FIRST-TF General Assembly, October 5, 2022

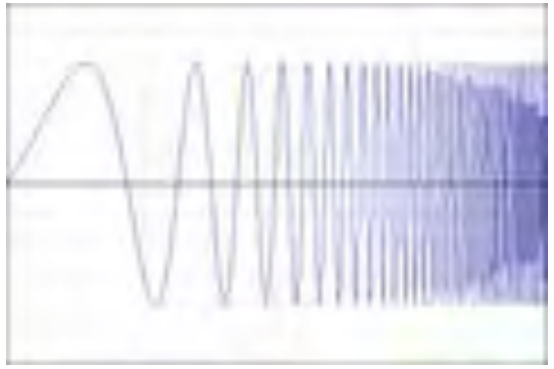
Oscillator IMP

Recherche et équipement (Enrico)

Plateforme au service des utilisateurs (Christophe)

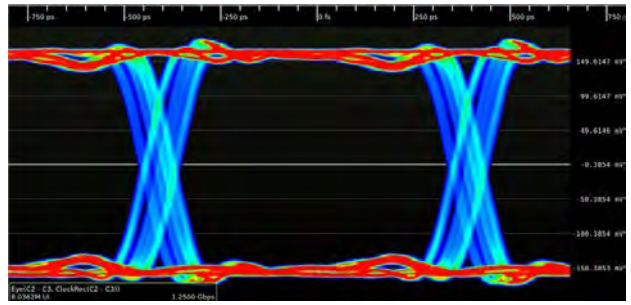
Why phase noise and short-term stability?

- Chirp radar
  - Distance –> frequency
  - Clutter



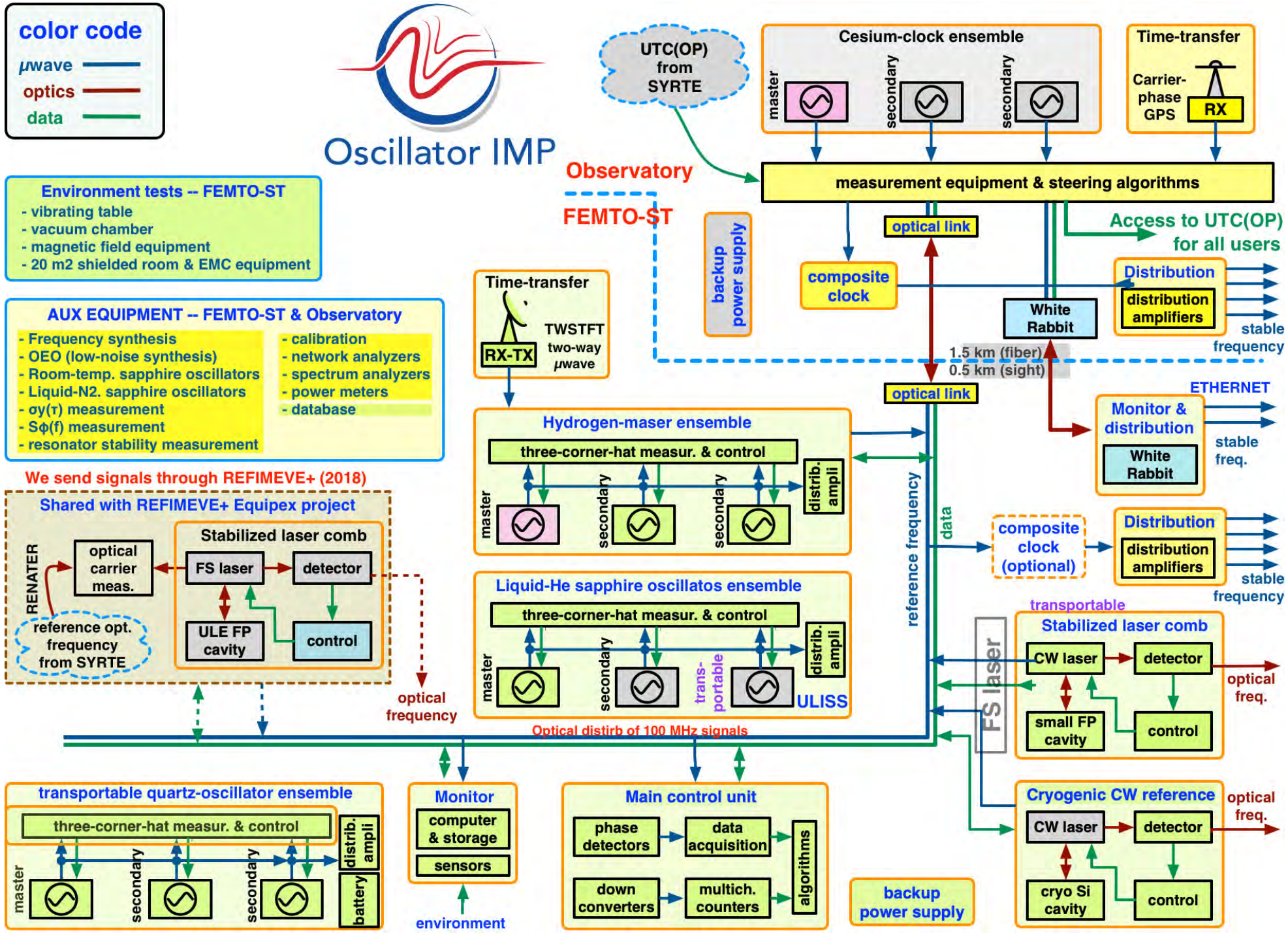
CC-BY Omegatron

- Telecom
  - Time jitter –> bit error



CC-BY Nmesisgeek

- Radio engineering
  - Superetherodyne receiver
    - Noise sidebands –> near channel interference
- Particle accelerators
  - Early kick –> lower intensity
  - Late kick –> lower energy
- Quantum computing
  - Correlation time –> lifetime of qbits
- RF-to-optics frequency multiplication
- VLBI & Geodesy
- Josephson voltage standard (4 fV/Hz)



