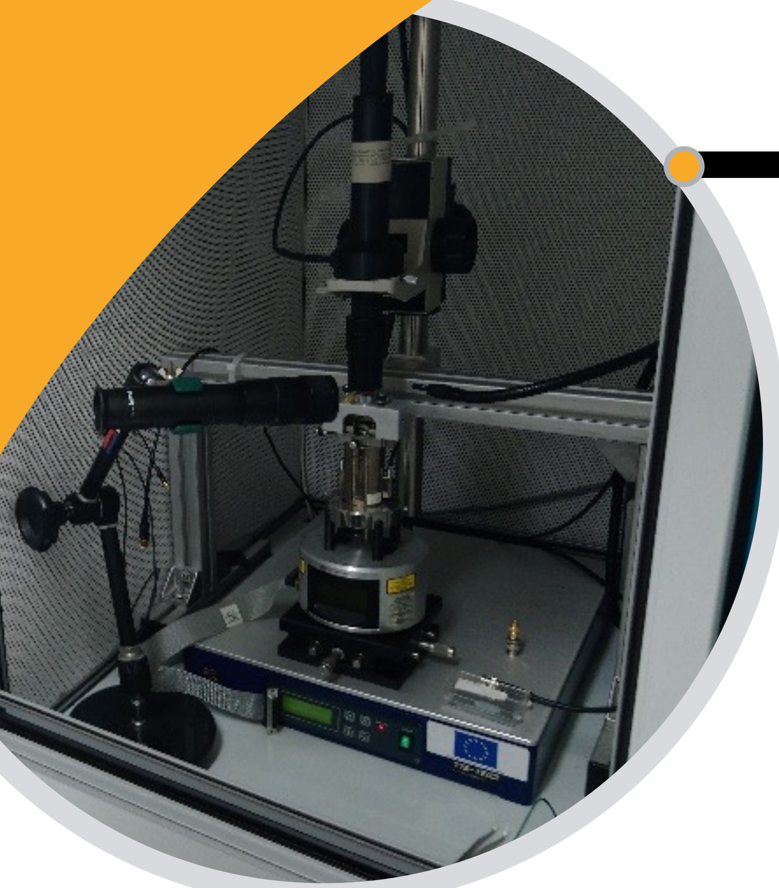
- **Sample dimension :** 5mm square to 20cm diameter
- **Scan range :** 10nm to 100µm - Max. Z range: 6µm
- **Resolution :** Lateral: nanometric - Vertical 50pm
- **Working Mode :** AFM Tapping, EFM, KPFM, CAFM, PFM, SThM, Force spectroscopy, SCM
- **Environnement :** Ambient air, Nitrogen gas
- **Temperature :** Ambient

→ ADVANTAGES & LIMITATIONS

(+) Large sample, large coarse displacement of the chuck (2µm resolution)
(−) Acoustic and vibrational Noise sensitive

PCP

AIR DOMAIN SPM's



MULTIMODE Bruker

Louis Thomas

- **Sample dimension :** 5mm square to 15mm diameter
- **Scan range :** 10nm to 10 or 100µm (two scanners available) - Max. Z range: 2 or 5µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM Tapping, EFM, KPFM, CAFM, PFM, Force spectroscopy
- **Environnement :** Ambient air, Nitrogen gas and Liquid
- **Temperature :** Ambient

→ ADVANTAGES & LIMITATIONS

- Low noise imaging
- Small sample
- Limited coarse deplacement

BIOSCOPE Bruker

Louis Thomas

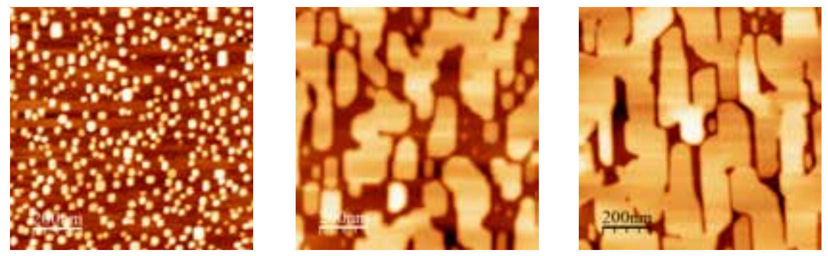
- **Sample dimension :** 5mm square to 5cm diameter
- **Scan range :** 10nm to 100µm - Max. Z range: 6µm
- **Resolution :** Lateral: nanometric - Vertical 80pm
- **Working Mode :** AFM Tapping
- **Environnement :** Ambient air and liquid
- **Temperature :** Ambient

→ APPLICATIONS

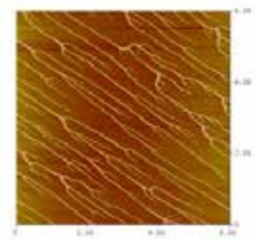
- In situ electrochemical growth monitoring

→ ADVANTAGES & LIMITATIONS

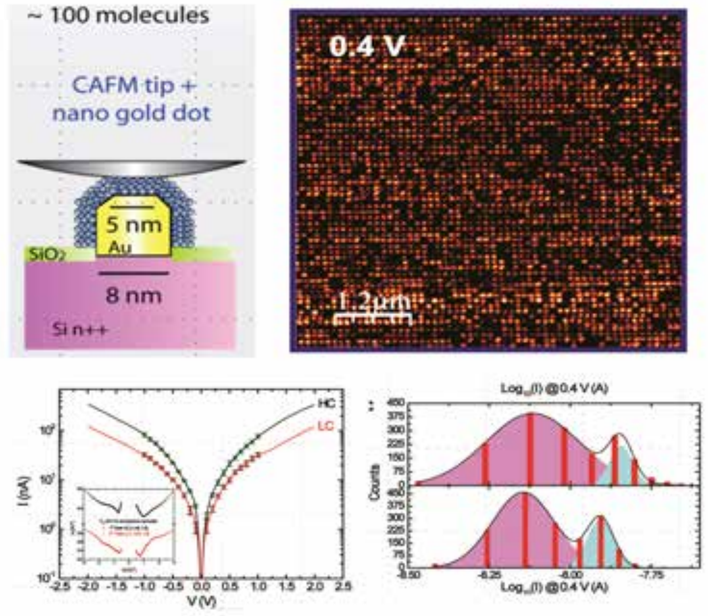
- Tip Enhanced Raman Spectroscopy (TERS[1] tip optical bench
- Acoustic and vibrational Noise sensitive



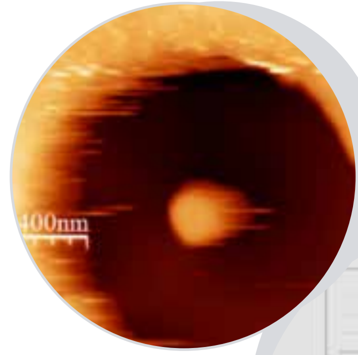
2D-3D growth GaSb/GaAs (AFM)

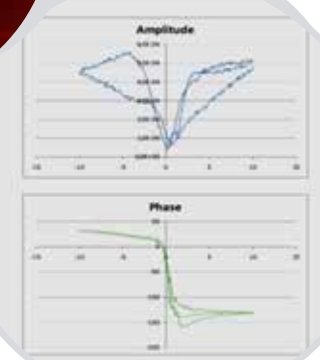


Collagen on silicon surface

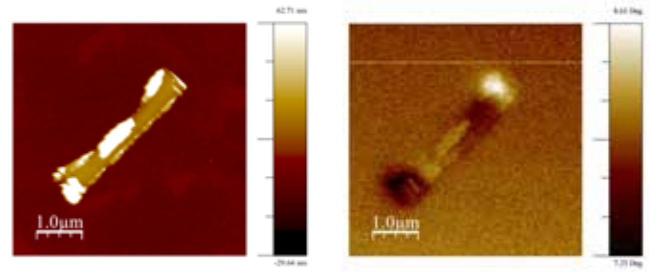


Conducting AFM statistics from a large array of sub-10 nm molecular junstions

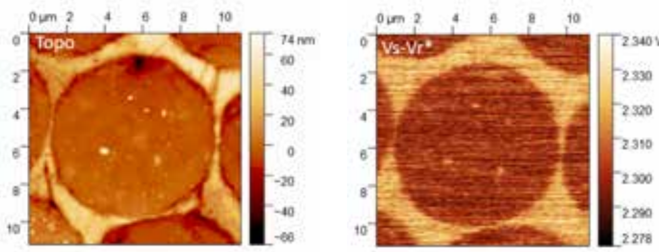




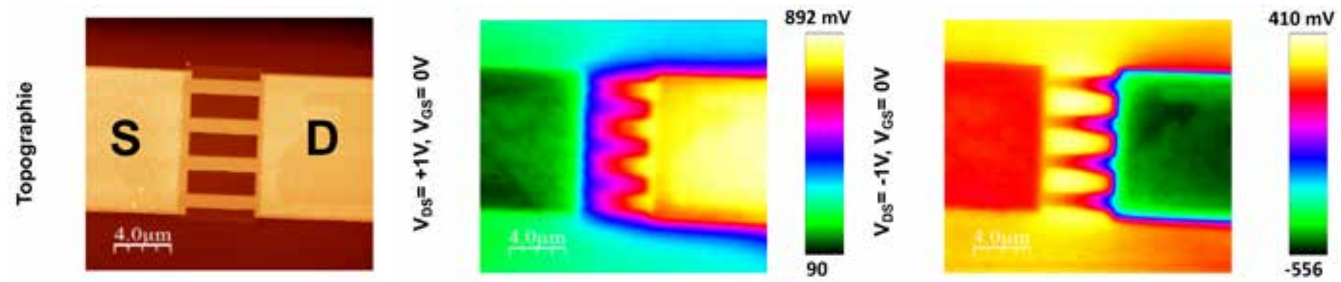
Topo and PFM cycle Of a 60nm PZT dot (1pm displacement sensitivity)



Topo and MFM image of ferromagnetic domain wall position in multiferroic heterostructures



Topography and thermal conductivity of carbon fiber in epoxy matrix (AFM-STHM)



Gas sensing transistor polarization (KPFM)

PCP

UHV DOMAIN SPM's

VTAFM Omicron

Sylvie Godey

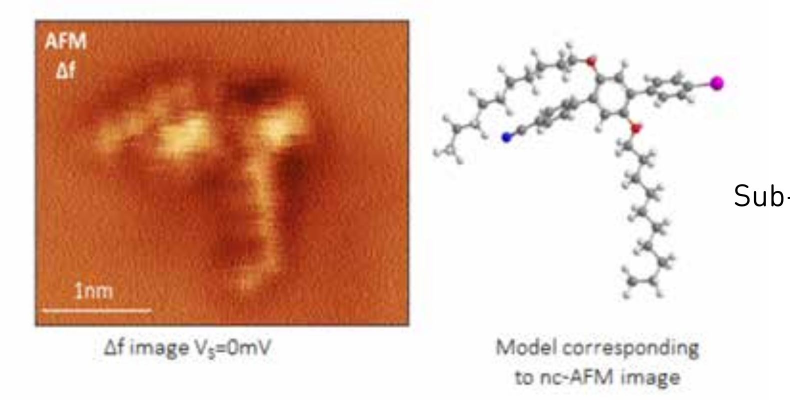
- **Sample dimension :** 4x6mm to 15mm square
- **Scan range :** 10µm - Max. Z range: 2µm
- **Resolution :** Lateral: nanometric - Vertical 30pm
- **Working Mode :** AFM, EFM, KPFM, CAFM, PFM, STM
- **Environnement :** Ultra High Vacuum
- **Temperature :** 50K to 1000K

→ **APPLICATIONS**

- Laser beam deflection (allow contact modes)
- Preparation chamber for sample and Tip
- Sample heater
- Mass spectrometer
- Ion gun
- 3 metal evaporator

→ **ADVANTAGES & LIMITATIONS**

(+) Variable temperature operation
(−) Small sample

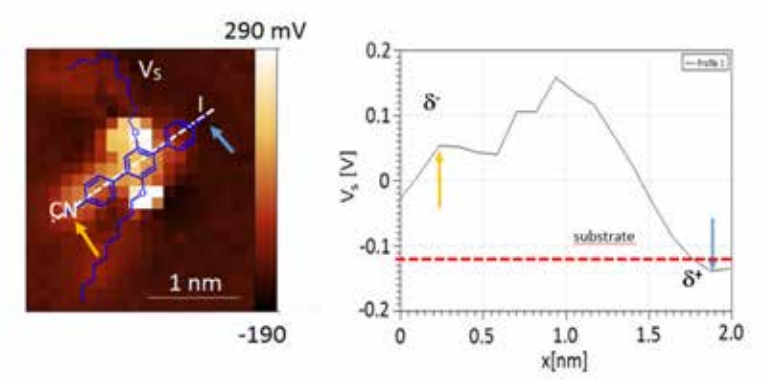


Δf image V_s=0mV

Model corresponding to nc-AFM image

Sub-molecular resolution

KPFM Spectroscopy



→ Identification of CN et I terminaison groups

JT-SPM SPECS

Sylvie Godey

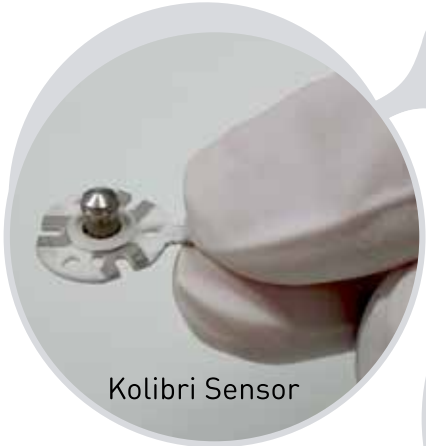
- Low temperature Scanning Probe Microscope, 1.2 K minimum (Joule-Thomson stage)
- STM/AFM modes, nc-AFM, KPFM
- Length Extension Resonator (Kolibri sensor): f0= 1MHz K=540 kN/m Q≈100000 at 4K, - Nanonis controller
- XY Scan Range 300K/4K : ~22µm/~4µm, Z Scan Range 300K/4K : ~2.3µm/~0.42µm
- 3T maximum magnetic field perpendicular to sample surface
- Ar sputter gun for surface preparation, LEED-AES
- KENTAX evaporator, CO functionalisation

→ **APPLICATIONS**

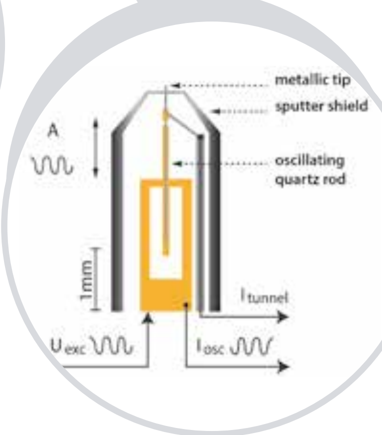
- Structure and electrostatic properties of surfaces, adatoms, unique molecules or molecular assemblies, nanostructures, nano-objects
- Surface potential determination, single charge transfer detection

→ **ADVANTAGES & LIMITATIONS**

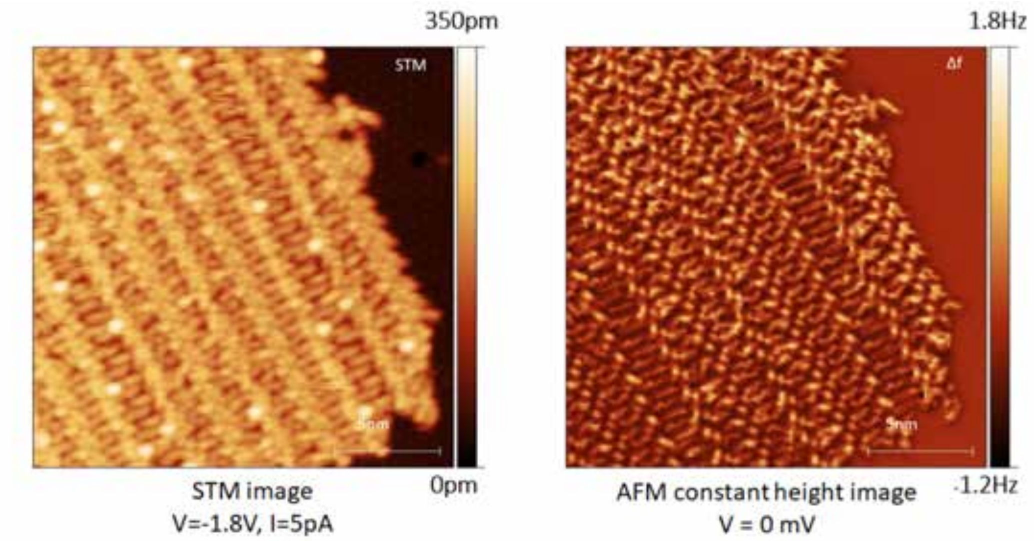
(+) AFM and STM simultaneous modes
(+) Submolecular resolution, tip functionalization
(+) constant height measurements
(−) need for a minimum density of objects of interest (of the order of one per 0.01 µm2) on about $1mm^2$



Kolibri Sensor



Self-assembled monolayers on Si:B



STM image V=-1.8V, I=5pA

AFM constant height image V = 0 mV

PCP

UHV DOMAIN SPM's

LT-STM Omicron

Maxime Berthe

- Surface imaging of conducting or semiconducting surfaces down to the atomic scale.
- Electrical testing on surfaces or nanostructures with atomic precision and ultra-low drift rate (<10pm/h).
- All modes of operation compatible with low temperature down to 4K.