WPs

Microwave photonics

Microwaves RF

Metrology

Time…

Digital electronics

Atoms

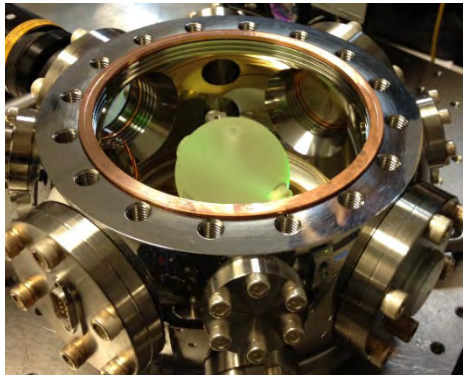
In 10 years

5 ME ANR (incl. FIRST-TF)

8 ME others (mainly Region)

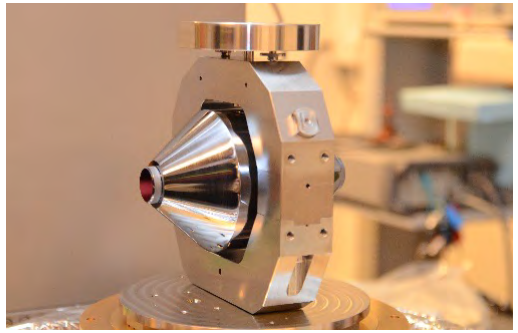
WP Microwave-Photonics

Optical reference



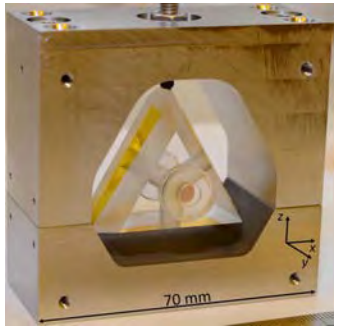
Reliable, stability ≈10^{-15}

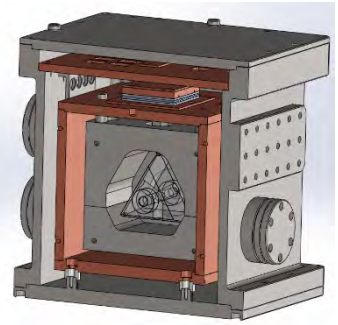
Optical reference



Cryogenic, in progress
$3x10^{-17}$ stability

Optical reference





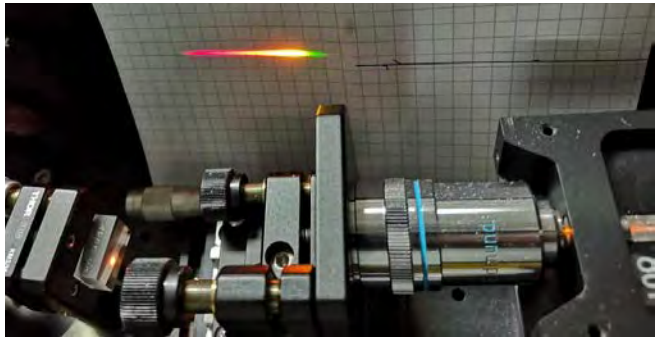
Compact, $7x10^{-15}$ @ 1 s (phase 1)

Digital

Optical link &
Pound-Drever-Hall

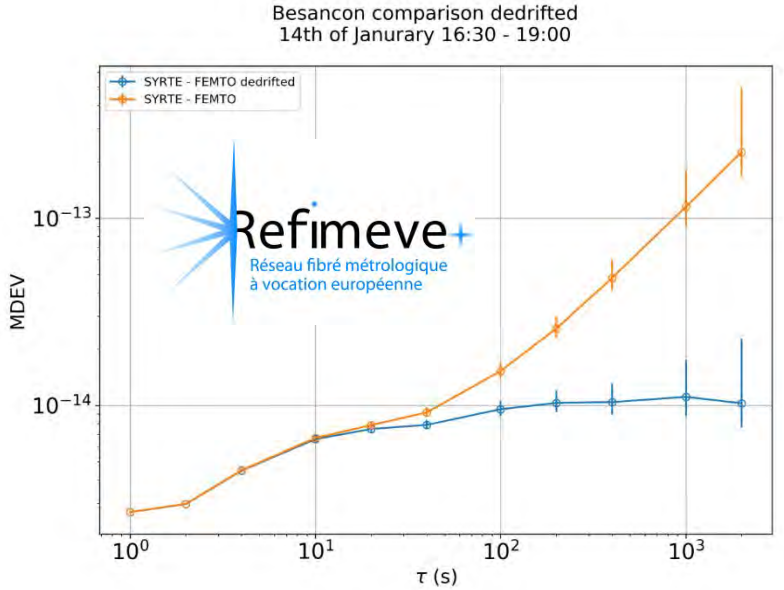
Jonathan

Optical Frequency Combs



Optical to µwave (H-Maser, CSO) comparison ≈10^{-15}
Stability transfer from 1.55 µm to 871 nm (Yb^+ clock laser)

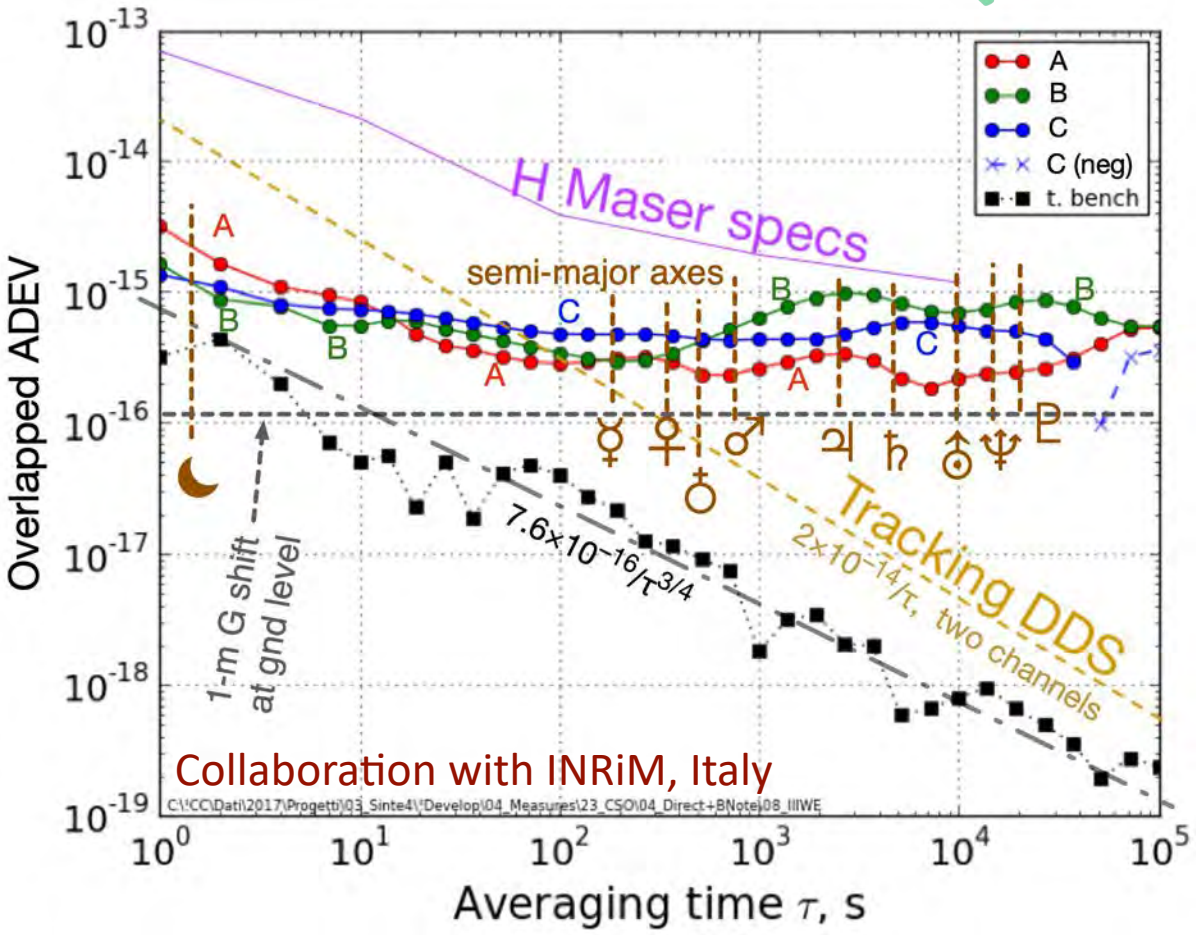
Optical comparison SYRTE – FEMTO-ST via Refimeve+ (Strasbourg node)