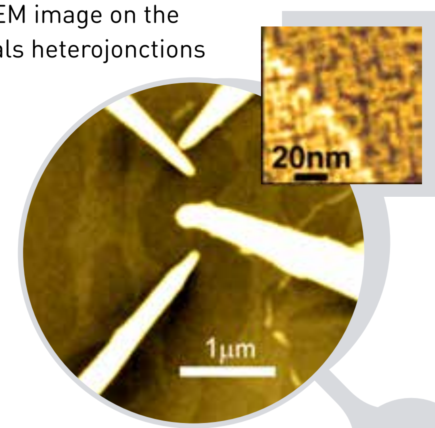
→ **APPLICATIONS**

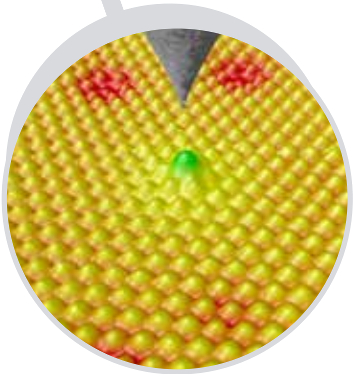
- Investigation of defects at the atomic scale in semiconductors and nanostructures by Scanning Tunneling microscopy (STM). Complementarity with TEM.
- Electronic properties of surfaces and nanostructures at the atomic scale by Scanning Tunneling Spectroscopy (STS). Complementarity with MBE, multiple-probe-STM, tunneling-induced light-emission spectroscopy.

→ **ADVANTAGES & LIMITATIONS**

- Extreme resolution (better than 100pm)
- Electronic measurements (local electronic density of states)
- Limited aspect ratio : only flat surfaces
- Only conducting and semiconducting samples

SEM Image of a four-point-probe measurement on a single domain of colloidal nanocrystals heterojonctions.
Inset : zoomed SEM image on the colloidal nanocrystals heterojonctions





3D representation of the reconstructed B-Si(111)-√3×√3 R 30°

NANOPROBE Omicron

Maxime Berthe

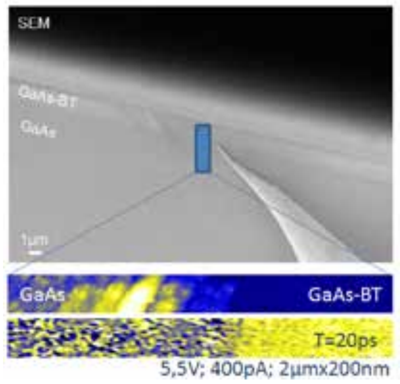
- Scanning Tunneling Microscopy (STM)
- Scanning Electron Microscopy (SEM)
- Nanoscale localization and manipulation
- Multiple-scale (100nm to 1mm) electronic transport measurements
- « fs-Laser-combined-multiple-probe-STM » for time-resolved (<1ps) nanoscale measurements .

→ **APPLICATIONS**

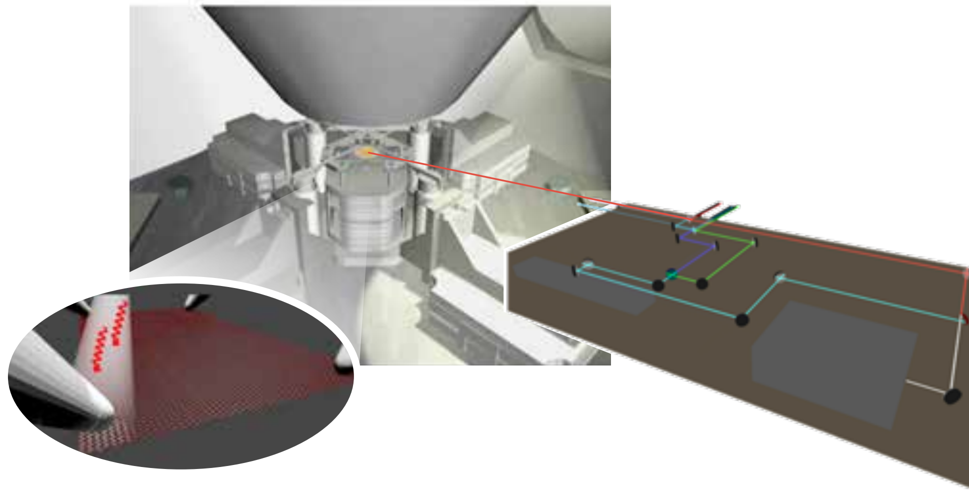
- Transport properties of surfaces and nanostructures. Complementarity with MBE, STM, tunneling-induced light-emission spectroscopy.
- Mapping of transport properties combined with STM. Complimentary with STM and electronics processing.

→ **ADVANTAGES & LIMITATIONS**

- Nanoscale imaging and manipulation with SEM monitoring
- Electronic transport measurements from nanometer to millimeter scale
- Limited STM resolution (nanometer) and stability



Top: SEM image of GaAs/LT-GaAs junction with one STM probe scanning accros the junction.
Bottom: Simultaneous acquisition through STM probe of (i)Topographic STM image and (ii) Lock-in-demodulated ultrafast optical signal.



CHOP

The CHOP service covers 900m², in a ISO8-certified environnement, of the IEMN's common resources enabling the characterization of the main electrical parameters of electronic components and subsystems in a wide range of frequencies, from DC to TeraHertz. Most of the measurement benches are modular in order to best meet the needs of research. Engineers develop the test setup in a continuous improvement in order to work in line with technological innovations. Some experiments have been designed to electrically test components under «hard» conditions such as low temperature (5.5 K) or high voltage (10 kV). The expertise in characterizing ultra-fast devices is internationally recognized and allows the CHOP to also play a very important role in the joint laboratory created between the IEMN and French manufacturer ST Microelectronics or foreign research centers. The CHOP hosts 22 research groups, several innovation projects and start-ups (Vmicro, Zymoptiq).

Head of CHOP
S. Eliet Barois

chop-contact@iemn.fr

CHOP iemn
Caractérisation Hyperfréquence Optique Photonique

SNOM MIR-THZ: SCANNING NEAR-FIELD OPTICAL MICROSCOPY

Sophie Eliet

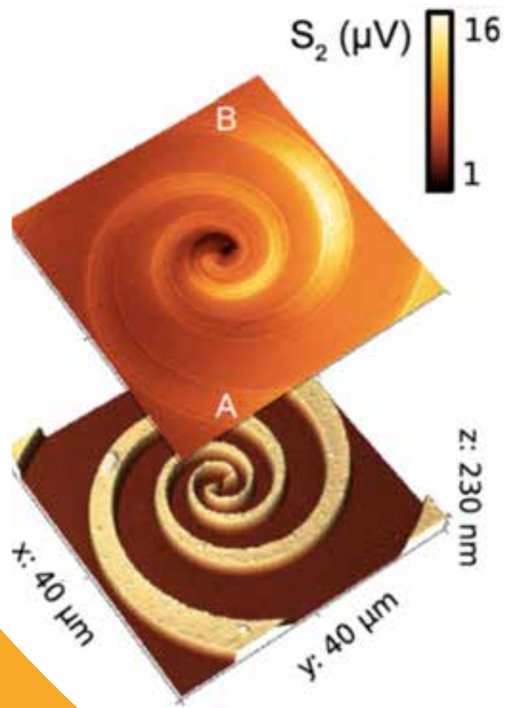
The SNOM MIR-THz is a near-field optical measurement bench allowing the acquisition of images respectively in the mid-infrared and TeraHertz range with a spatial resolution of the order of 30 nm (limitation by the size of the AFM tip). For this, two laser sources are currently available: a 10µm quantum cascade laser and a THz molecular laser pumped by a CO_2 laser.

→ EXAMPLE

- This technique is well suited for the qualitative study of 2D materials such as graphene, molecular electronic nanostructures, doped materials (even weakly) or the study of waveguides induced by laser inscription in glasses.
- It is a complementary with others Scanning Probe techniques (cf PCP service)

→ ADVANTAGES & LIMITATIONS

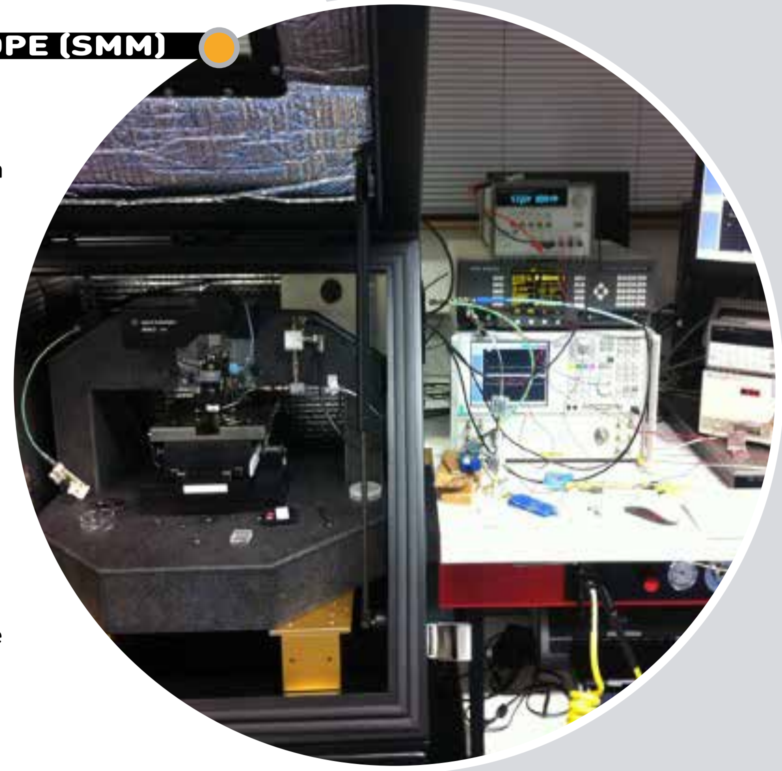
- The spatial resolution is linked to the apex of the probe (almost few tens of nanometers).
- Materials must have a MIR or THz contrast (plasmons resonance ...)
- Sample must be relatively flat few hundreds nanometers of relief maximum



Example of SNOM-THz image of Logarithmic Spiral Antenna @ 2,5 THz (up), simultaneously recorded with AFM topography IRMMW Conference, 2021

SCANNING MICROWAVE MICROSCOPE (SMM)

Sophie Eliet



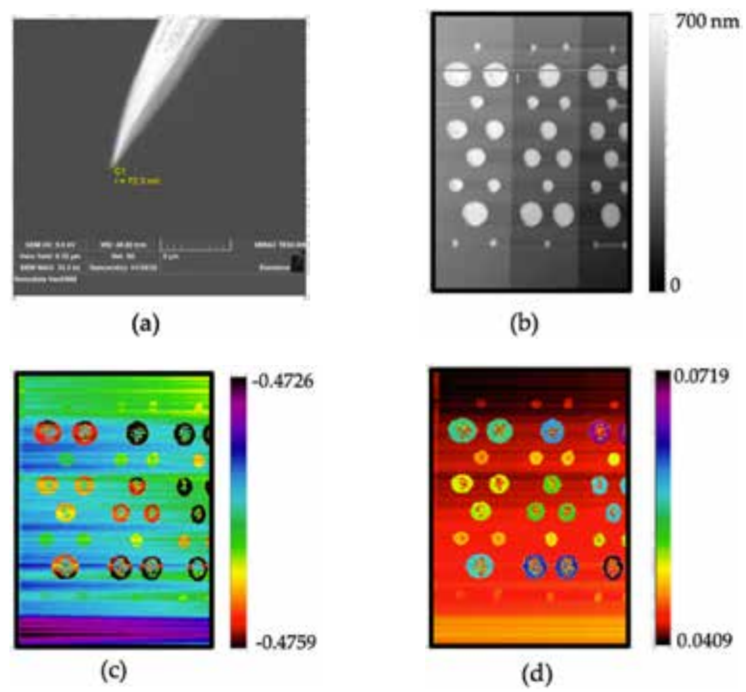
Scanning Microwave Microscopy is Scanning probe technique. It is based on a AFM technique coupled with VNA (Vector Network Analyzer). The probe is specially designed and integrated into a specific support and radio-frequency connectors.
At CHOP, there are 2 types of SMM:
- At air , 3600 LS Keysight, up to 12 GHz
- Under vacuum, a home-made system integrated in a Tescan SEM, up to 67 GHz

→ APPLICATIONS

The technique is based on AFM but develops a specific contact electric mode at microwave frequencies (2-67 GHz) that allows to map material or device surfaces at the nanoscale for topography and microwave reflectivity. The sample must be compatible with AFM topography measurements.

Example

SMM in SEM illustration



Combined AFM, SMM and SEM images obtained in the home-made system (a) SEM image of the apex tip. (b) AFM topography image of a set of metallic dots deposited on a SiO_2/Si substrate to form capacitances, (c) real part and (d) imaginary part images of the complex reflection coefficient ΓM at 30 GHz. The dots diameters range from 1 to 4 µm. From Appl. Sci. 2021, 11, 2788

→ ADVANTAGES & LIMITATIONS

- It combines topography and microwave nanoscale measurement over a large microwave range. The spatial resolution is linked to the apex of the probe (a few tens of nanometers) but also to the microwave frequency. It allows to observe surface contrasts of microwave dielectric properties. The resolution is in the aF range. It can be combined with DC biasing up to 10 V. Traceability to microwave standards is still under study. Calibration based on the probe shape is possible but indicative with several µS uncertainty. The sample must be flat within a few hundreds of nanometers maximum.

CHOP

DC - LOW FREQUENCY

JANIS probe station cryogenic RF/DC

DC-CV-PULSE-SOLAR MEASUREMENTS

Etienne Okada Ayman Rhellab

Mandatory for any electric component, DC characteristics can be provide by several equipment. To make a technological return as soon as it comes out of production.

Benches can be adapted to supply several circuits or study one device. With connector or on wafer (from 1 to 16 pins simultaneously) we can measure characteristics to identify performances, homogeneity of manufacturing and also robustness.

Several environments can be use (ask for compatibility), temperature, pressure, lighting/darkness.

- DC are made from 0 to 210 V with current up to 2A.
- Impedance meter is available to highlight capacitance effect. CV from 1 kHz to 100 MHz.
- Pulsed measurements are helpful to mark trapping effect on GaN transistor or to eliminate heating effect. Pulse from 300nsec up to msec.
- Solar Simulator is used to characterize solar cells. Laser beam can be also provided on device

→ ADVANTAGES & LIMITATIONS

- High voltage and current are available but power is limited by the setup.
- Both can be perform on or off wafer.

Equipment installed in PCP Service

LASER VIBROMETER MSA 500

Maxime Berthe Marc Faucher

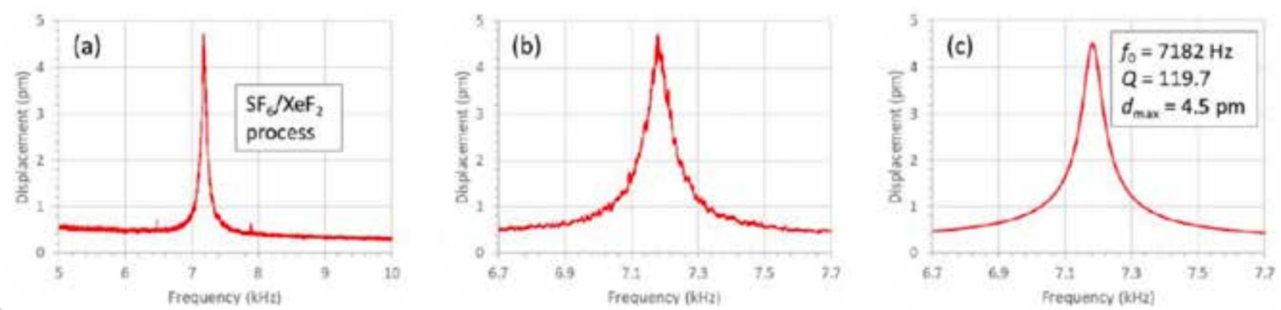
Visualizing surface deformations, knowing the speed, frequency and distance of displacement of a vibrating element, are essential information for MicroElectroMechanical Systems (MEMS).

This equipment is based on Doppler effect. Thanks to a laser and an interferometer it is possible to know how an elements vibrates. It is possible to map vibrations modes of a device.

→ ADVANTAGES & LIMITATIONS

- Max displacement +/- 75nm, frequency 0 up to 24MHz

Example of measured vibration of a cantilever made in IEMN CMNF by NAM6 team



Experimental and modelled resonance curves of a microcantilever fabricated the mixed SF_6/X_EF_2 process.
(a) 5-10 kHz frequency sweep, (b) zoom over 1kHz, and (c) modelled resonant frequency curve.
The inset to (b) shows a microcantilever fabricated using this process.

DC-110GHz - RF-CHARACTERIZATION

Sylvie Lepilliet Ayman Rhellab

CHOP has acquired and developed several test benches made up of vector network analyzers, power supplies and marble stations fitted with coplanar tips. This equipment and the know-how of CHOP allow in DC regime the establishment of current-voltage characteristics and in RF-regime, the measurement of S parameters.

It is possible to characterize components on wafer or in package (coax) according to different frequency bands. The design of the electrical accesses for placing the probes or the connectors must correspond to the available materials and physical possibilities (see "limits of the technique"). Meet the CHOP team!

To make a technological return as soon as it comes out of production or for the design of complex circuits (frequency converter, amplifier, micro processor, etc.), small signal measurements up to 110GHz are at the core of the CHOP expertise.

→ This can be a first step before other types of measures:

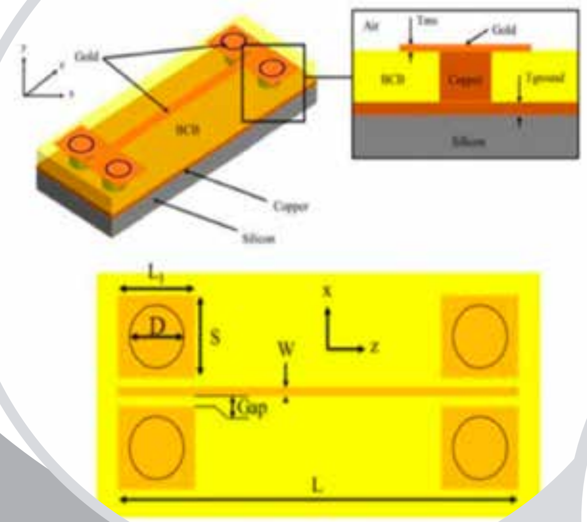
- Millimeter-waves measurements
- Noise measurements
- In power regime
- At High Voltage or High Current measurements

If microwave measurements are required (up to 67 GHz) in cryogenic mode, this is also possible in CHOP

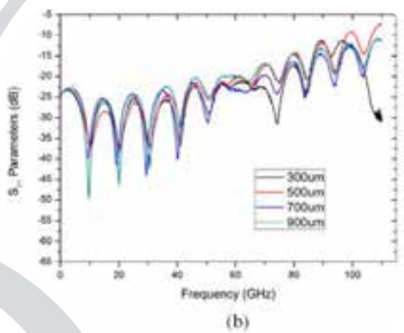
→ ADVANTAGES & LIMITATIONS

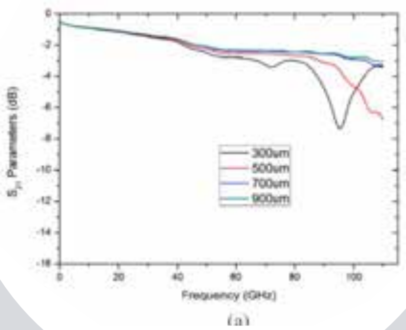
+ Designed of electrical access must be taken into account, come in CHOP for more details!
+ Coaxial availlable up to 67GHz versus 110GHz under probing method.