WP Microwave & RF

Distribution of 100 MHz & 10 GHz stable signals in the lab
TCH frequency stability measurements (three covariances)

A Probe for the Solar System

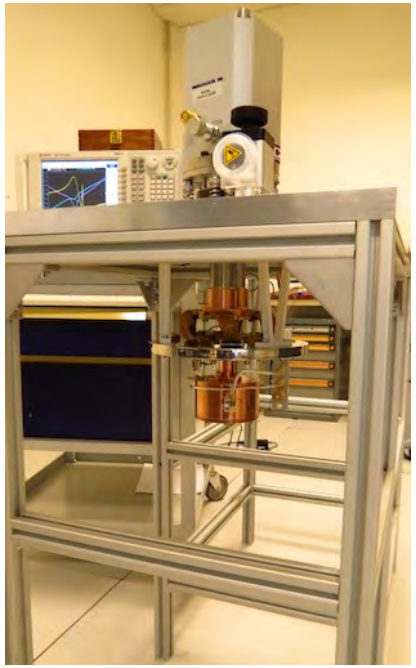


Collaboration with INRiM, Italy

Vincent

ULISS 3G & 70 K CSO for spectral purity (in progress, Region grants)

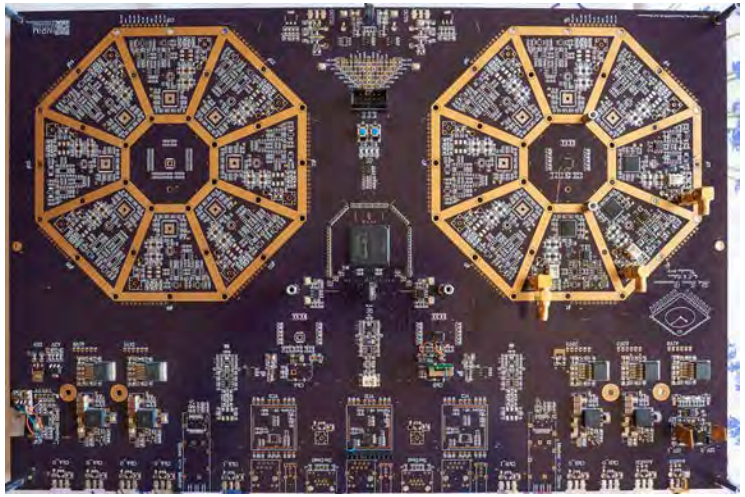
Uliss®
ULTRA-LOW INSTABILITY SIGNAL SOURCE



With FC'Innov:
3 –> USNO/USA, GPS
1 –> NPL/UK
1 –> NTSC/CN
1 –> INRiM

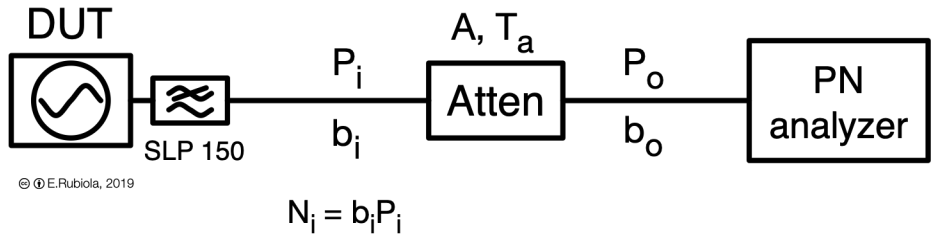
Vincent –> New cryocooler

WP Metrology



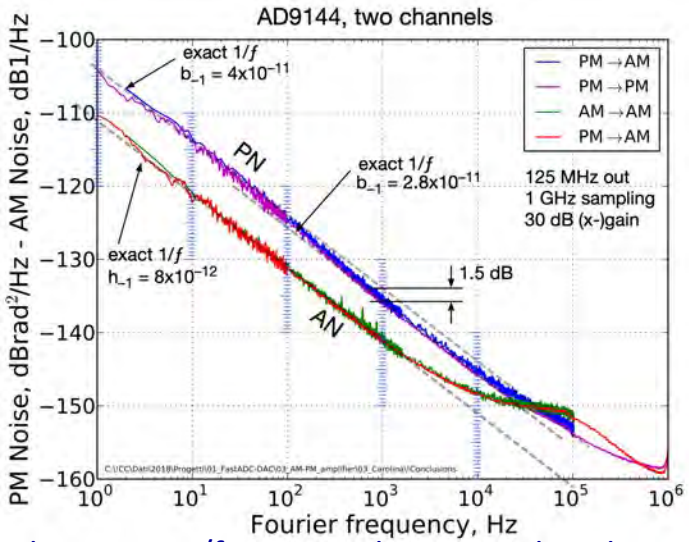
With INRiM, Italy
16-channel
frequency **comparison,**
10^{-14} at 1 s
10^{-15} at 1 s
etc.

Fundamental limits and artifacts in AM/PM test instruments, with
– Rohde Schwarz R&D, München
– Synergy Microwave Corp, NJ, USA
– A. Rus, YO3HHZ, Bucharest