Modelled GCPW-MS-GCPW transition including input and output coplanar-microstrip transitions with grounding via-holes and a microstrip transmission line in between



Example of measurements up to 110GHz





Measurmed S-parameter as function of the via-hole diameter: (a) S_{21} and S_{11}

OPTO-HYPER MEASUREMENTS

Sophie Eliet Emilien Peytavit

Objectif: establissement of electrical model for material and knwoledge of performances

Technical Specifications:

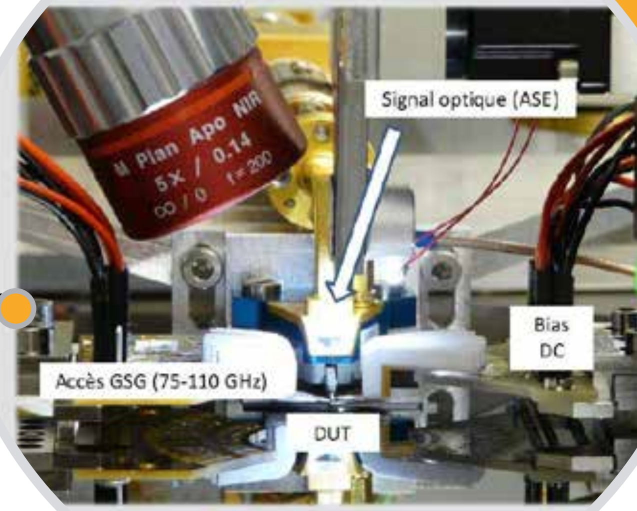
- Lasers: 780 nm/1064 nm/1300nm/1550 nm. Output power :<10 mW
- Optical Amplifier: 780 nm/1550 nm. Output power: <500 mW
- Near diffraction limit optical focusing capabilities (free space and fiber coupled)
- Optical beam characterization (powermeter / optical spectra analyzer)

Expertise:

- On-wafer S parameter characterization of device under CW illumination up to 320 GHz (limited by RF probes)
- Frequency response (up to 320 GHz) and noise characterisation (up to 50 GHz) of photodetectors
- Optical waveguide and grating coupler characterization

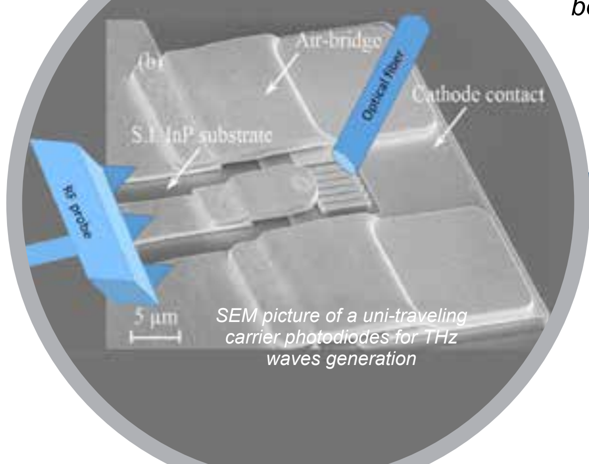
→ ADVANTAGES & LIMITATIONS

+ Probing on wafer with several type of wavelenght, come in CHOP for more details!

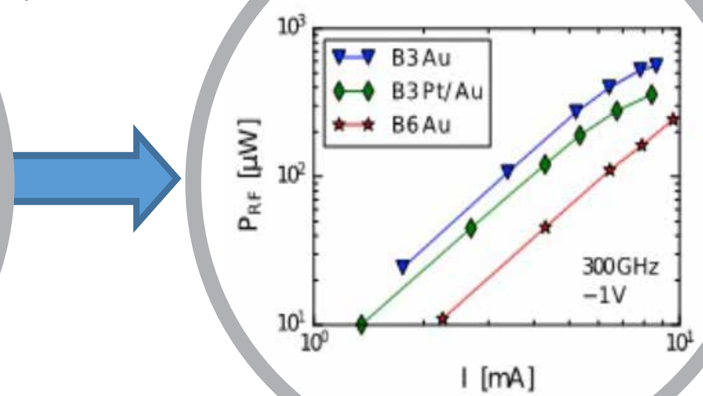


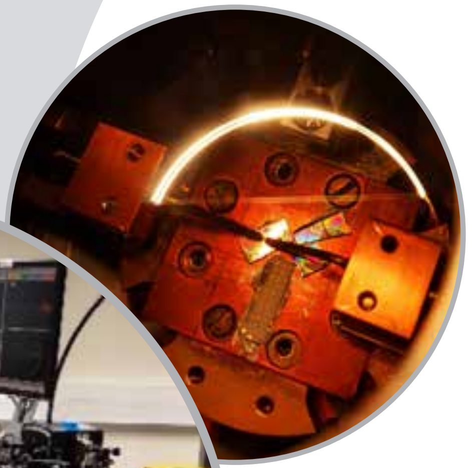
Characterization (S parameter/ Frequency response) of ultrafast photoconductors up to 320 GHz

On wafer characterization of ultrafast photodetectors beyond 320 GHz



SEM picture of a uni-traveling carrier photodiodes for THz waves generation





CRYOGENIC DC AND RF MEASUREMENT

Sylvie Lepilliet

Cryogenic & Vacuum Micro-manipulated Probe Systems

Characterizing components or devices in cryogenics presents an interest in the analysis of specific changes in the physical parameters of components, such as transistor, diode, amplifier. Cryogenic characterization extends to optoelectronic components.

JANIS probe station cryogenic RF/DC

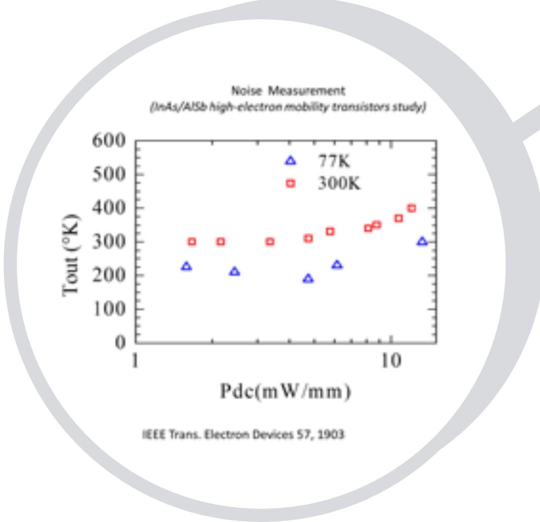
Features :

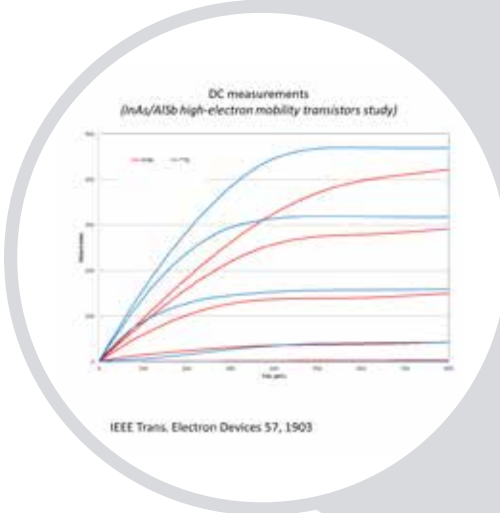
- Low Temperature : 5.5K
- High Temperature : 380K
- Liquid helium or liquid nitrogen
- Without vibrations to sample
- 2 probes RF 0 to 67GHz
- 4 probes DC

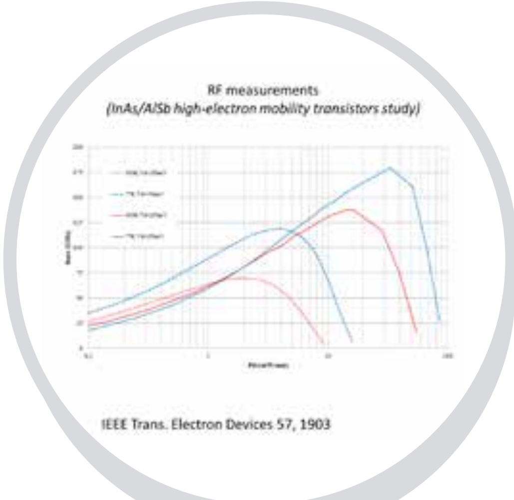
LAKESHORE probe station cryogenic DC/field magnetic

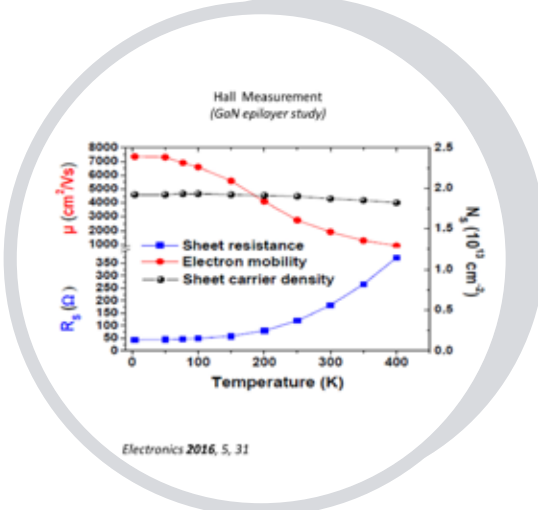
Features :

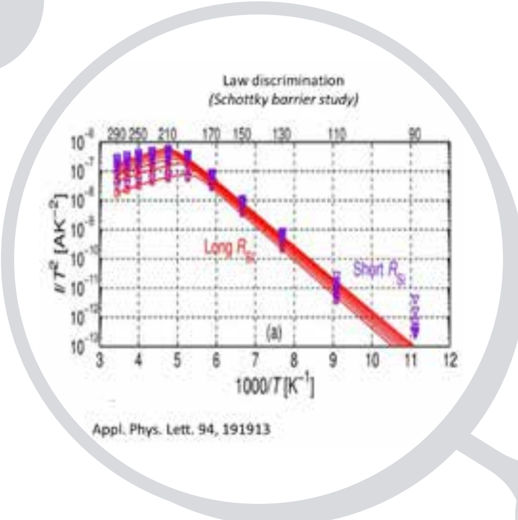
- Low Temperature : 5.5K
- High Temperature : 380K
- Liquid helium or liquid nitrogen
- Without vibrations to sample
- Verticaly Field supraconducting magnetic : to +/- 2.5T
- 4 probes DC

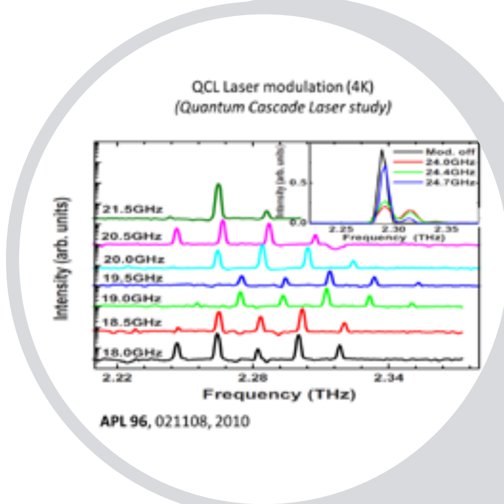


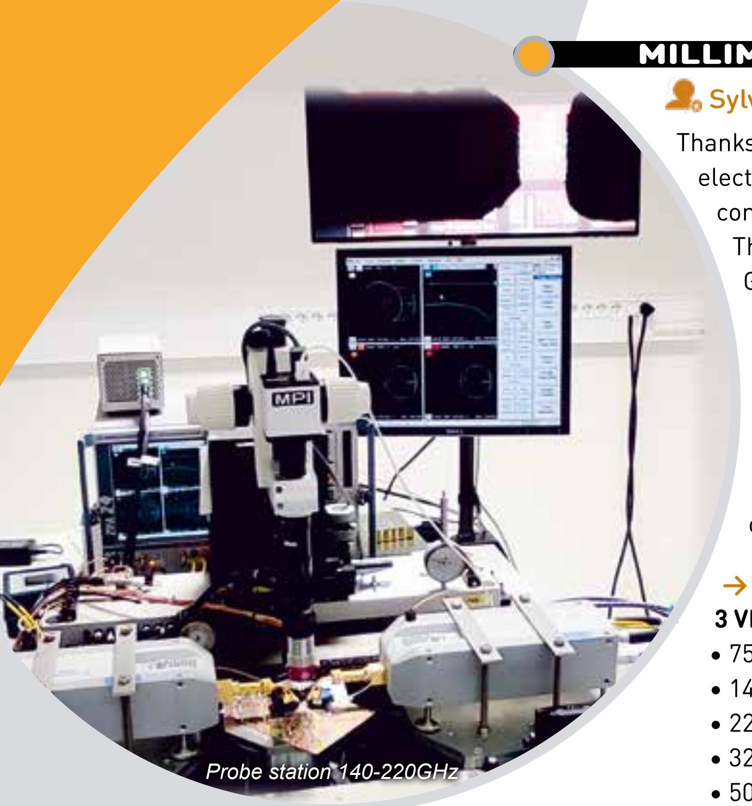












Probe station 140-220GHz

MILLIMETER WAVES UP TO 1.1THZ

Sylvie Lepilliet

Thanks to technological advances in the field of micro and nano electronics, more and more applications are emerging and are being considered in the millimeter frequency band (mmW) above 100 GHz. The millimeter frequency band is defined between 30 GHz and 300 GHz, corresponding to wavelengths between 10 mm and 1 mm respectively. Beyond 100 GHz, the millimeter frequency band intersects with the Terahertz (THz) spectrum up to 300 GHz. This frequency band (100 GHz - 300 GHz) commonly known as Sub-THz offers an important lever for increasing the performance of existing systems and opens up prospects for new applications. This part of the millimeter band is of interest mainly in the fields of spectroscopy, imaging and telecommunications.

→ Vectorial measurement capabilities

3 VNAs with 6 converters :

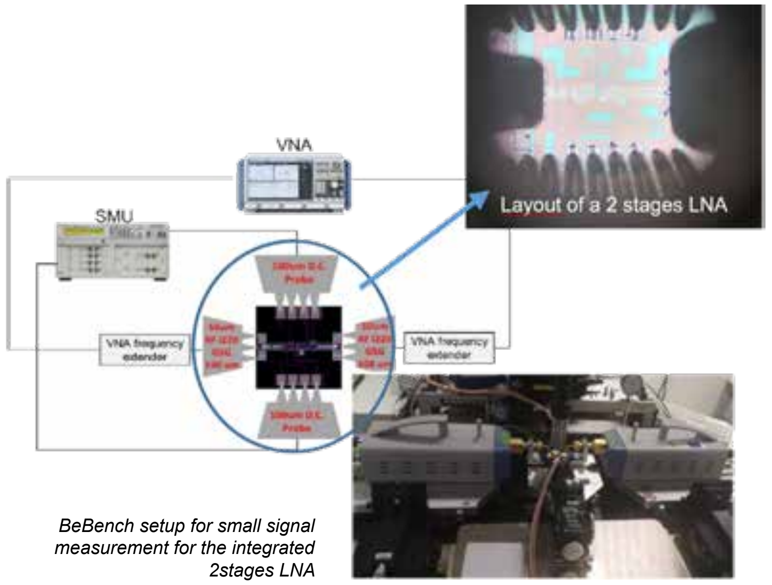
- 75-110GHz – WR10
- 140-220GHz – WR05
- 220-325GHz – WR03
- 325-500GHz – WR2.2
- 500-750GHz – WR1.5
- 750-1100GHz – WR1.0

→ Scalar measurements capabilities:

- Spectrum analyzer mixers up to 1 THz
- Absolute power (PM5 Erickson) 60GHz – 2THz, 1µW – 200mW
- Multiplication chains (80-360, 580-720 GHz)
- Pyroelectric detector: 100GHz – 30THz, 100nW – 100mW free space
- Waveguide integrated zero-bias detectors (Schottky): WR 3.4 (220-325 GHz), WR 1.5 (500-750 GHz) 100GHz, 140-220GHz, 750-1100GHz

→ Photonics-based sources/receivers for THz communications & instrumentation, 200-340 GHz:

- Sources for amplitude modulation and I/Q measurements, in THz range (yp to 340 GHz)
- Receivers for wideband signal reception (60-340 GHz)
- Bit error testers (realtime, 2 channels 25 GBit/s)
- Generation & Analysis of I/Q signals (developed with PhLAM, Lille)
- IP3 bench of scalar evaluation of active devices intermodulations based on photonics techniques (up to 330 GHz)



BeBench setup for small signal measurement for the integrated 2stages LNA

Example 1

Highly Tunable High-Q Inversion-Mode MOS Varactor in the 1–325-GHz Band

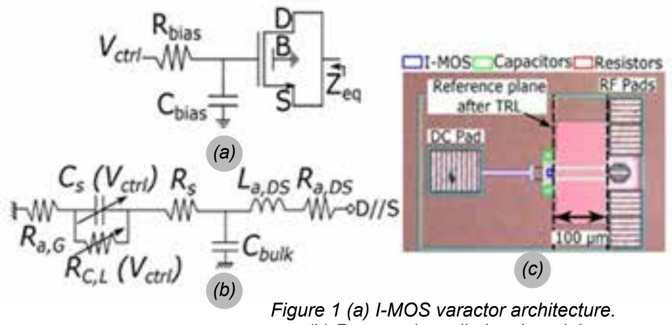


Figure 1 (a) I-MOS varactor architecture.
(b) Proposed small-signal model
(c) Micrograph of the fabricated circuit

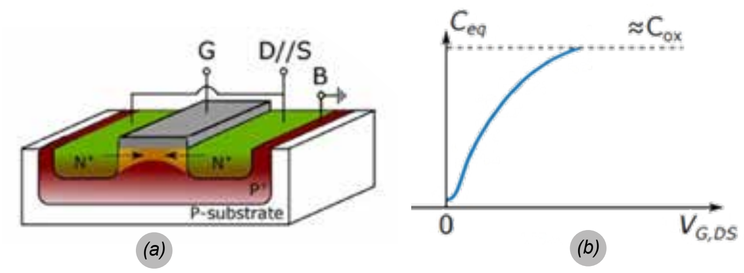


Figure 2 (a) nMOS-based I-MOS varactor
(b) Capacitance versus $V_{G,DS}$

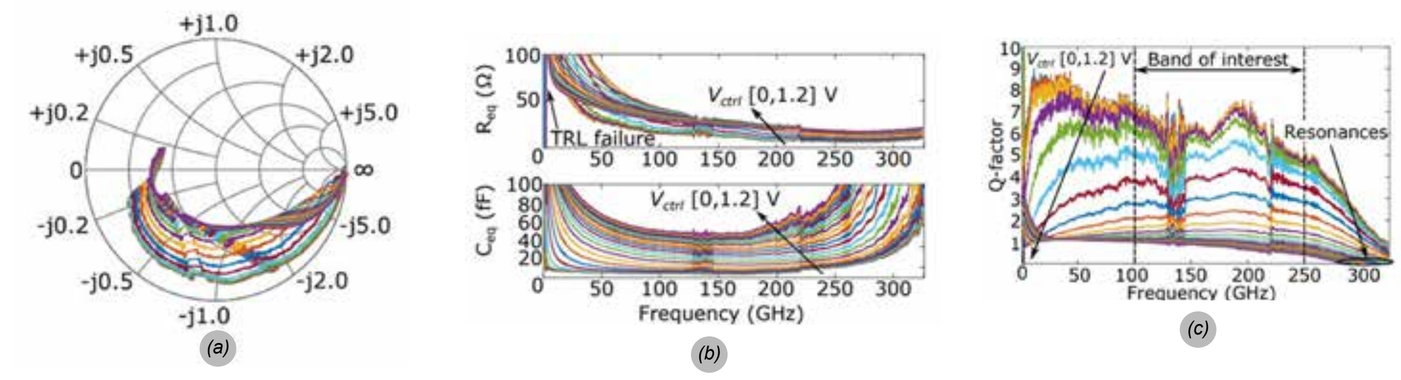
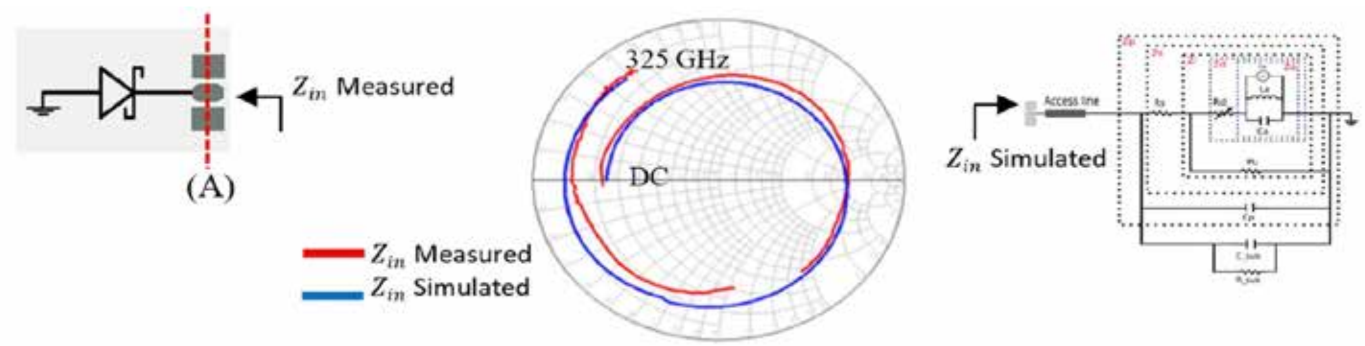


Figure 3 Measurement results in the 1 GHz to 235 GHz band as a function of V_{ctrl} (a) S_{11}, (b) R_{eq} and C_{eq}, and (c) Q-factor

«Highly Tunable High-Q Inversion-Mode MOS Varactor in the 1–325-GHz Band,» in IEEE Transactions on Electron Devices, vol. 67, no. 6, pp. 2263-2269, June 2020, doi: 10.1109/TED.2020.2989726.

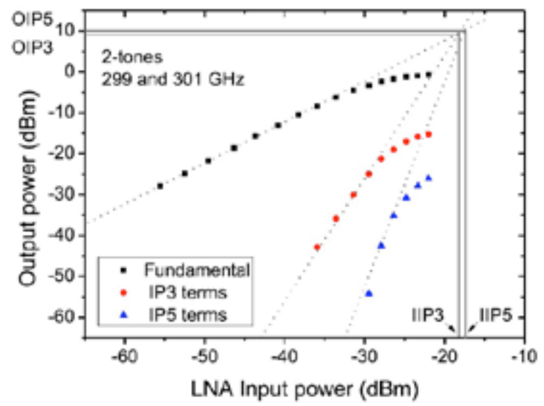
Example 2

To validate the extraction methodology, the unput impedance of this simulated electrical model id compared to the impedance extracted from the S-parameters , in the range DC-325GHz

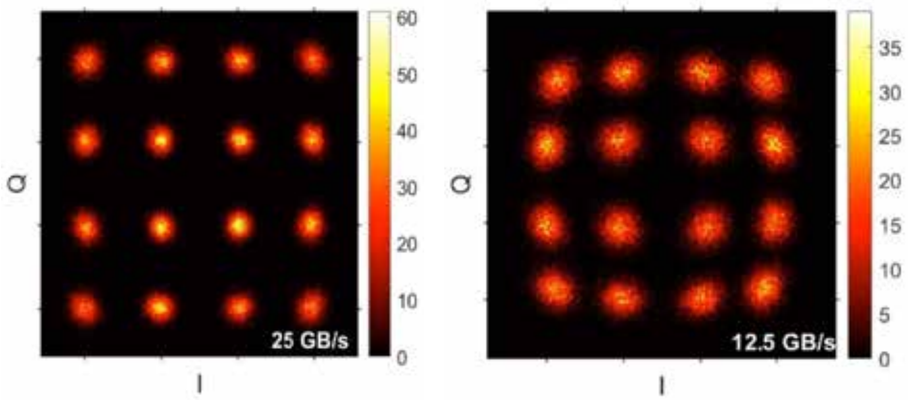


Example datacom

IP3 and I/Q analysis of the compression curve of LNA:
IP3 measurement of 300 GHz LNA



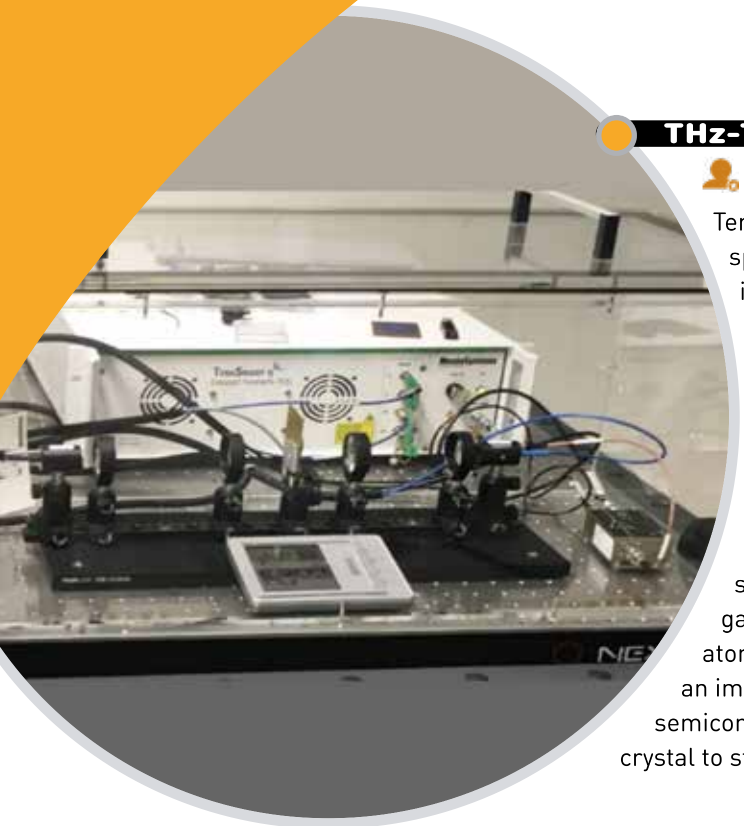
(1) Is an example of 100 GBit/s IEEE 802.15.3d (300 GHz)



(2) LNA output with QAM16 compression (300 GHz)

CHOP

MILLIMETRIC & THz



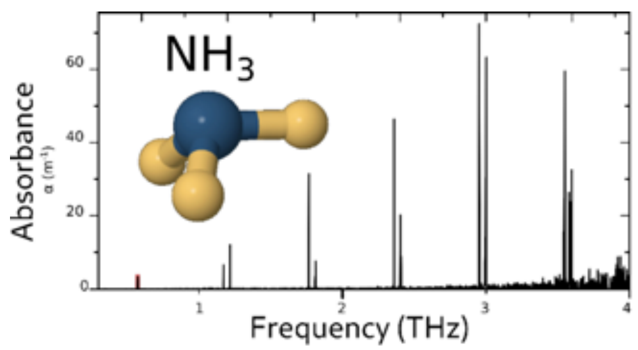
THz-TDS: TERAHERTZ TIME DOMAIN SPECTROSCOPY

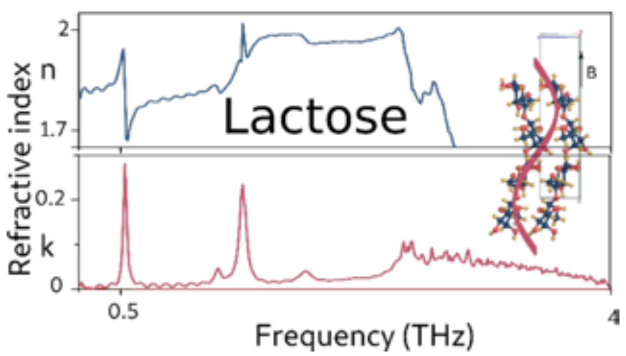
Sophie Eliet

Terahertz Time-domain-spectroscopy is the most spread THz spectroscopy setup for broadband THz spectral measurements. It is based on a femtosecond laser of which pulse is transferred in the THz spectral range thanks to a photoconductive antenna (in our case). The resulting THz pulse is, then, time sampled using another photoconductive antenna trigged by the femtosecond laser after a controlled delay. It leads to time traces that a Fourier transform transfers in the spectral domain.

→ APPLICATIONS

TDS spectroscopy is used on all kinds of samples: gaseous, liquid solid and even plasma. It is used to probe the rovibrational lines of gas with a very good specificity when molecules have from ~3 to ~10 atoms. It is very sensitive to polar liquid such as water and thus plays an important role in biology. THz broadband spectroscopy is used on semiconductor sample to probe very low level of doping and on molecular crystal to study their conformation.





→ ADVANTAGES & LIMITATIONS

- Spectral range: 0,2 - 5 THz
- Total scan range: 850 ps
- Spectral resolution limited by the Fast Fourier Transform : <1,2 GHz
- Dynamic range : 100 dB
- Better resolution possible by temporal signal processing
- Type of sample: Solids (wafers, powder, pellets…) , gases or suspended particles

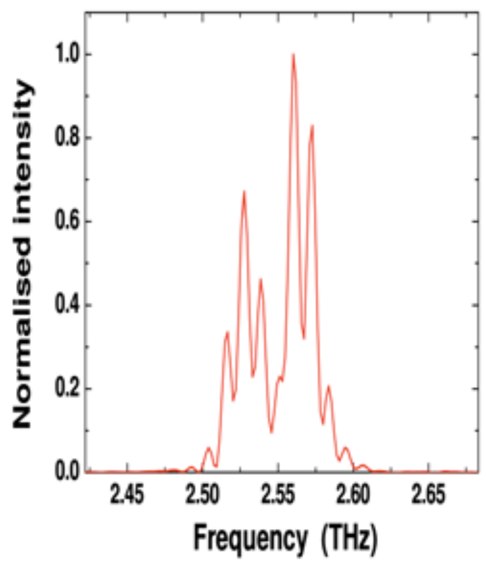
FTIR: FOURIER TRANSFORM INFRARED SPECTROMETER, COUPLED WITH MICROSCOPE

Sophie Eliet

This N_2-purged FTIR allows spectral acquisition from the mid-IR to the THz spectral range
Total Spectral range: 8 000 – 50 cm^{-1} (1,25µm- 200µm) (240 THz- 1,5 THz)
Spectral resolution: = 0,4 cm^{-1}
Detectors: Internal DLATGS 8000-350cm^{-1}; Internal DTGS/PE 680-50cm^{-1}
External MCT (cooled 77K): 12000-600cm^{-1}
Internal source: Blackbody
Coupled to a MIR microscope and internal MCT detector (cooled 77K): 12000-600cm^{-1}
Microscope mapping:
- Precision of step: 0.1µm
- Repeatability: 1µm
- Positioning precision: +/-3µm

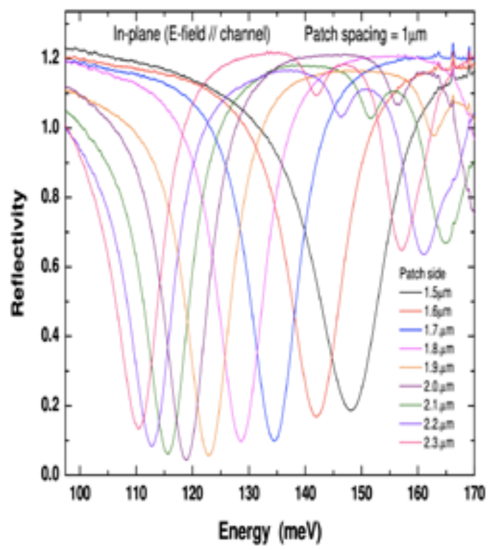
Example 1

Emission spectrum of a THz quantum cascade laser



Example 2

Reflectivity spectra of 2D periodic array (1µm period) of square metallic patch cavities of different side



The cavities consist of a GaAs/AlGAs heterostructure sandwiched between metallic top contact and ground plane. Spectra are measured in reflection geometry with the mid-infrared microscope.

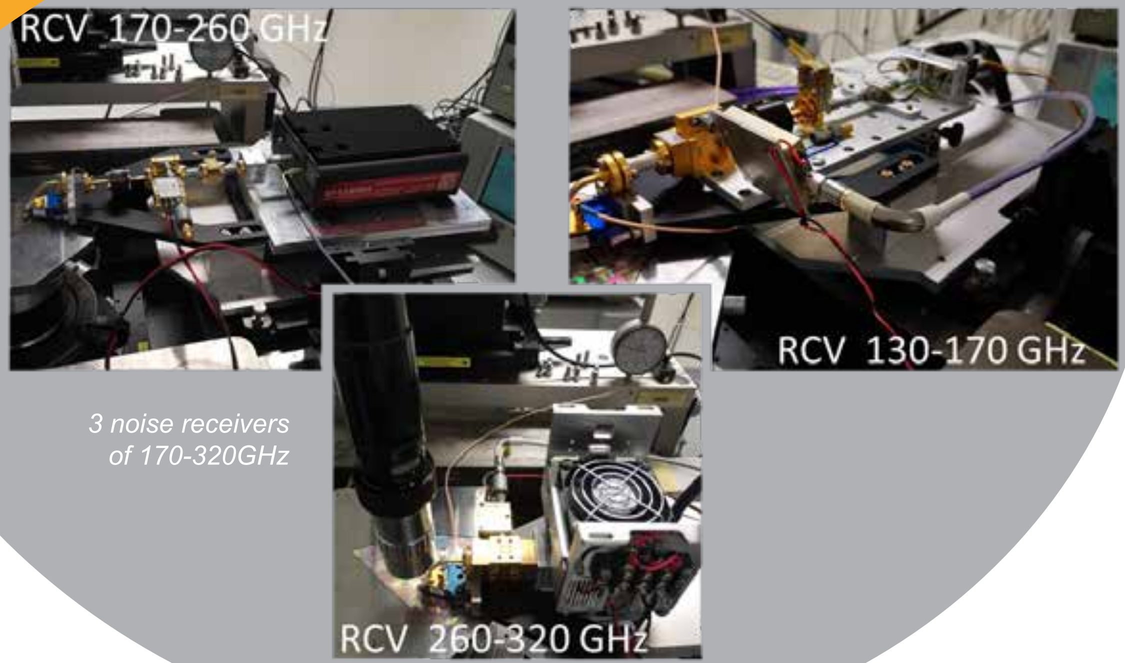
ACS Photonics 8. 464 (2021)

→ ADVANTAGES & LIMITATIONS

- Spectral range depend of the couple beamsplitter / detector
- Type and dimensions of sample for Hyperion module: flat sample of maximum dimensions ~5x7cm

CHOP

NOISE MEASUREMENT

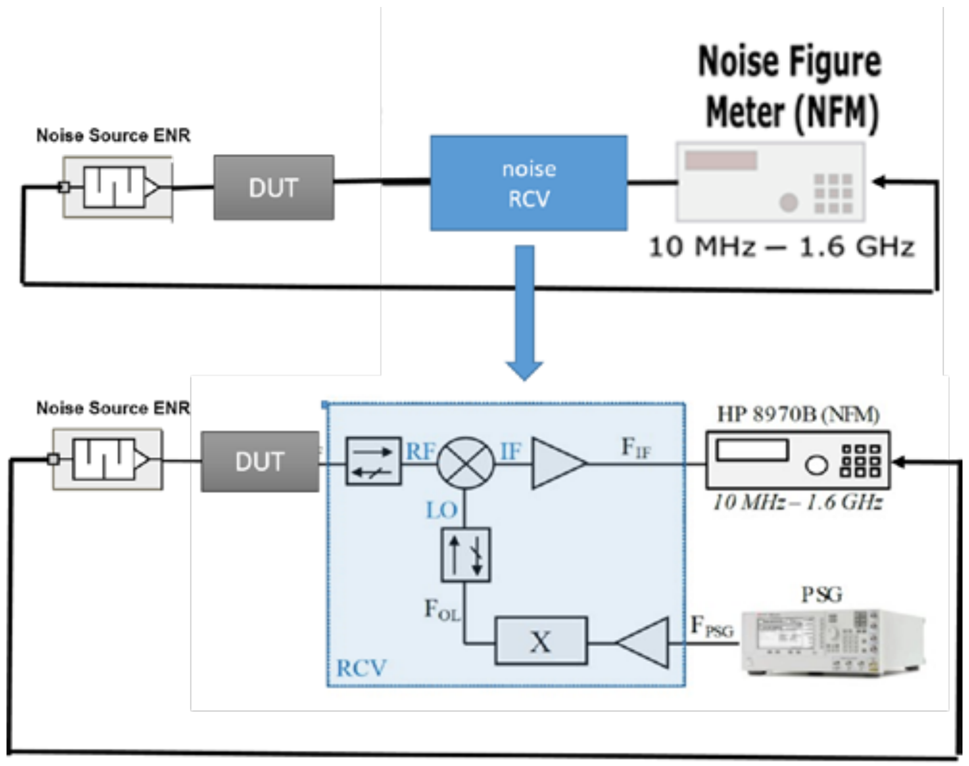


3 noise receivers of 170-320GHz

NOISE MEASUREMENTS

Sylvie Lepilliet

The term "Noise" is normally used to express the unwanted fluctuations that may disturb the information propagation within the signal, or reduce the quality of its contents.
Noise figure (NF) is measures of degradation of the signal-to-noise ratio (SNR), caused by components in a signal chain. It is a number by which the performance of an amplifier or a radio receiver can be specified, with lower values indicating better performance.