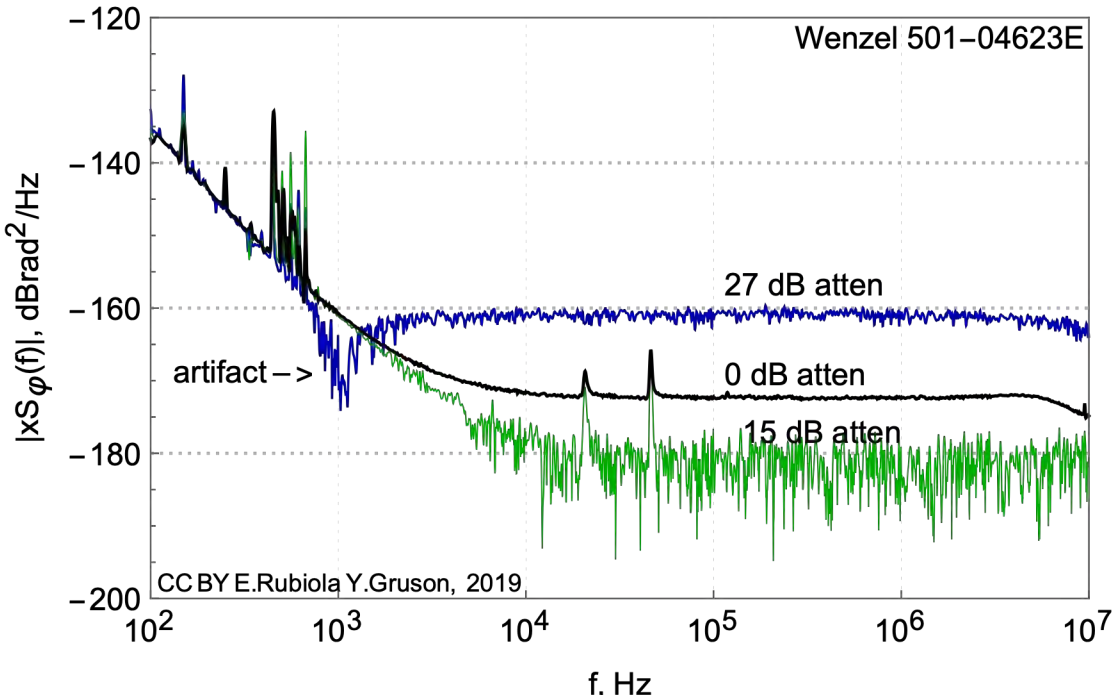


$N_i = b_i P_i$

New methods for AM/PM noise of DACs and DDSs (with INRiM, It)



Also: exact 1/ƒ measured over 7.5 decades



WP Time …

Infrastructure

- Schéma énergétique stabilisé/testé
- Procédures, documentations (accreditation / F.Meyer)

Étalons

- 3 Cs Agilent/Keysight/….
- 3 H Masers T4Sience
- **Absolute accuracy |UTC(OP)B – UTC(OP))| < 10 ns**

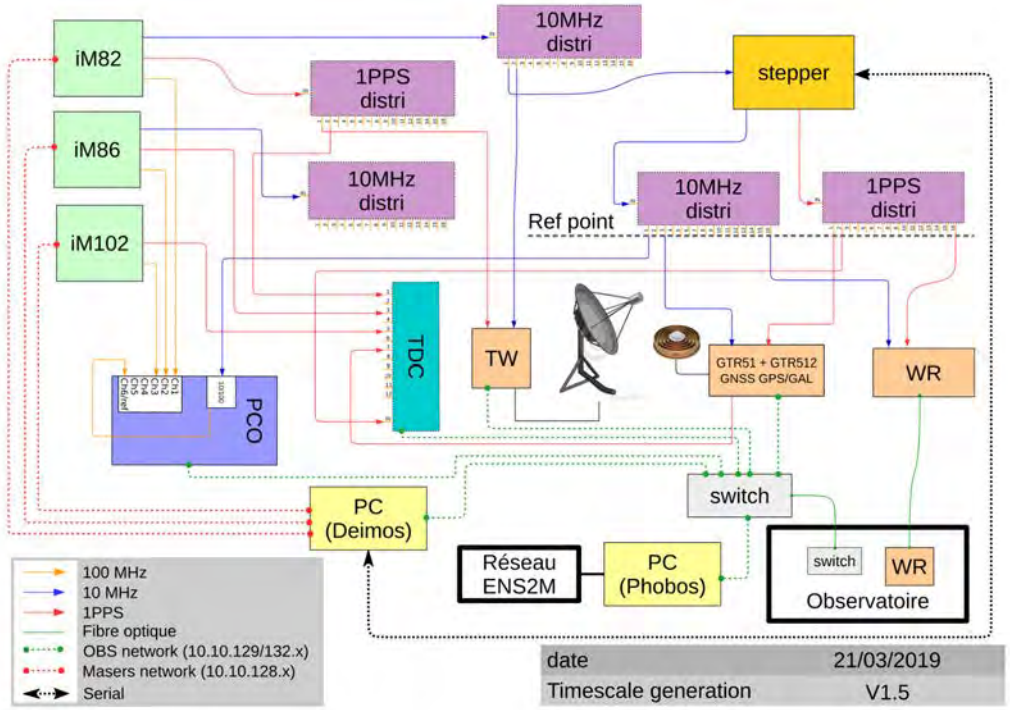
Raccordements :

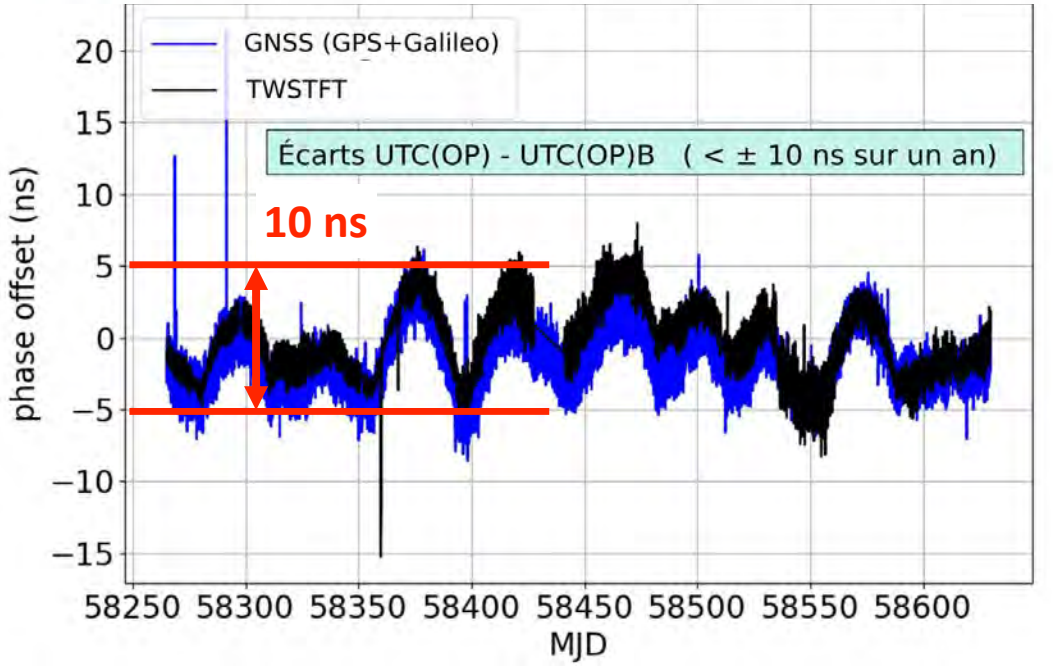
- GNSS (& Galileo) 21 satellites
- GPS rollover (avril 2019)
- TWSTFT opérationnel, personnel formé