Block diagram of noise measurement

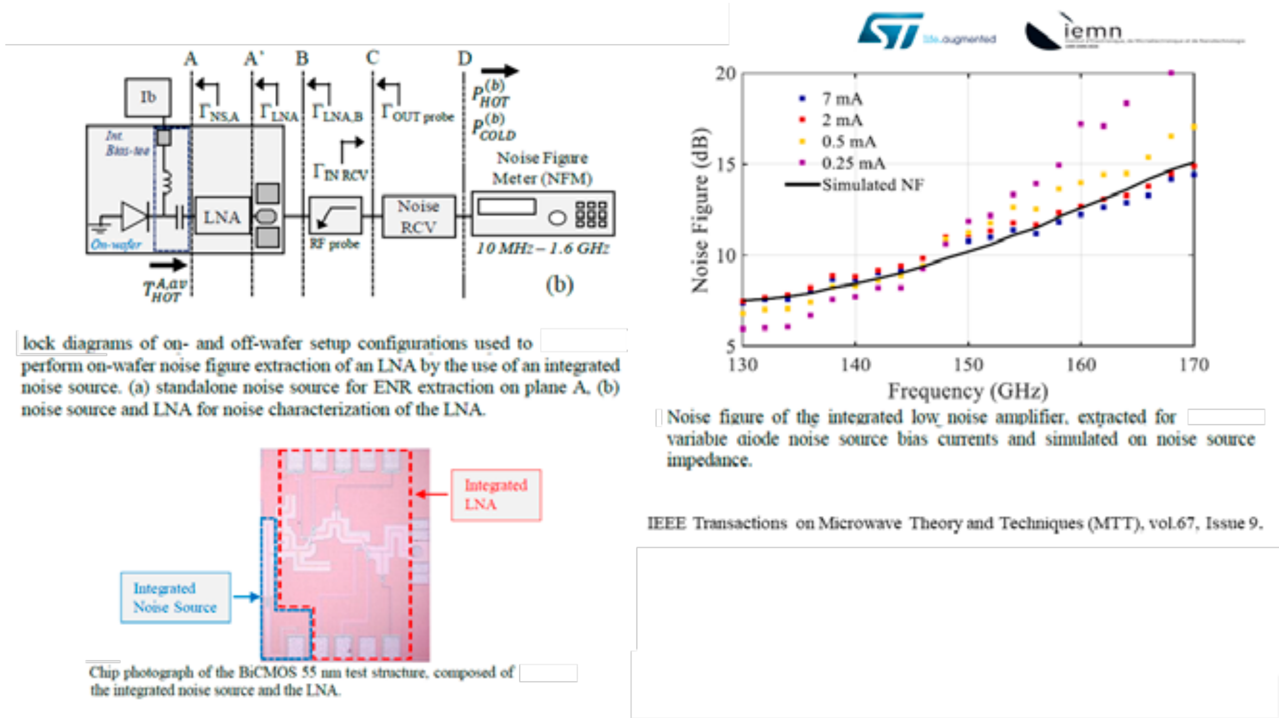
For the extraction of the four noise parameters [gamma opt, Nfmin and Rn] of semiconductor devices studied, several automated measurement benches make it possible to measure the available gain and the noise figure (Noise Figure) of microwave components. according to the following frequency ranges:

6 noise receivers:

- 6-20GHz
- 20-40GHz
- 75-110GHz
- 110-170GHz
- 170-260GHz
- 260-325GHz

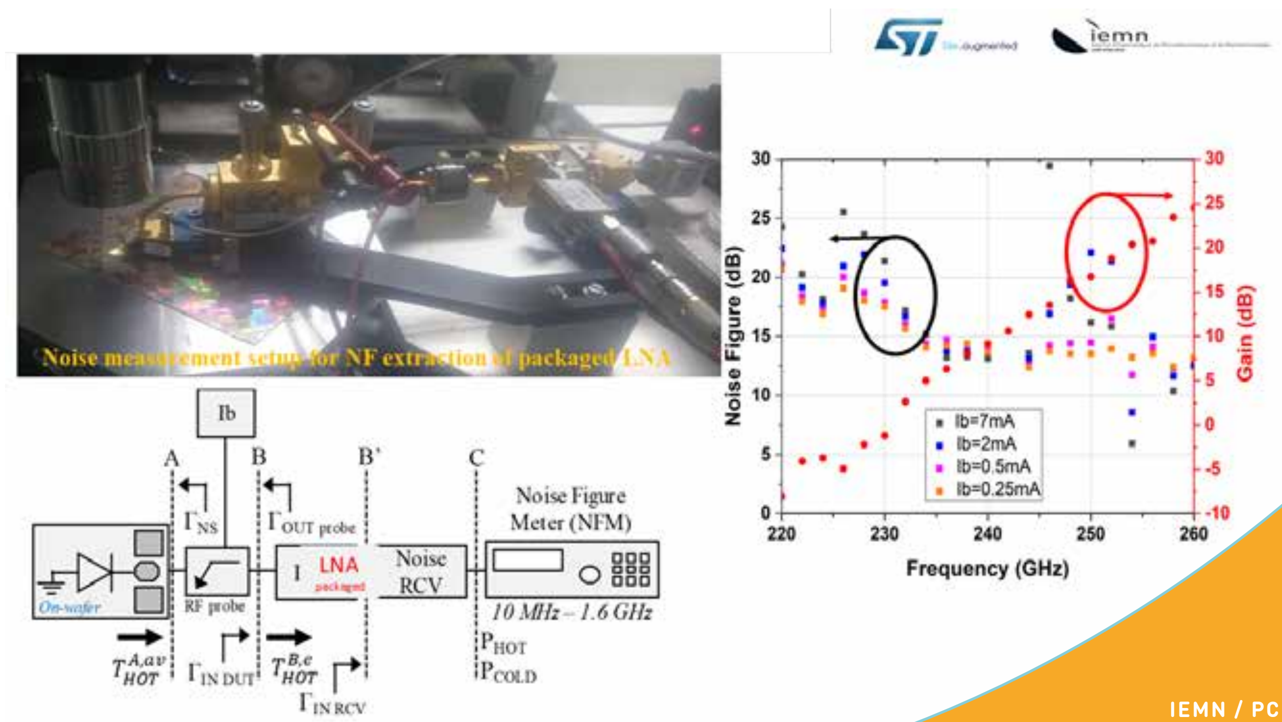
Example 1

Noise Measurements (LNA integrated 130-170GHz)



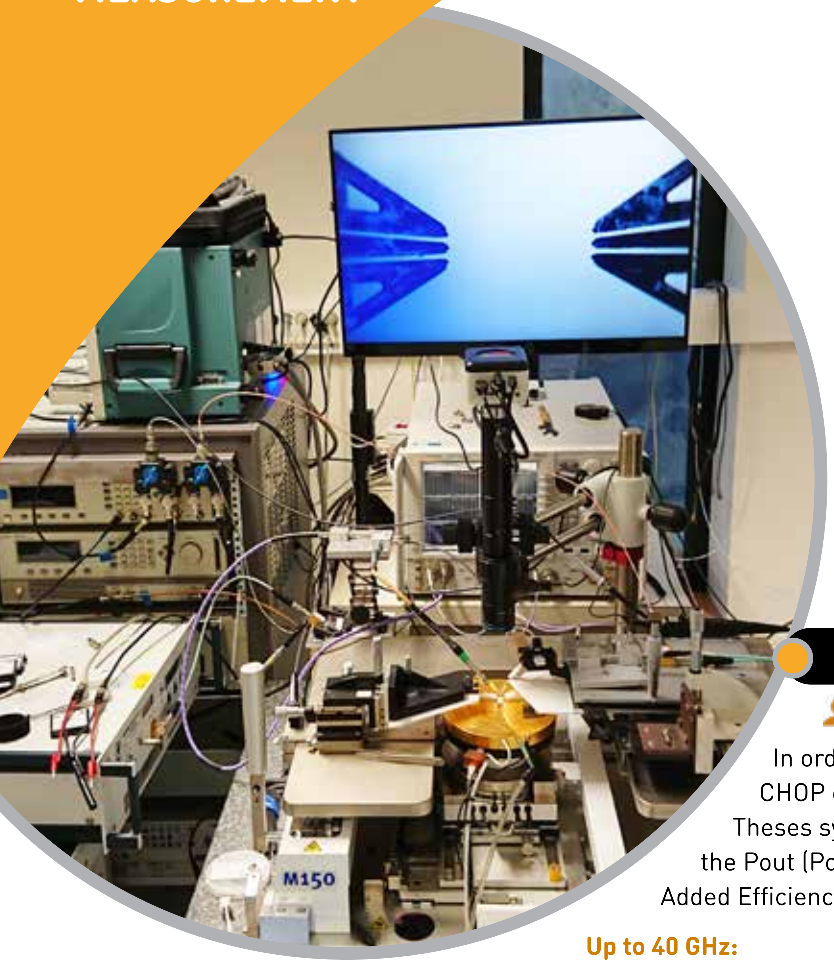
Example 2

Noise Measurements (LNA packaged 220-260GHz)



CHOP

POWER MEASUREMENT



40 & 94 GHz LOAD-PULL CHARACTERIZATION

Etienne Okada

In order to measure the power performance of transistors, the CHOP developed specific "Load-Pull" measurement benches. Theses system make it possible to determine the Gp (Power Gain), the Pout (Power available at the Output) as well as the Pae (Power Added Efficiency) of transistors and amplifiers.

Up to 40 GHz:

Since these parameters can only be determined under saturated conditions, a high power level is required to energize the device under test. For this, several power amplifiers are available and the bench have been optimized to carry the measurement up to the saturation of the DUT at 6, 10, 18 and 40GHz. At these frequencies, we can apply up to +30dBm at wafer level. Devices under test can be bias up to 50V.

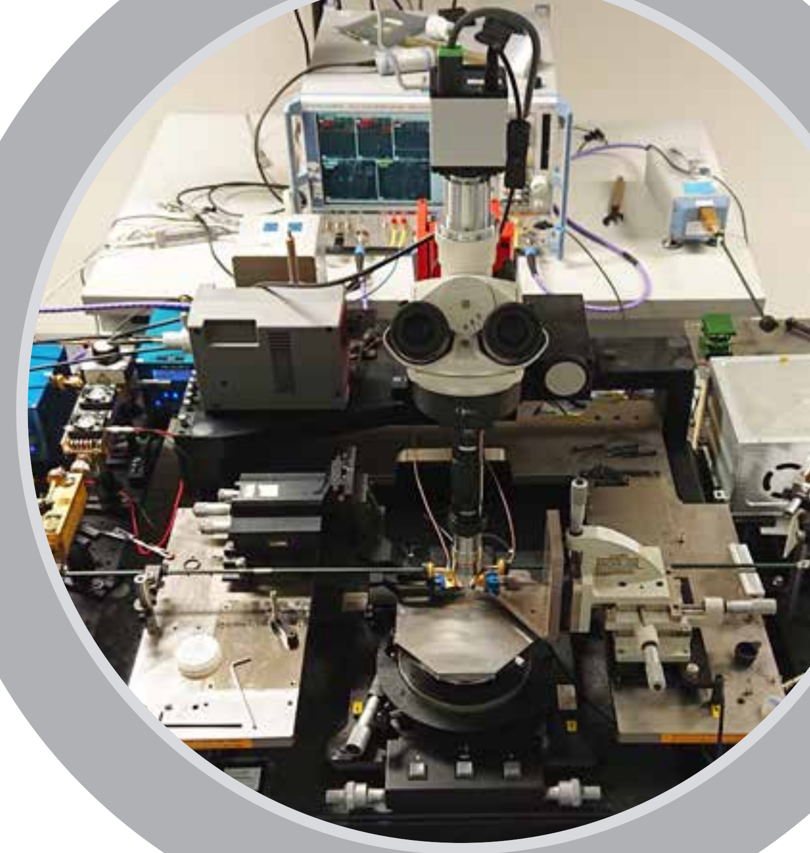
These measurements can be made in «load-pull» mode to modify the impedance presented at the output of the device under test. For this, we developed an active Load-Pull setup to reach high magnitude reflection coefficients. This helps determine the optimal impedance to maximize Gp, Pout or Pae.

All these measurements are possible in CW condition (continuous) or pulsed condition (pulsed bias + pulse RF) with a pulse width of 1µs and a duty cycle of 1%. Pulse measurements make it possible to overcome trap and thermal phenomena, thus maximizing the performance of the components under test.

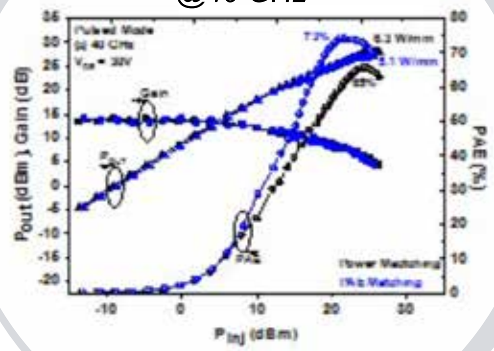
Large signal reliability test can also be made with this bench. We apply a large signal to the DUT and we measure its performance versus time for hours.

@94 GHz:

The 94GHz Load-Pull measurement bench is based on an active Load-Pull technique also. It is quite similar to the 40GHz bench with specific modification due to the high frequency. Big improvements are underway on this bench to reach higher power. Only CW measurement are available for now, pulsed measurements are in development.

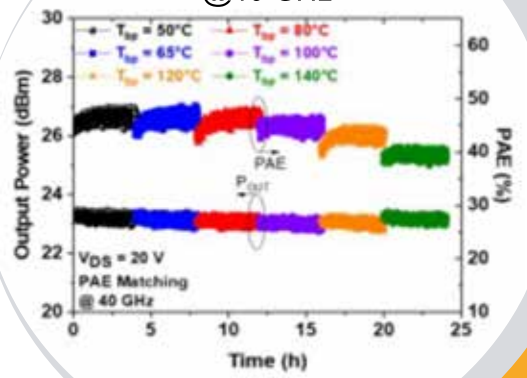


Large signal measurements @40 GHz



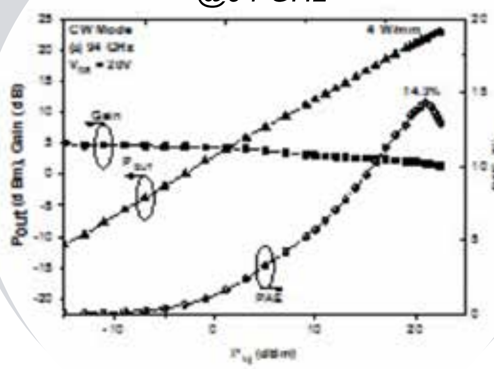
IEEE J. Electron Devices Soc., vol. 7, 2019

Large signal reliability @40 GHz



2020 IEEE IRPS

Large signal measurements @94 GHz



2020 IEEE IMS

I/V MEASUREMENTS HIGH VOLTAGE OR HIGH CURRENT

Etienne Okada

Based on a Keysight B1505A device analyzer coupled with a MPI TS150-HP probe station, this system allows on-wafer measurement up to 10kV DC for breakdown characterization. It also permit high current measurements: 20A @ 20V (Pulsed). We can also extract Dynamic RDS-ON of transistors by switching the device OFF to ON in just 50µs and monitoring the evolution of the current versus time.

Coupled with our HP-4294A Impedance Analyzer we are able to carry capacitance measurement from 1kHz up to 1MHz under bias voltage up to 3kV.

- This equipment can test components or materials up to voltages of 10 kV for breakdown measurements or 20 A @ 20 V.

ADVANTAGES & LIMITATIONS

High voltage and current are available but power is limited by the setup.

ΣCOM

The SIGMACOM service offers a large set of advanced scientific equipment's for the conception and test of new radio modules communication systems, (up to the millimeter wave range) and sensors. We can address wide area single hop or multi-hop networks as well as mixed radio-fiber connectivity for smart devices, implementing edge and near sensor computing to optimize rate, power consumption, reliability and/or latency. This service offers both software and hardware facilities to design, program and test both the analog and digital parts of smart and connected devices, up to 110 GHz. We can for example address the challenges related to IOT, 5G and beyond.