Distribution

- RF et Optique OK

Statistics





WP Digital Electronics

- **GitHub** repository https://github.com/oscimp
  - Several with projects including CPU/FPGA co-design …/oscimpDigital and the PN simulator and analysis tools
- **GPS spoofing** demo <—> **FAST-LAB** common lab
  Uses Oscillator IMP facilities (http://jmfriedt.free.fr/misc_gps.pdf).
- **European GNU Radio Days**
  - **Analog Devices staff will attend** (designed the PlutoSDR)
  - Demonstration of the CPU/FPGA co-design PlutoSDR
- Improved PN test set —> GitHub
- White Rabbit (synch) —> training students
- Passive radar <—> OscillatorIMP http://jmfriedt.free.fr/WiFi-based_imaging_for_ground_penetrating_radar_applications.pdf
- Characterization of RF digital frontend (with INRIM http://jmfriedt.free.fr/CarolinaTUFFC_phase-noise-frequency_corrected.pdf)
- **Optical beat note** measurement (stability, PN), two-channel X310 USRP (S. Denis & J. Millo)
- **Optical link stabilization** (B. Marechal) —> Oscillator IMP digital

White Rabbit / Latest news

Capability of campus-size time/frequency transfer over Ethernet demonstrated

- 1 ns pulse accuracy (equiv. 20 cm cable)
- 60 ps pulse jitter (equivalent)
- Any frequency up to 400 MHz with high resolution

Projet LNE/SYRTE, soutien BIPM

(JMF, J. Achkar, E. Meyer F. Meyer)

- TX/RX SDR pour le TWSTFT
- Méthodes SDR
- Note: UTC est fabriqué avec TWSTFT

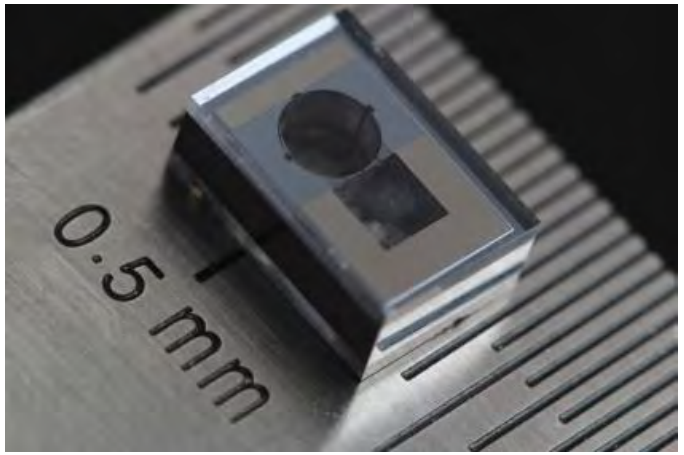
WP atoms Optical oscillators

Anthony

µ-wave oscillators

Miniature Cs CPT clock

R.Boudot



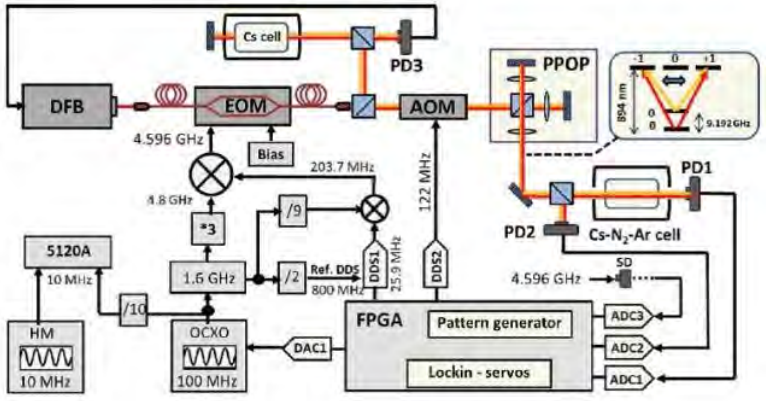
$\sigma_y = 2{,}5 \cdot 10^{-11}\ \tau^{-1/2}$

Volume < 5 L

Operational

earlier results, now improved

High-performance Cs CPT clock



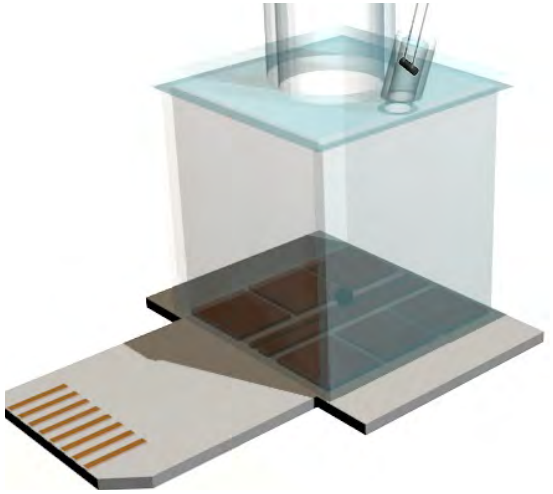
$\sigma_y = 2 \cdot 10^{-13}\ \tau^{-1/2}$

Volume < 200 L

Operational

Compact Yb^+ optical clock

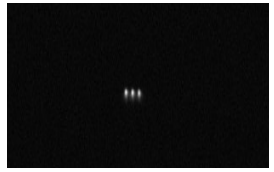
C.Lacroûte



$\sigma_y \rightarrow 10^{-14}\ \tau^{-1/2}$

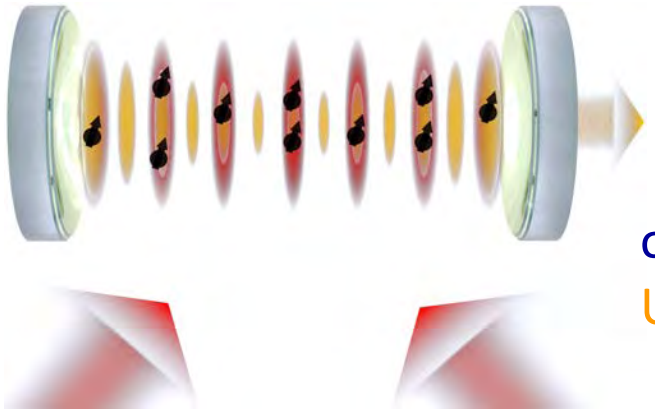
Volume < 500 L

Under development



Ytterbium superradiant laser

M.Delehaye



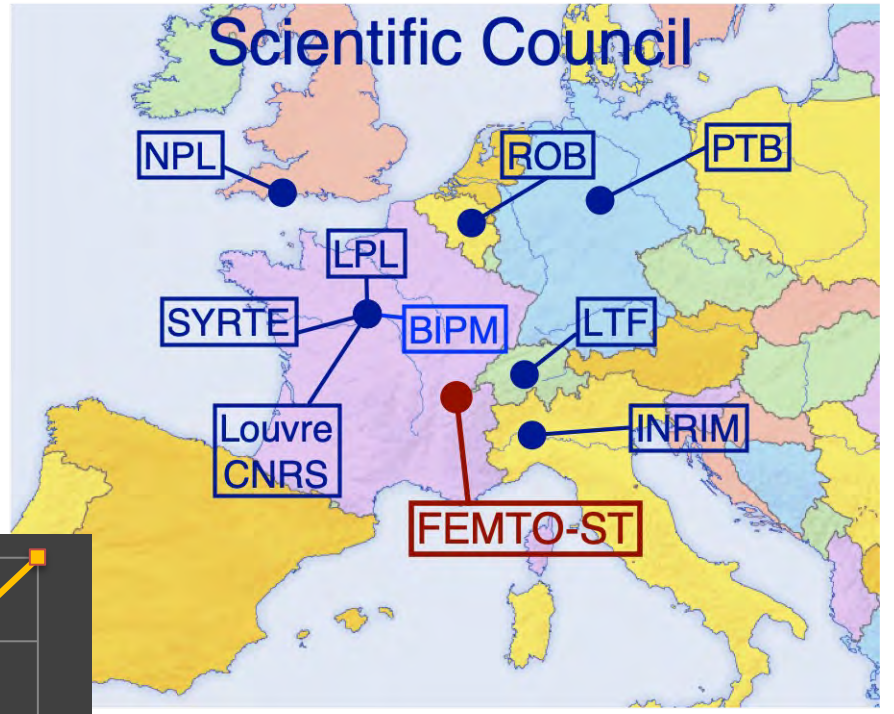
$\sigma_y \rightarrow 10^{-18}\ \tau^{-1/2}$

Under development

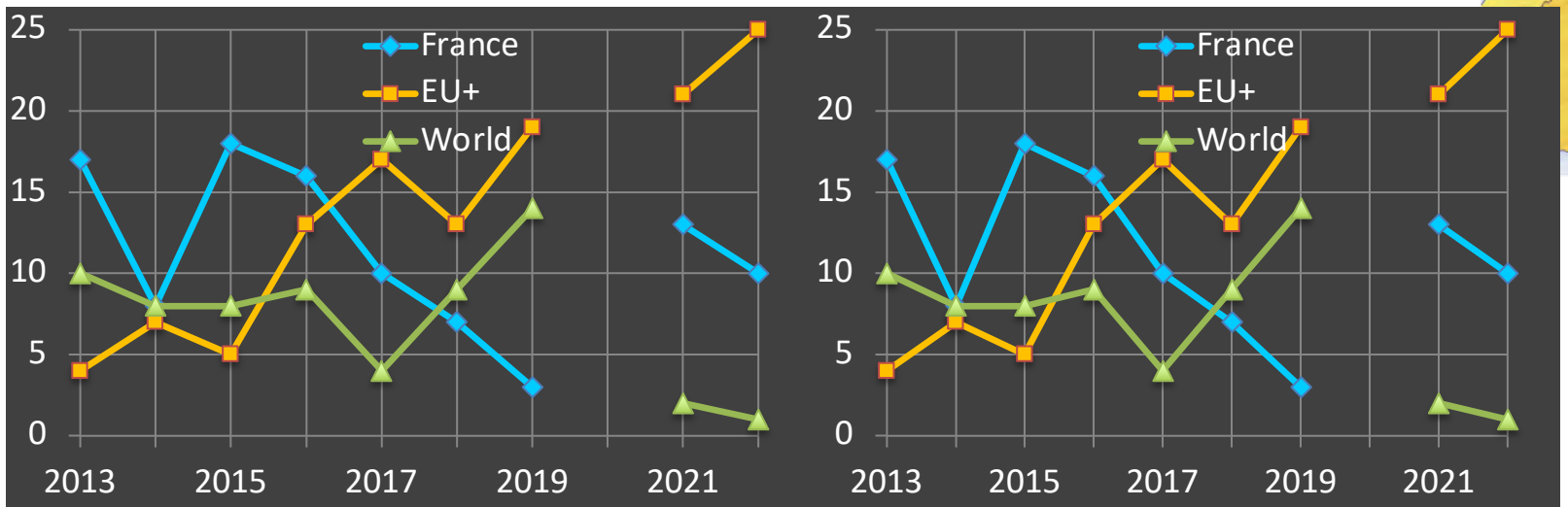
European Frequency & Time Seminar

- Crash course on T&F for newcomers
- Fair competition with the NIST T&F Seminar
- Oscillators, measurement, atomic standards, time scales, and general topics
- Broad target audience
- Balance between academic and applied issues
- Instructors from leading European institutions
- Full week, 23 H plenary lectures and 12 H labs in small groups

EFTS
EUROPEAN FREQUENCY AND TIME SEMINAR



290 people trained



Next
June 26-30, 2023
(unofficial)

Partage entre Oscillator IMP, LNE-LTFB et FC'Innov

Taille des "•" à reviser

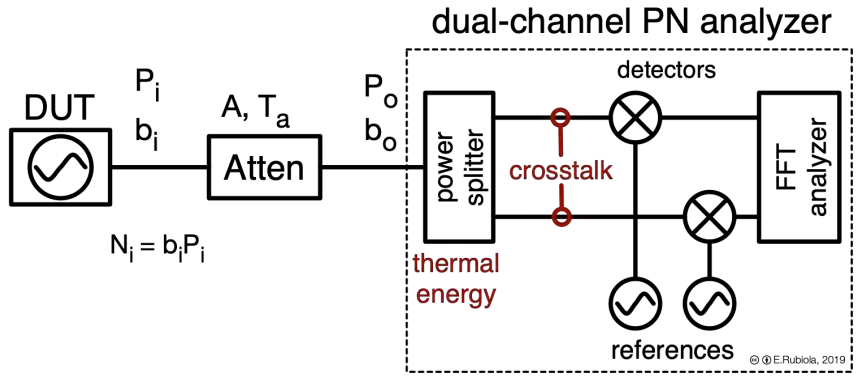
Domaine d'activité	Oscillator IMP	LNE-LTFB	FC'Innov
Recherche	●●●	–	–
Services pour la recherche	●	•	●
Métrologie pour la recherche	●●	•	–
Services pour l'industrie	–	•	●●
Métrologie accreditée	–	•••	–
Designated Institute (LNE, et DI BIPM)	–	●●●	–