Head of SigmaCom
R. Kassi

- **Analog and digital communication systems** — III. 1-8
  - → Redha Kassi → David Delcroix
  - Telecom test bench
  - Software-defined radio
  - Multifunctional analog and digital I/O devices
  - Energy efficiency test bench
- **Optical communication systems** — III. 9-12
  - → Redha Kassi
  - Optical telecom testbed
  - Optical measurement bench

sigmacom-contact@iemn.fr

SIGMACOM

IEMN / PCMP

SIGMACOM

ANALOG AND DIGITAL COMMUNICATION SYSTEMS

Real-Time Open Multi user RF communication Test-Bench with Controlled Channel

TELECOM TEST BENCH

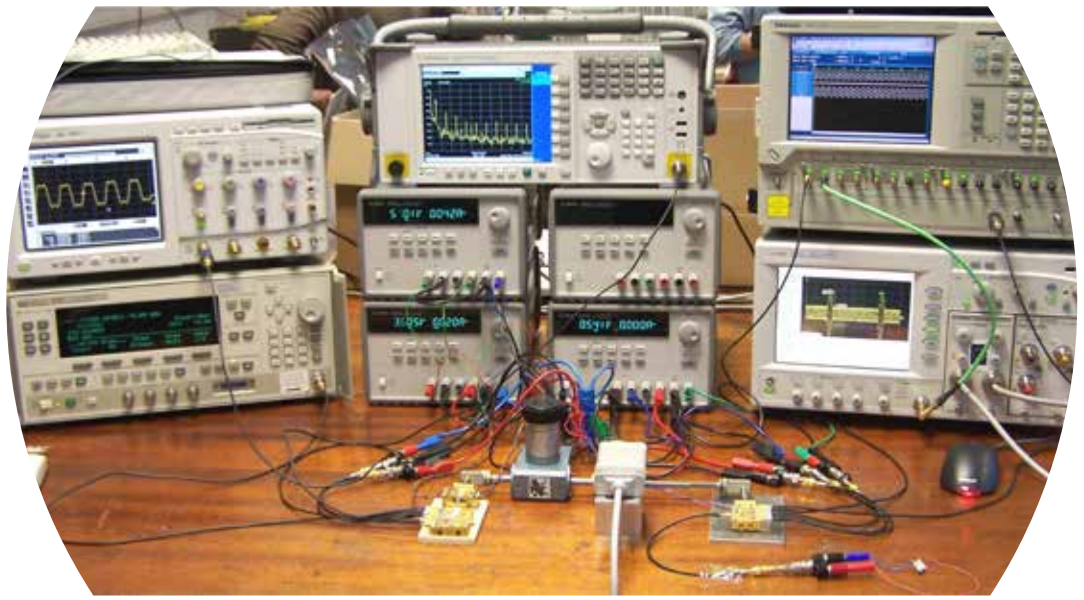
Rédha Kassi

This telecom test bench offers a wide range of state-of-the-art scientific equipment for the characterization of new radio modules and communication systems, covering frequencies up to the millimeter wave range. It is particularly well suited for wireless ad hoc networks for smart objects and sensors. In addition, the telecom platform aims at the generation and analysis of complex telecom signals to demonstrate new concepts for wireless communication links.

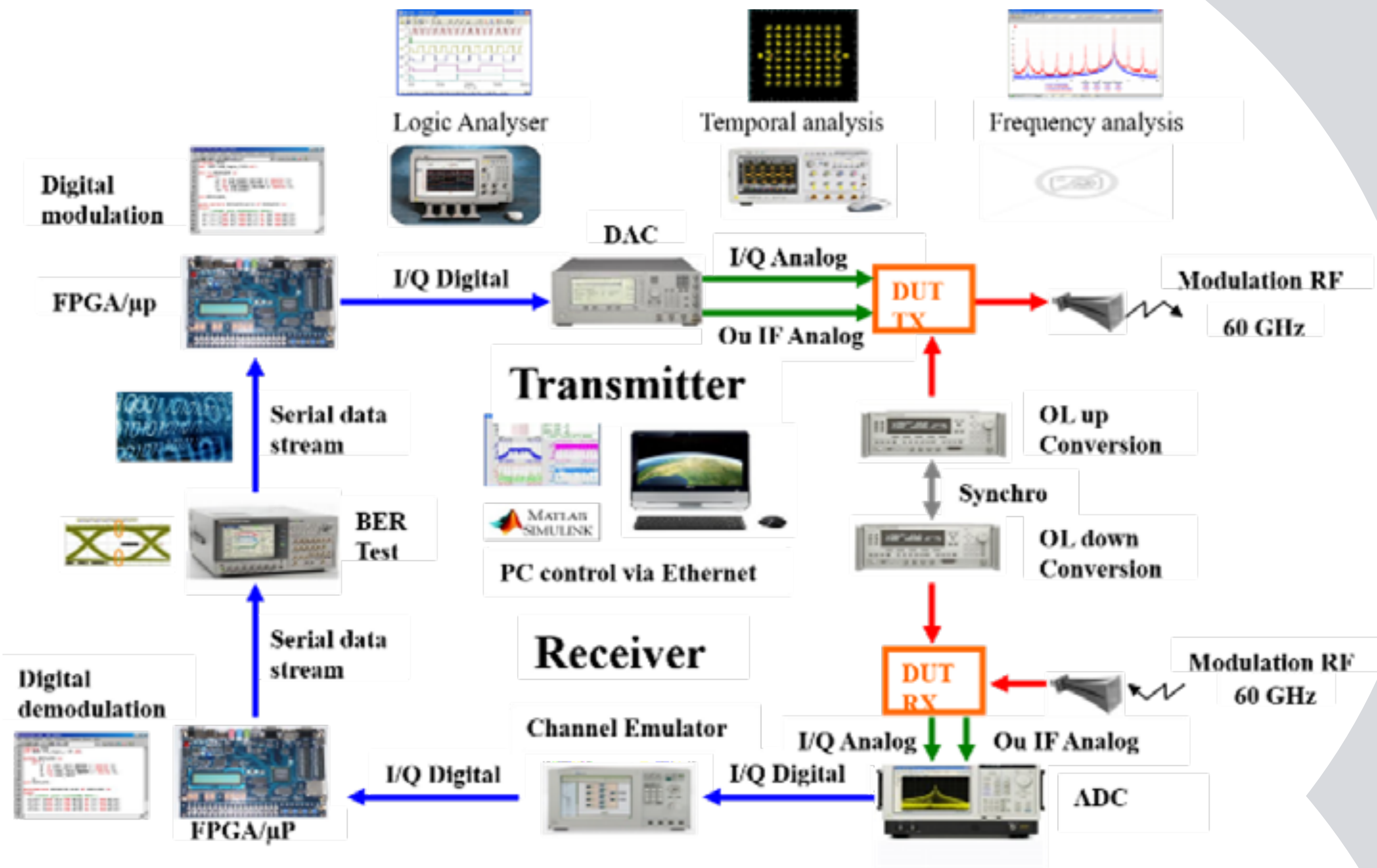
→ APPLICATIONS

- The bench includes a wide range of test systems and software that can provide a flexible and powerful environment to perform key telecom up to 60 GHz tests such as:
- Real-time characterization of a complex transmission and/or reception system, from baseband generation to RF transmission.
- Real-time characterization of a transmission/reception system from demodulation to data recovery with options to analyze RF signal integrity at each channel stage (EVM, channel power measurements, Occupied bandwidth, Modulation accuracy...), digital signal (BERT, PER, eye diagrams, jitter measurements), and mixed signals.
- Characterization of link robustness against real-time RF channel emulation, interference analysis.
- Physical testing of interoperability in heterogeneous sensor networks
- Testing the non-linearity of an amplifier on the communication channel and hard/soft correction.
- Testing frequency and phase synchronization.
- Testing clock accuracy and stability.
- Optimizing transmission packet size.
- Optimize the size of the synchronization preamble.
- Measure component temperature drift and impact on transmission.

Some measurement techniques can be used by the CHOP cluster for THz communications.



Mixed signal test bench for an UWB-IR communication system operating at 60 GHz



Characterization of a real-time communication

→ HIGHLIGHTS

Generation of complex analog, digital or mixed signals:

- Generation of vectorial signals up to 20 GHz with a 1 GHz analog bandwidth
- Generation of arbitrary wave form signals up to 1.25 Gs/s with a 15 bits resolution.
- Generation of arbitrary wave form signals up to 20 Gs/s with a 10 bits resolution.
- Pulse and data generation up to 3.35 Gb/s
- Frequency synthesizers up to 75 GHz

Time and frequency domain analysis of analog, digital or mixed signals:

- Automatic phase noise test set up (10 KHz - 110 GHZ), baseband noise, AM, FM measurement, variance, frequency meter.
- Vectorial signal analyzers up to 50 GHz with a potential 160 MHz analog bandwidth
- Sampling oscilloscopes up to 75 GHz
- Single shot oscilloscopes up to 12 GHz
- Spectrum analyzers up to 110 GHz
- Real time spectrum analyzer up to 14 GHz and 14 bits resolution
- Power meters up to 110 GHz
- Differential vectorial network analyzer (100 MHz-26.5 GHz) for RF circuits or radio
- Electrical Clock Recovery Module up to 2.5 Gb/s
- Logic analyzers up to 800 Mb/s for each of the 34 channels
- Bit Error Rate Test bench up to 13 Gb/s

Real time modelling for the channel propagation:
Baseband generator and channel emulator (4*2 or 2*4 MIMO Max, 24 multi-paths per channel, Channel BW 120 MHz, Sample rate 150 Msa/s Max)

Real time telecom signal generation and analysis

- modulation and demodulation for cellular (LTE/LTE-Advanced/LTE-A Pro FDD, GSM, GPRS, W-CDMA...) and non-cellular technologies (Wifi, Bluetooth, ZigBee, LoRa, SigFox, RFID...)

Software suite:

- Labview
- signal studio
- 89600 vsa

Multi-standard communication Gateway

USRP-2954

SOFTWARE-DEFINED RADIO

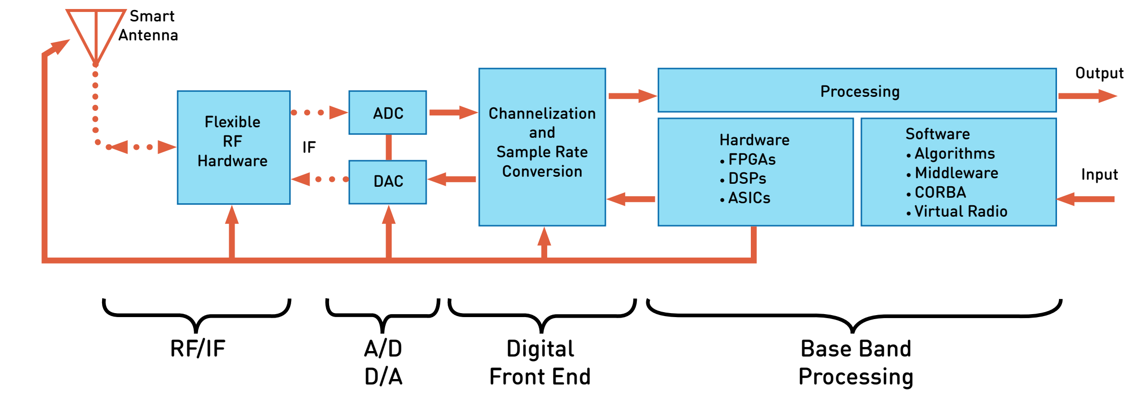
Rédha Kassi

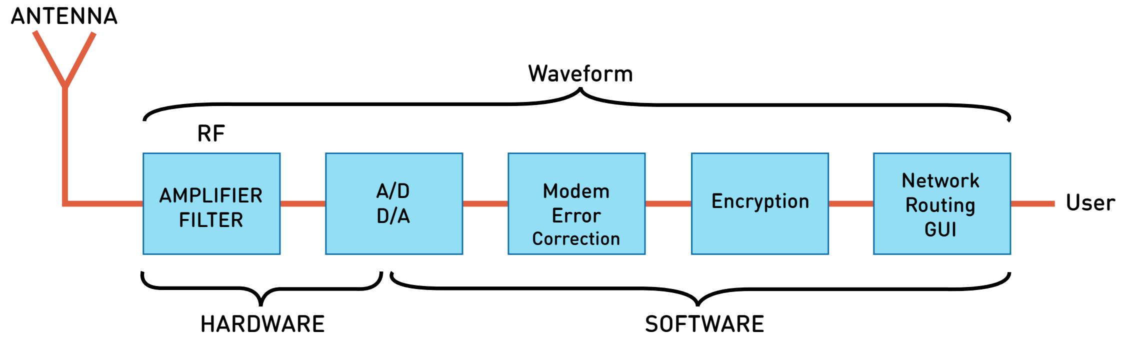
We offer a range of NI Universal Software Radio Peripherals (USRP) to define Software Defined Radios (SDRs) used for RF applications. These integrated hardware and software solutions enable rapid prototyping of wireless communication systems. NI USRP transceivers can transmit and receive RF signals in multiple bands. The USRP hardware architecture integrates RF analog front-ends (high-low conversion, filters, amplifiers), RF I/Q modulation-demodulation stage, ADCs and DACs, a processor or FPGA connected by wire to a host computer (PC or PXI chassis) for sending, and receiving properly formatted baseband I/Q data. The USRPs are programmed using the LabVIEW development environment. This solution offers great flexibility for software radio prototyping and communications research.

→ APPLICATIONS

The USRP hardware allows a wide range of applications.

- Dynamic access to the RF spectrum and real-time recording of signals over a long period of time.
- PHY and MAC layer research for robustness of radio links.
- Build custom transmission or reception protocols.
- Build multi-standard communication gateways
- Integrate USRP into a standard radio communication network to test new wireless algorithms (TDD, FDD) to improve communications.
- Test channel coding or source coding blocks
- Simulate channel degradation and verify the impact on transmissions.
- Implementing of MIMO technology





→ HIGHLIGHTS

Main hardware features of USRP

The USRP are equipped with a GPS-disciplined 10 MHz oven-controlled crystal oscillator (OCXO) reference clock. The GPS disciplining delivers improved frequency accuracy and synchronization capabilities. It is equipped with a reconfigurable FPGA

Transmitter:

- Number of channels 2
- Frequency range 10 MHz to 6 GHz
- Frequency step < 1KHz
- Maximum output power (Pout) 50 mW to 100 mW (17 dBm to 20 dBm)
- Gain range 0 dB to 31.5 dB
- Gain step 0.5 dB
- Maximum instantaneous real-time bandwidth 160 MHz
- Maximum I/Q sample rate 200 MS/s
- Digital-to-analog converter (DAC) Resolution 16 bit
- Spurious-free dynamic range (sFDR) 80 dB

Receiver:

- Number of channels 2
- Frequency range 10 MHz to 6 GHz Frequency step
- Frequency step < 1KHz
- Gain range 0 dB to 37.5 dB
- Gain step 0.5 dB
- Maximum input power (Pin) -15 dBm
- Noise figure 5 dB to 7 dB
- Maximum instantaneous real-time bandwidth 160 MHz
- Maximum I/Q sample rate 200 MS/s
- Analog-to-digital converter (ADC) Resolution 14 bit, sFDR 88 dB

Software suite

- Labview
- Labview FPGA Module
- Labview communications system design suite
- GNU Radio, Python, Matlab, Simulink, C/C++.

SIGMACOM

ANALOG AND DIGITAL COMMUNICATION SYSTEMS

Test bench of a neuromorphic system-on-chip

MULTIFUNCTIONAL ANALOG AND DIGITAL I/O DEVICES

Rédha Kassi

We offer several PXI chassis integrating a controller and different multi-channel I/O modules (analog, digital or mixed) allowing to realize several instruments adaptable for multiple test and measurement applications. The originality of this modular, synchronous, standardized solution is to quickly offer several specific instruments to generate, acquire, store and analyze different signals in a single chassis. The National Instrument programming environment is used to create or use software applications to drive the hardware, process, analyze stored data and/or visualize it in continuous time.

→ APPLICATIONS

There are many test and measurement applications, the only limitations of which depend on the technical characteristics of the equipment.