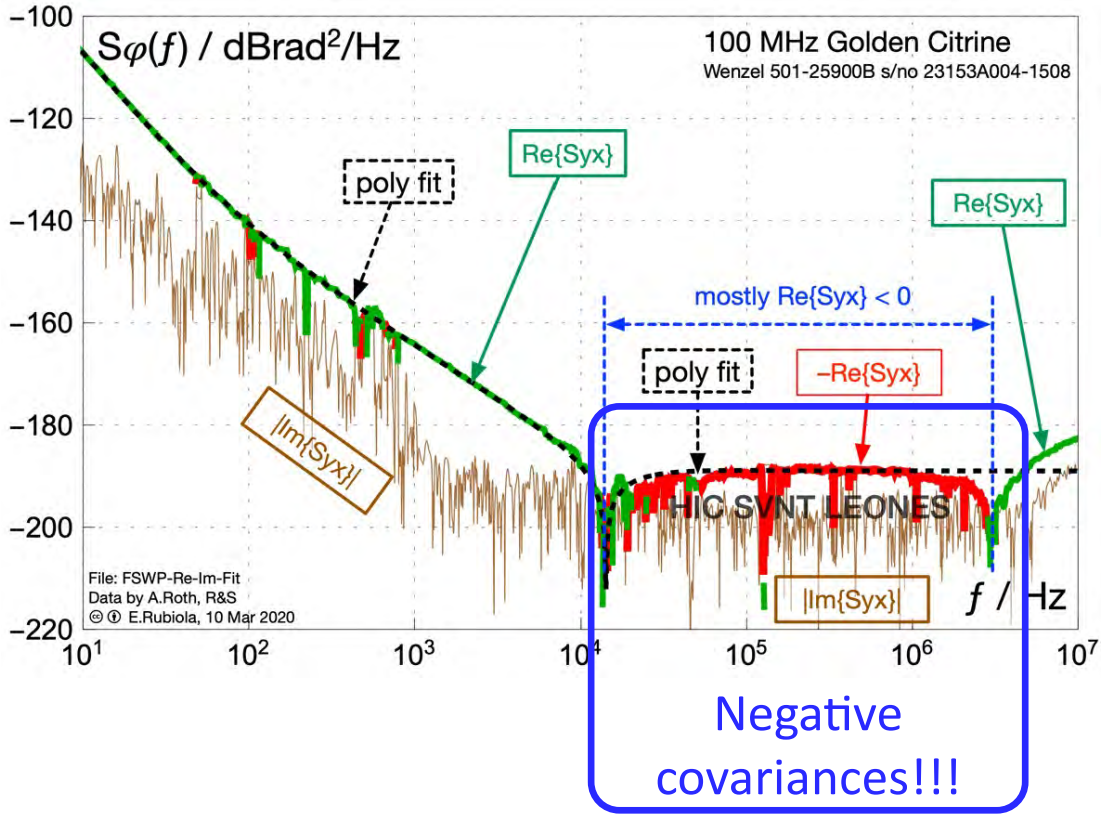
Christophe takes over

I am often bad with time, probably because of my obsession for precision frequency measurements

Metrology / Phase noise analyzers

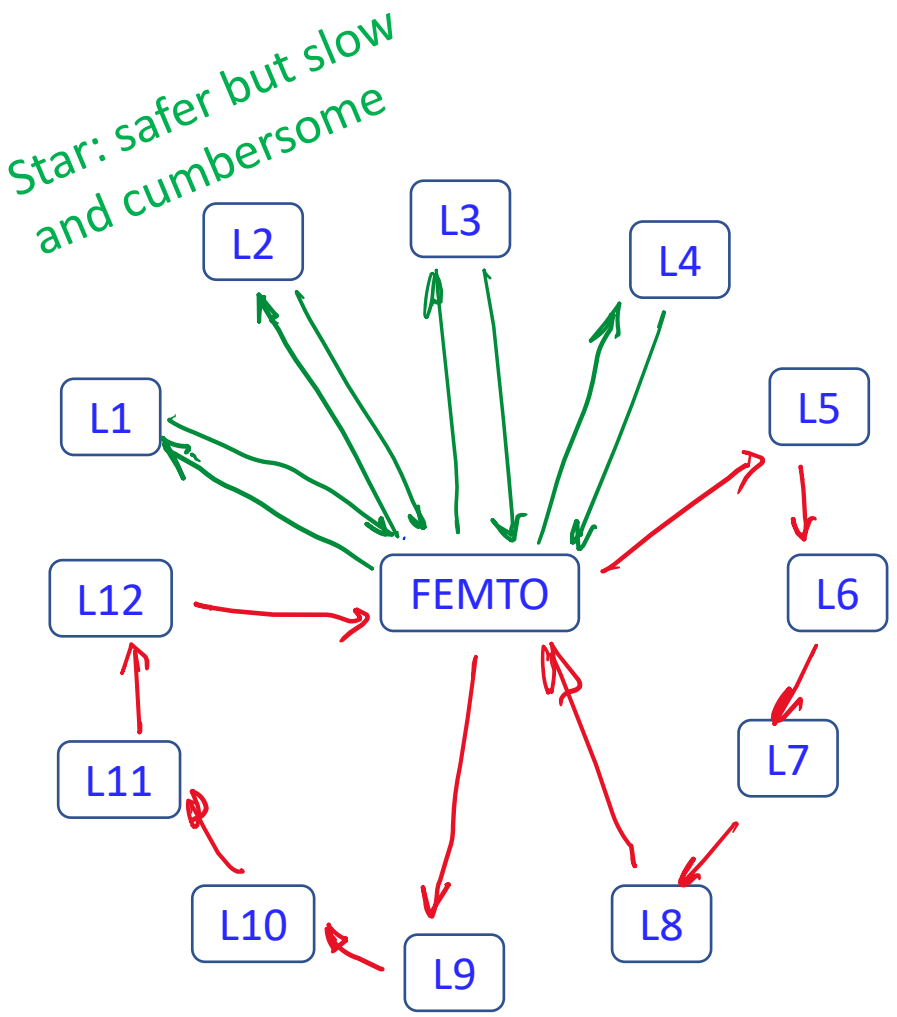
- Awareness of conceptual flaws
  - Knowledge raised by NIST and FEMTO-ST
  - Major brands are concerned
- What happens
  - The problem relates to correlation
  - Crosstalk makes things worse
  - Inconsistent/nonsensical results with lowest-noise oscillators
  - B-Type uncertainty
  - Negative covariances hidden in the “dB” scale





International Comparison

- Travelling standards
  - Selected oscillators
  - Send to Gov labs and industries
  - Compare the results
- Common metrology practice
  - Mass, chemistry, etc.
  - Never done with phase noise
- Joint effort driven by us
  - Ask LNE and EURAMET support
  - Science
  - Prepare future business



Polygon: faster and simpler. Try only after fully consistent closure

Électronique numérique

- Plusieurs projets à base de Software Defined Radio
  - Notammant, la synchronization two-way en collaboration avec le SYRTE
- LabComm ANR Gorgy
- TF –> précision et debit
  - Valeur stratégique pour les labo
- Interdisciplinaire
  - Leurage GPS, distribution du temps précis/sécurisé, capteurs passifs, MEMS, radar passif, microbalances, communications satellite, glacéologie…
- Difficulté majeure
  - JMF est seul (départy de PYB)
  - Pérennisation IR (G.G-M)

Collaboration avec INRiM/IT

- Time Processor
  - Monitoring d'horloge le plus performant au monde
- Portage de techniques optiques de frequency-lock vers le microondes
  - 10^3 leverage effect
- Méthodes de mesure du bruit
  - ADCs/DACs