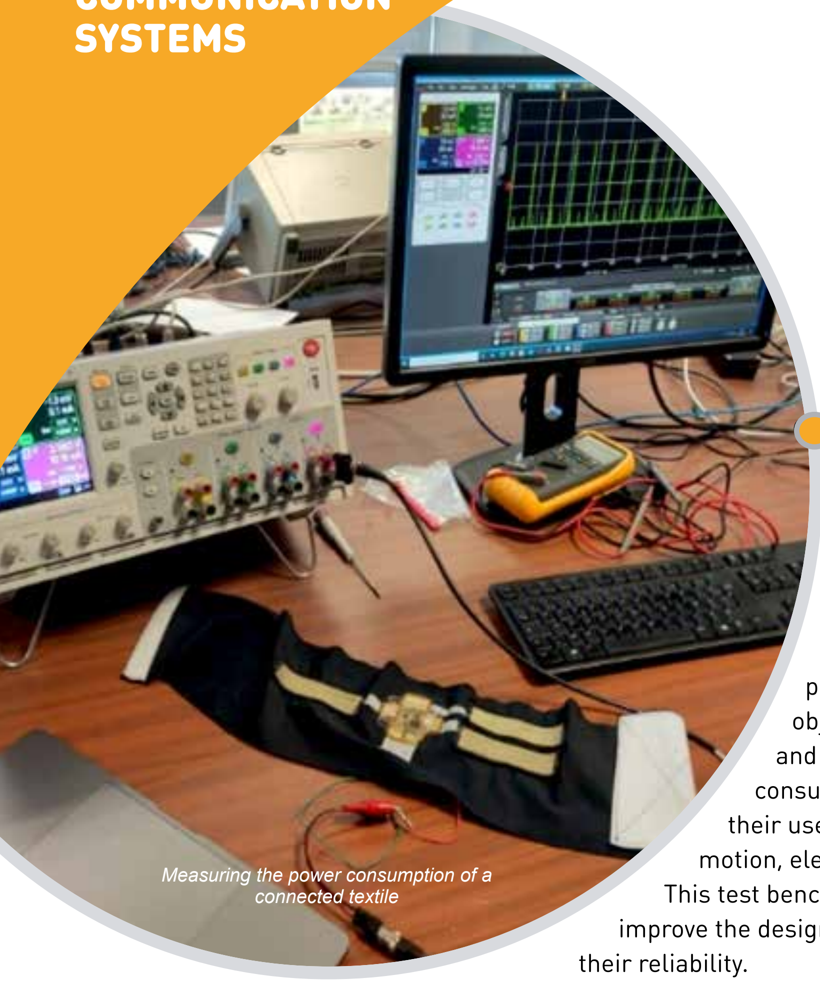
- Generation (DAC) and acquisition (ADC) of data and control
- Instrumentation (function generator, AWG, digital signals, oscilloscope, spectrum analyser, ...)
- Wireless communication test (acquisition and real time generation of baseband or IF)

RF test bench

→ HIGHLIGHTS

- **16-bit PXI analog output module, 8 channels, 1 MS/s (8 TTL/CMOS 5V digital I/O lines)**
- **16 simultaneous 24-bit PXI analog inputs module (204.8 kS/s sampling rate, 114 dB, 4 gains, AC/DC coupled)**
- **PXIe, 16 AI (16 bits, 1,25 MS/s/ch), 4 AO, 48 DIO, module I/O multifunction**
- **100 MHz Bandwidth Transceiver Adapter Module (this module must be combined with a PXI FPGA)**
- **200 MHz digital I/O adapter module, 32 LVDS channels (this module must be combined with a PXI FPGA)**
- **Digitizer adapter module 50 MS/s, 14 bit, 16 channels (digitizer must be combined with a PXI FPGA)**

RF Signal Analysis



Measuring the power consumption of a connected textile

ENERGY EFFICIENCY TEST BENCH

Rédha Kassi

This energy efficiency test bench offers the possibility of optimising the energy consumption of communicating objects for IOT, 5G and beyond, by enabling the energy impact of electronic systems to be measured precisely in a controlled environment through the choice of low-power hardware and software architectures. One of the objectives is to limit the frequent recharging of batteries and to maximise their lifespan. Knowing the AC/DC energy consumption of objects also makes it possible, depending on their use, to size ambient energy recovery technologies (solar cell, motion, electromagnetic, etc.) to create energy autonomous objects. This test bench allows numerous measurement possibilities in order to improve the design of objects to increase their performance and guarantee their reliability.

→ APPLICATIONS

Measure and analyse the power consumed by a system or the sub-systems of a complex object.

• To measure the current and voltage accurately over a wide dynamic range depending on the operating state of the object (on, standby, communication, ...)
• Measure the exact power consumption with sufficient bandwidth not to miss fast digital events.
• Synchronize the power consumption measurement with the software subroutines of the powered object to optimize processor scheduling and maximize the object's battery life.
• Correlate load consumption with RF events and events in the object's sub-circuits.
• Consider the impact of power consumption as a function of RF interference with other wireless devices in a real or controlled environment by combining it with the telecom test bench (influence of channel model, RF disturbance, interferer, electromagnetic pulse, ...).
• Test in difficult electromagnetic environments (C2EM: anechoic chamber, reverberation chamber)

Evaluating the battery characteristics of a device

• Visualize the evolution of the power consumed by an object according to its use and record it over a long period of time in a point file.
• Replay a stored point file to check the performance of a battery and estimate its lifetime.
• Characterize the charge and discharge of a battery over time.
• Analyze statistically (CCDF) the power consumed

Analysis of the energy consumption of a device under test

→ HIGHLIGHTS

Device current waveform analyzers

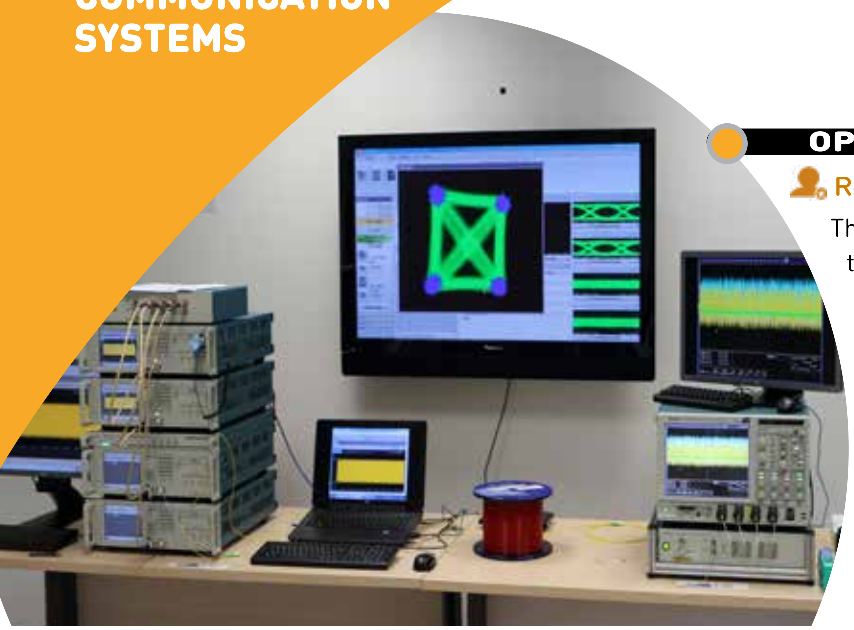
• Widest current measurement range: 100 pA to 10 A
• Capture fast transient effects of spikes with bandwidth up to 200 MHz
• Max sampling rate: 1GSa/s
• Purpose-built low power IoT chip or device characterization

DC power Analyzer and source measure unit

• 20W and 80W power generators
• Measure wide range of current from sub µA to 8 A and voltage in one pass
• Function as current / voltage source and e-load
• Purpose-built for battery drain analysis
• Long term data logging (up to 200 KSa/s, log current drain up to 1000 h, energy consumption measurements (Ah, Wh, Joules, Coulombs)
• Battery emulation mode
• Meter view (output voltage, current and power)
• Scope view (displays output voltage and current as a function of time)
• Data logger view (hours of measurements with a maximum time resolution of 20 µs can be logged internal memory or an external USB)
• CCDF (complementary cumulative distribution function) view (quantify the impact of design changes – hardware, firmware or software- on current flows in your design.
• ARB capability (step, ramp, staircase, sine, pulse, trapezoid, exponential, sequence, user defined; max size of 64000 waveform points, max bandwidth of 100 KHz, two quadrant operation)

SIGMACOM

OPTICAL COMMUNICATION SYSTEMS



Measurements of an optical transmission

OPTICAL TELECOM TESTBED

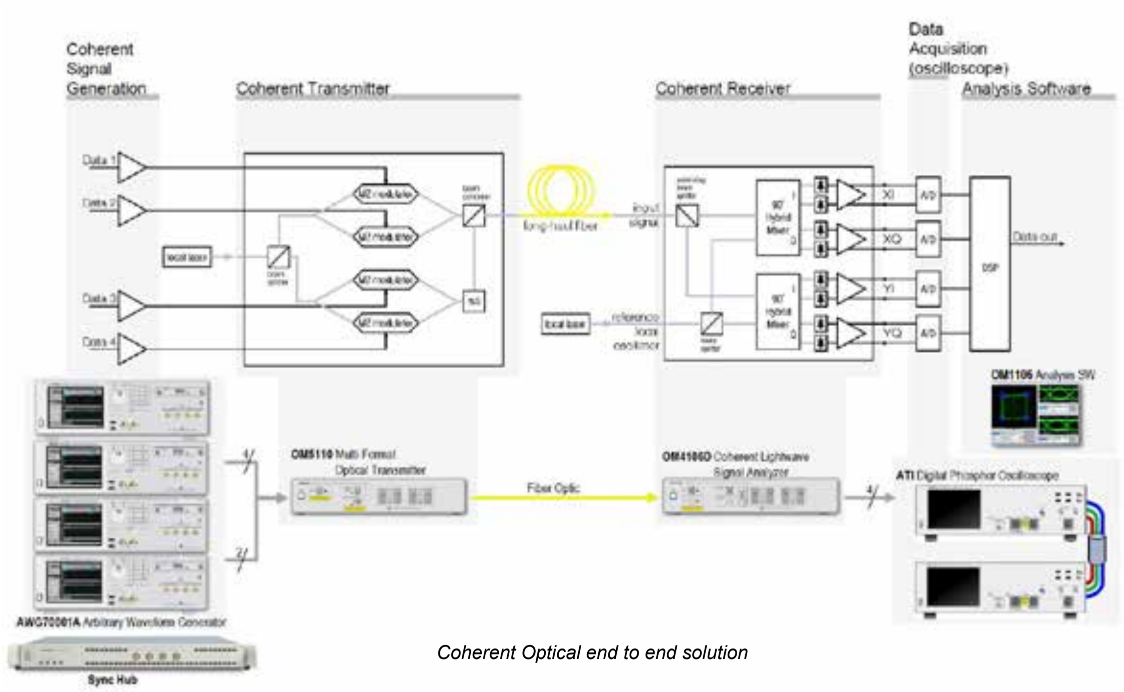
Rédha Kassi

This optical telecom testbed allows the exploration of technologies such as photonic space division multiplexing while combining coherent optical technology with wireless transmissions up to THz to support the insatiable demand for ever increasing data transmission capacity worldwide. This instrumentation test bench is a complex chain of very high speed coherent optical transmission systems that can generate, acquire and analyze the data transmission quality of optical communications systems that allow the combination of THz radio technologies. A software suite allows the instrumentation to be controlled and the transmission quality to be quantified in terms of BER, EVM and eye diagrams for different modulation standards at data rates up to 512 Gb/s. This bench, located at the IRCICA, is managed by the PHLAM and shared with the IEMN.

The instruments constituting the telecom testbed may also be used individually in experiments with high requirements, such as synchronized acquisition of fast electrical or optical signals (group of sampling oscilloscopes with 4 ATI ports at 70 GHz or 8 ports at 33 GHz); or the generation of complex electrical or optical signals (group of arbitrary function generators with 8 ports at 22 GHz).

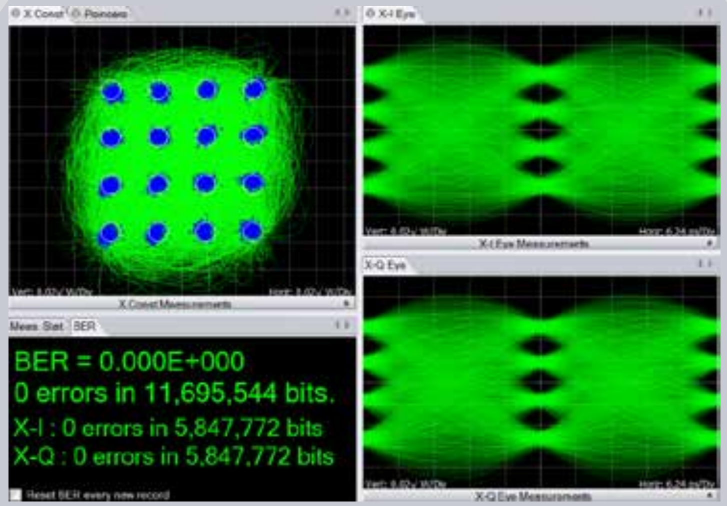
→ APPLICATIONS

- Transmission quality (EVM, Q, BER) in optical fiber on optical carrier ;
- Transmission quality (EVM, Q, BER) in free-space on THz carrier ;
- Coherent modulation formats (N-QAM, 32 Gbaud) ;
- Digital signal processing (DSP, MIMO 4x4) ;
- Shaping and detection of fast optical signals (33 GHz) ;
- Spatial and modal multiplexing.
- Space-time coding
- Implementation of very high speed transmissions on new generation slightly multimode optical fibres using spatial multiplexing such as modal multiplexing to characterise crosstalk.
- Coupling coherent optics technology to wireless transceiver technology in the terahertz range.



Coherent Optical end to end solution

• 32 Gbaud 16-QAM optical signal
• EVM = 6.5%



→ HIGHLIGHTS

This transceiver test bench has several instruments:

- Arbitrary Wave Generator (BW up to 15 GHz, 10 bit vertical resolution, DAC 50 Gs/s)
- Instruments for AWG synchronisation (random jitter 315 fs)
- Multi-format coherent optical transmitter and receiver (46 GBaud BPSK, PM-16 QAM, C or L band lasers or external, Ix, Qx, Iy and Qy base band signals)
- Real time oscilloscope (70 GHz, <7 ps rise time, 200 GS/s sample rate, 100fs jitter noise floor, single-ended 62,5 mv to 300 mv)
- Software generation of RF communication standards
- Display constellation diagrams, EVM, phase eye diagrams, Q-factor, Q-plot, BER,...
- Measures Polarization Mode Dispersion (PMD)
- Coherent lightwave signal analyzer software

SIGMACOM
OPTICAL COMMUNICATION SYSTEMS

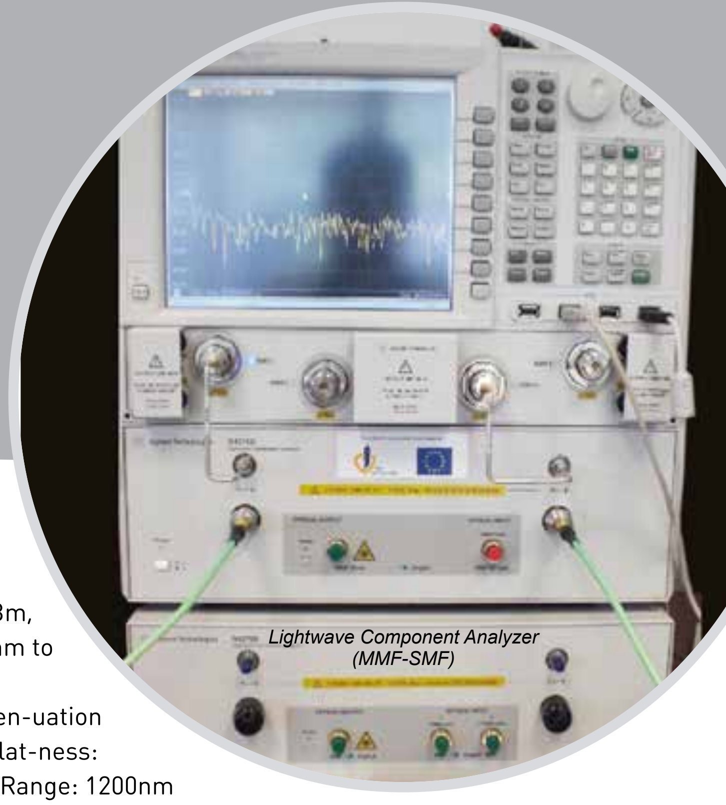
OPTICAL MESUREMENT BENCH

Rédha Kassi

We have specific instruments for the characterization of systems incorporating optical components. We can generate and analyze optical signals to verify the optical performance of fibers, photodiodes and electro-optical components. S-parameter, optical power and reflectometry measurements can be performed. These instruments are complementary to the optical telecom test bench for radio over fiber or the telecom test bench for communications over fiber.

APPLICATIONS

• Fiber radio requires an RF frequency response (from 10 MHz to 26.5 GHz) around an optical wavelength (850 nm, 1550 nm or 1310 nm) in order to accurately characterize an optical transmission chain by measuring the S parameters of electro-optical components (detector diodes, modulators) using a Lightwave Component Analyzer (LCA).
• Basic platform for testing 10 GbE optical and electro-optical components, Fiber Channel FC*8, FC*10, FC*16
• Qualitative analysis of modulated signals with an electrical spectrum analyzer or oscilloscope.



HIGHLIGHTS

Lightwave Measurement System:
• Variable Optical Attenuator Module for Multimode Fiber Applica-tions (50 µm and 62,5 µm, input power level up to 27 dBm, at-tenuation range: 0dB to 60 dB, wide wavelength range: 700 nm to 1400 nm)
• Variable Optical Attenuator Module with Angled Interface (atten-uation Range: 0dB to 60dB, High Input Power Level: 2W, Wavelength Flat-ness: < 0.05dB, High Attenuation Accuracy < 0.1dB, Wide Wavelength Range: 1200nm to 1700nm (SMF))
• Reference transmitter for Optical Receiver Stress Test (10MHz to 33 GHz typical electro-optical bandwidth, Optical wavelength1310 nm & 1550 nm Single Mode Fiber, Operational data rate 622 Mb/s to 14.2 Gb/s, Rise and fall times < 15 ps)
• Reference Receiver is an O/E converter optimized for transceiv-er loop-back test (Opto-electrical modulation bandwidth DC to 9.3 GHz (typical), Wavelength range 750 nm to 1650 nm, MMF 62.5 µm/125 µm, Op-erational data rate 622 Mb/s to 12.5 Gb/s, Rise and fall times < 35 ps)
• General Purpose Optical Power Head (Wavelength range 800 nm to 1700 nm, power range 40 dBm to -90 dBm, Low polarization dependence)

Lightwave Component Analyzer:
• Operation frequency range 10 MHz to 26.5 GHz
• Transmitter and receiver specifications MMF
• Optical input 62.5 µm
• Optical output 50 µm
• Input wavelength range 750 nm to 1650 nm
• Output wavelength 850 nm
• Transmitter and receiver specifications SMF
• Optical input/output 9 µm single mode angled
• Input wavelength range 1250 nm to 1640 nm
• Output wavelength 1310 nm and 1550 nm

C2EM

The C2EM service is devoted to both Electromagnetic Compatibility (EMC) measurements and, in generic words, to Electromagnetic (EM) characterization in a wide frequency range (few Hz to 20 GHz) with dedicated equipments and instrumentation.
EMC studies / EM interactions between electronic/electrical equipments and their functioning environment. The aim is to ensure that such equipments will operate correctly both with a sufficient level of EM immunity against external sources and without generating EM emissions susceptible to disturb communication systems.
EM characterization concerns all EM measurements (e.g antennas characterization) requiring a standard 'quite' site and the on-site measurements such as the telecom propagation channels characterization.
The service gathers in a same area of 180 m2 various measurement's chambers and cells, each of them attempting to represent a certain EM environment required for research and EMC testings.

1. Radio Frequency Anechoic Chamber (RF-AC): 6m x 6m x 2.8 m
2. Transverse ElectroMagnetic Cell (TEM-cell) : 2m x 1m x 0.6 m
3. Mode Stirrer Reverberation Chamber (MSRC), 5.6m x .4m x 2.8 m

Head of C2EM
P. Laly

- **EMC chambers and cells** IV. 1-2
  → Pierre Laly
  Radio frequency anechoic chamber (RF-AC)
  Transverse electromagnetic cell (TEM-cell)
- **EM site characterization**, IV. 3-4
  → Pierre Laly
  Mode stirrer reverberation chamber (MSRC)
  Transfer impedance (ZT) bench test
- **Electronic prototype study and realization** IV. 5-6
  → Pierre Laly
  Massive multiple input multiple output system acquisition (MAMIMOSA)

c2em-contact@iemn.fr

C2EM

EMC CHAMBERS AND CELLS

RADIO FREQUENCY ANECHOIC CHAMBER (RFAC)

Pierre Laly

The actual RFAC consists in a 137m3 shielded room whose internal walls are covered with radio-frequency (RF) absorbing foams. It is intended to represent a standard free space propagation environment with known properties. The geometrical dimensions and the electromagnetic characteristics of the absorbing materials limit the bandwidth of the chamber, in particular in the lower frequency range. This chamber is devoted to ElectroMagnetic Compatibility (EMC) testing and to all electromagnetic (EM) characterization requiring quiet EM environment (e.g. for antennas radiation pattern and gain assessments). According to the application, the frequency range is from 30 MHz up to 18 GHz. For EMC purpose, the chamber meets the basic EMC requirements in terms of field uniformity and site attenuation for a 3 meters testing. Therefore, it is quite usable for EMC pre-compliance testing according to European and to some military and aeronautic EMC standards, for radiated immunity and emission.

To ensure its functioning, the following instrumentation is available:

• Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
• VNA RS ZVA 24 (10 MHz -24 GHz)
• Synthesized RF generator (10 MHz -20 GHz, 10 dBm)
• Turntable table
• Broad band antennas (30MHz -18 GHz) : bi-conical, log-periodic, double ridge
• Broad band amplifiers: 30W (1 MHz-1 GHz), 25W (800MHz-4 GHz)
• Broad band Electric field probe (100 kHz-6 GHz), E-field max 200V/m

→ **ADVANTAGES & LIMITATIONS**

- (+) High EM isolation against EM disturbances (90 dB min @1GHz),
- (+) Standard plane waves environment
- (−) Low frequency limitation for antennas characterization (Fmin=200 MHz),
- (−) Size limitation, e.g. 5 m distance max available for RFID tags characterization
- (−) Height scanning limited (1.2m to 1.80m) for EMC testing

→ **MAIN EMC APPLICATIONS**

• Radiated emissions and radiated immunity characterisation of electronic/electric equipments,
• Shielding effectiveness measurement of flat materials,
• Experimental validation of EMC numerical models

→ **OTHER APPLICATIONS**

• Characterisation of RFID (Radio Frequency Identification) tags performance (860 -950 MHz),
• Characterisation of antennas arrays (radiation pattern, gain, antenna factor),
• Experimental validation of antennas numerical models

TRANSVERSE ELECTROMAGNETIC CELL (TEM CELL)

Pierre Laly

The TEM cell is a shielded strip line like a tapered transmission line (TL) of rectangular cross-section with a flat inner conductor (septum). It is intended for establishing standard uniform EM field in the low frequency range (f<30 MHz) where RF-AC and MSRC are not functioning. The cell geometry is designed to give a 50 Ω characteristic impedance for the TL. Within the working volume (under the septum), the fields are those of a plane wave as far as the fundamental TEM mode remains dominant. The cell operates from DC to an upper frequency such that high order modes excited in the cell remain negligible compared to the TEM mode. Therefore, the maximum frequency of measurement depends on the dimensions of the cross-section of the cell and of the size of the device under test (DUT).
The TEM cell constitutes a powerful experimental tool which enables various experiments in EMC domain for the study of EM fields coupling phenomenon to cables and PCB traces.

To ensure its functioning, the following instrumentation is available:

• Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
• VNA Agilent E8733 (30 kHz-6GHz)
• Synthesized RF generator (10 kHz -1 GHz, 13 dBm)

→ **MAIN EMC APPLICATIONS**

• Measurement of radiated emissions and susceptibility of embedded electronic devices,
• Characterisation of the EMC behaviour of partially shielded cables for aeronautic applications,
• Calibration of electrically small size E and H-field probes,
• Study and validation of numerical models of the EM coupling to cables

→ **Complementary with other techniques present at IEMN :** Pole SigmaCom for HF RFID tags characterization

→ **ADVANTAGES & LIMITATIONS**

- (+) Standard plane wave environment at low frequency
- (−) High frequency limitation (e.g, 100 MHz for our TEM-c)

MODE STIRRER REVERBERATION CHAMBER (MSRC)

Pierre Laly

In contrast with the RFAC (Radio Frequency Anechoic Chamber), the MSRC is a very complex of high Q-factor measurement tool intended to simulate realistic EM environments such as that encountered by electronic devices in large screened boxes, aircrafts, automotive vehicles, etc. The MSRC consists in an electrically large chamber with highly conducting walls . The lowest working frequency (LWF) of a MSRC is such that its wavelength is smaller than the smallest dimension of the chamber. A MSRC is equipped with a metallic paddle (the stirrer) which can be moved by means of a continuous or stepped motor. Physically, a MSRC acts as an oversized cavity in which a high number of resonant modes can be excited around any frequency higher than the LWF. Thus, the rotation of the stirrer allows achieving different boundary conditions, and consequently, it generates a complex EM environment with randomly distributed field in amplitude, phase and polarisation. However, far from the wall > than a quater of wave length, the fields remain in average, statistically uniform and isotropic within the chamber. Consequently, all the physical quantities (e.g. E-field, power, etc) are measured as averaged values of sets of data collected when the stirrer is moving. Uniformity and isotropy properties are checked through a normalized calibration procedure based on the standard deviation (STD) of E field samples acquired at different locations in the chamber. Due to the high Q-factor, high field level can be achieved with low input power

To ensure its functioning, the following instrumentation is available:

- Spectrum Analyzer RS FSV30 (10 Hz -30 GHz)
- VNA RS ZVA 24 (10 MHz -24 GHz)
- Synthesized RF generator (10 MHz -20 GHz, 10 dBm)
- Broad band antennas (30MHz -18 GHz) : log-periodic, double ridge
- Broad band electric field probe (100kHz – 6 GHz)

→ MAIN EMC APPLICATIONS

- Measurement of radiated emissions and susceptibility of electric/electronic equipments
- Characterisation of the shielding effectiveness of flat materials, shielded cables and connectors

→ OTHER APPLICATIONS

- Characterisation of RFID (Radio Frequency Identification) tags radiation efficiency
- Emulation of telecom multipath propagation channel
- Emulation of diffuse environment for assessing human body specific absorption rate

→ Complementary with other techniques present at IEMN : Pole SigmaCom, CHOPE

→ MSRC is an alternative EMC testing site to RFAC

→ ADVANTAGES & LIMITATIONS

- (+) Low cost equipment v.s RFAC
- (+) High Q (quality) factor environment enabling high level of E- field inside the chamber with low power amplifier.
- (+) Low insertion loos v.s free space and RFAC
- (+) Spatial homogeneity of the field over the working volume
- (+) No need of changing antennas polarization and using turntable table when performing EMC testing.
- (+) Capability for measuring the total isotropic power radiated by an equipment
- (–) Loos of antennas directivity,
- (–) Need of rotating the stirrer during any measurement

TRANSFER IMPEDANCE (ZT) BENCH TEST

Pierre Laly

In EMC problems, cables play an important role both in the radiation and in the susceptibility phenomenon of the equipments they interconnect. When the cables are shielded, their EMC performance is generally evaluated, (depending on the field of application), either by a measure of the shielding effectiveness or by measuring a well-known parameter: the transfer impedance denoted Zt.
The IEMN staff TELICE is pioneer in studying Zt measurement's methods. The Zt bench test used in C2EM service as been studied and constructed according to IEC (International Electrotechnic Commission) requirements.

→ APPLICATIONS

- Transfer impedance and shielding effectiveness measurement of shielded cables and connectors

→ ADVANTAGES & LIMITATIONS

- (+) Wide frequency range (few kHz to 2 GHz),
- (+) High sensitivity (e.g. 0.1μΩ/m) in low frequency range (few kHz to 30 MHz)
- (–) Low frequency sampling above 100 MHz

C2EM

ELECTRONIC PROTOTYPE STUDY AND REALIZATION

MASSIVE MULTIPLE INPUT MULTIPLE OUTPUT SYSTEM ACQUISITION (MAMIMOSA)

Pierre Laly

Channel sounder MIMOSA (Multiple Input Multiple Output System Acquisition) real-time MIMO (16Tx, 16Rx) and Massive MIMO (64Tx, 16Rx) channel analyzer. The actual model can operate from 1.3 GHz until 10 GHz. Two frequencies are available for now, 1.35GHz and 5.89GHz with 80MHz bandwidth. The sounder is based on numerical processing by FPGA coupled at a computer for data recording.

MaMIMOSA is based on space-frequency division multiplexing, giving a large possibility of tone and antenna allocation. This channel sounder belongs to the new generation of software radio design based systems. The architecture of proposed approach was designed with the highest flexibility thus opening a wide range of applications. In addition, the channel sounder has been built to avoid heavy post-processing: i) the Tx signal is pre-processed to include the non-linearity of the Tx and Rx chain, ii) Thanks to the high sampling frequency of the FPGA, a real digital baseband signal is transmitted to the RF chain avoiding I/Q impairment, iii) the output file gives the 4.Ntx.Nrx transfer function in a versatile binary format. Finally, the power consumption of the sounder is low and can be powered with a 24 V battery with a 8 hours autonomous.

→ **MAIN APPLICATIONS**

- Real-time propagation channels characterization in indoor,
- Real-time propagation channels characterization in mobility context (such as vehicular, aerial, ship, etc.),

→ **OTHER APPLICATIONS**

- Cybersecurity,
- Staff fall detection in a confined environment (e.g. ship)
- Localization in a complex environment (e.g. forest)
- Test of new communications techniques (5G, 6G, etc

→ **Complementary with other techniques present at IEMN : Pole SigmaCom**

→ **ADVANTAGES & LIMITATIONS**

- ⊕ Real Time
- ⊕ Flexibility
- ⊕ Low post-processing
- ⊕ "Mobile"
- ⊕ New filters for new frequencies,
- ⊕ Mobile but need to adapt to the new environment.

Signal in Baseband		Radio Frequency	
• Multiplex • Used sub carrier • Outputs • N subcarrier / output • Delta frequency • Symbol duration	IFDM 6560 8 820 97.7 kHz 81.92 µs	• Frequencies • Bandwidth • NTx (switched mode) • Power / Tx • NRx • AGC Dynamic	1.35 GHz / 5,89GHz 80 MHz 8 (16 ou 64) 1 to 100 mW 16 63 dB
Sounding characteristics			
• CIR* • Max CIR*	10.24 µs 50 M	- CIR Resolution - Matrix H(16,16,1024) - Matrix H(16,64,1024)	12.5 ns 1 Mo 4 Mo

Manufacturer: IEMN/Telice/Univ. Gent

@

Sylvie GODEY
Coordinator
sylvie.godey@iemn.fr
✆ 03 20 19 78 64 / Office 034

PCP-SPM

IEMN Central Lab
pcp-contact@iemn.fr

Maxime BERTHE
maxime.berthe@iemn.fr ✆ 03 20 19 78 63 / Office 036

Sylvie GODEY
sylvie.godey@iemn.fr ✆ 03 20 19 78 64 / Office 034

Louis THOMAS
louis.thomas@iemn.fr ✆ 03 20 19 78 63 / Office 036

CHOP

IEMN Central Lab
chop-contact@iemn.fr

Sophie ELIET
sophie.eliet@iemn.fr ✆ 03 20 19 79 30 / Office 277

Sylvie LEPILLIET
sylvie.lepilliet@iemn.fr ✆ 03 20 19 78 45 / Office 277

Etienne OKADA
etienne.okada@iemn.fr ✆ 03 20 19 79 30 / Office 277

Ayman RHELLAB
ayman.rhellab@iemn.fr ✆ 03 20 19 79 30 / Office 277

SIGMACOM

IRCICA
sigma-contact@iemn.fr

Rédha KASSI
redha.kassi@iemn.fr ✆ 03 62 53 16 04

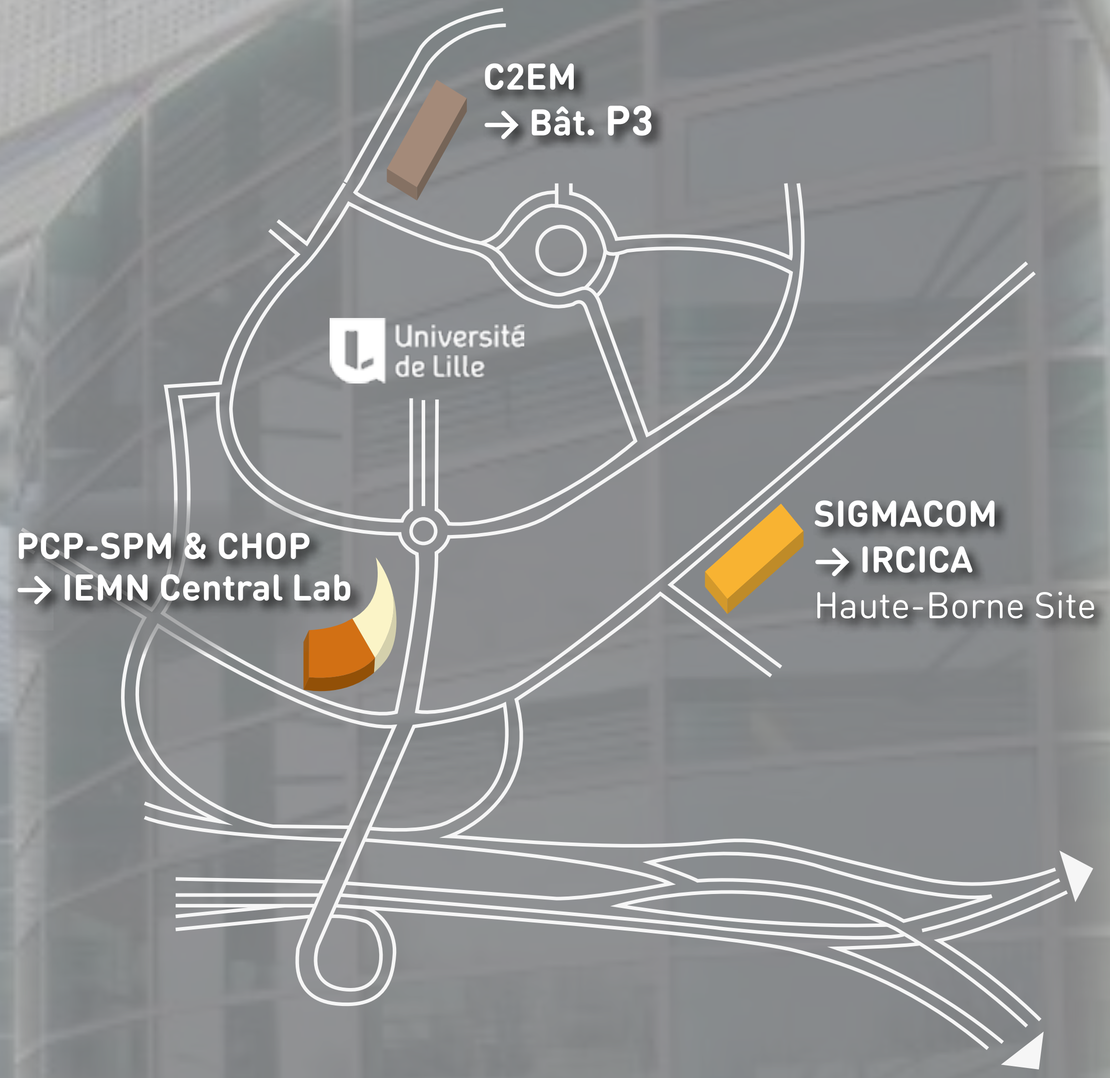
David DELCROIX
david.delcroix@iemn.fr ✆ 03 62 53 16 04

C2EM

University of Lille - Building P3
C2em-contact@iemn.fr

Pierre LALY
pierre.laly@iemn.fr ✆ 03 20 33 59 59 / Office 002

Access to the PCPM Platform is regulated.
Please contact the head of each PCMP Service to request access.



pcmp-contact@iemn.fr

IEMN / PCMP

iemn
Institute of Electronics, Microelectronics and Nanotechnology

IEMN - Laboratoire Central
UMR CNRS 8520
Cité Scientifique
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 19 79 79
Fax: +33 (0)3 20 19 78 78

IEMN - Antenne Université de Lille
Cité Scientifique, Bât. P.3 & P.5
Avenue Poincaré BP 60069
59652 Villeneuve d'Ascq Cedex - France
Phone: +33 (0)3 20 43 67 06
Fax: +33 (0)3 20 43 65 23

IEMN - Antenne OAE
Université Polytechnique Hauts-De-France
59313 Valenciennes Cedex 9 - France
Phone: +33 (0)3 27 51 12 39
Fax: +33 (0)3 27 51 11 89

IEMN - Antenne CCHB
CAMPUS Haute-Borne CNRS IRCICA-IRI-RMN
Parc Scientifique de la Haute Borne
50 Avenue Halley BP 70478
59658 Villeneuve d'Ascq - France
Phone: +33 (0)3 62 53 15 00

IEMN - Antenne JUNIA
41, Boulevard Vauban
59046 Lille Cedex - France
Phone: +33 (0)3 20 30 40 50
Fax: +33 (0)3 20 30 40 51

https://www.iemn.fr
pcmp-contact@iemn.fr

iemn
Institute of Electronics, Microelectronics and Nanotechnology
UMR CNRS 8520