Plateforme Oscillator IMP

Christophe Fluhr – FEMTO Engineering

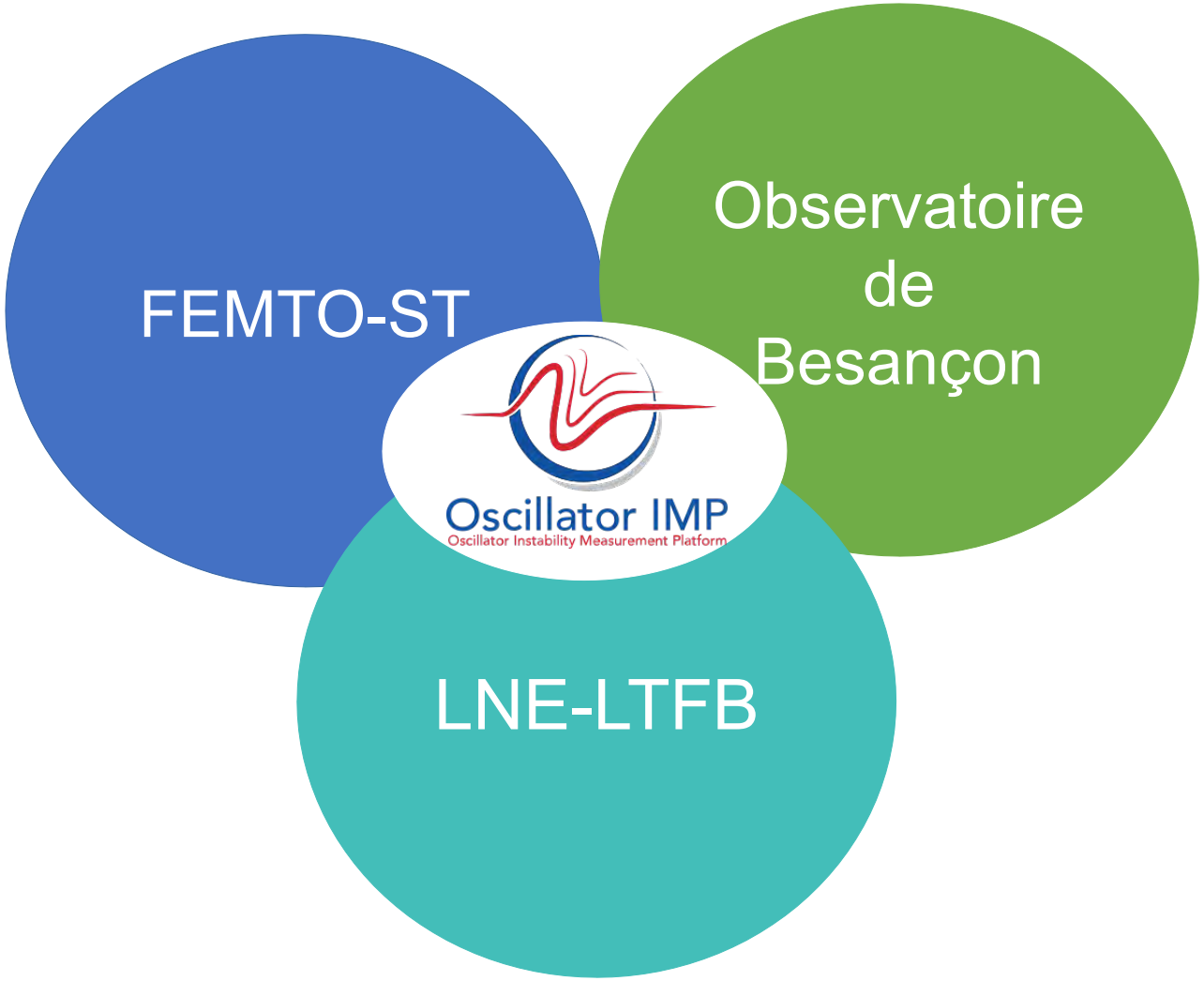
Assemblée Générale LabEx First-TF
Besançon 5 octobre 2022

Etude de marché

Tematys
Exploration of photonics markets

- L'organisation de la plateforme (accés, tarifs, domaines expertises…) n'est pas suffisament claire.
- Déficit d'informations sur la plateforme surtout du côté des indutriels.
- Trop d'informations avec une multiplication des sites webs rendant le structure incompréhensible (ltfb.fr, uliss-st.fr, femto-engineerging.fr, oscillator-imp.com).
- Taille très limitée du marché des services accrédités.

Organisation



FEMTO Engineering

Effectif 20 salariés (docteurs ingénieurs)

Produits d'exploitation 2 M€

Statut Fondation FC'INNOV

Nom commercial FEMTO Engineering

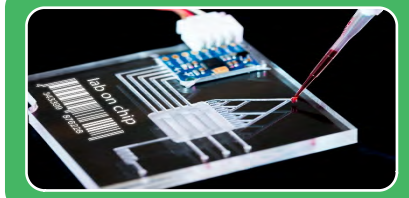
Agrément Crédit Impôt Recherche

- Prolongement de l'Institut de recherche **FEMTO-ST**

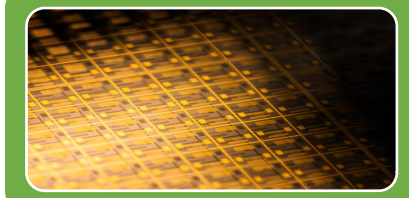
Nos services

Etudes techniques, tests de faisabilité

Développement de nouveaux procédés de micro-fabrication



Prototypage

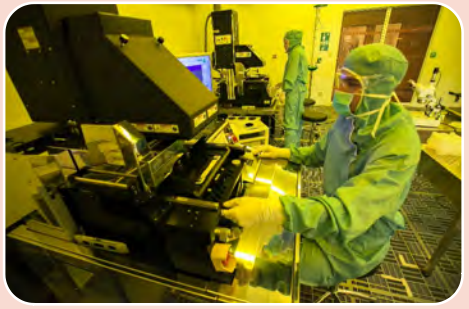


Fabrication de petites séries

Nos domaines technologiques

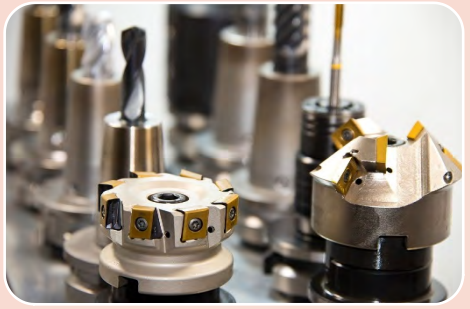
Photonique et usinage laser

- Micro et nano usinage par faisceaux de Bessel
- Découpe de verres ultra-durs
- Micro-puits et vias à rapport de forme élevés



Micro-technologies de salle blanche

- Développement de procédés (Si, verres, quartz, LN…)
- Etudes de faisabilités



Mécanique

Caractérisation mécanique

- Vibrations des structures et vibroacoustiques
- Essais mécaniques
- Essais tribologiques

Micro-usinage des carbures de tungstène et céramique

Nos domaines technologiques

Génie électronique et hyperfréquences

- Conception électronique
- Caractérisation de systèmes électroniques bas bruit
- Caractérisation de système HF

Robotique et Micro-robotique

- µ-assemblage
- µ-manipulation
- Programmation, commandes de systèmes complexes

Modélisation électromagnétique

- Création et mise au point d'outils de modélisation
- Simulation et analyses

Intelligence artificielle

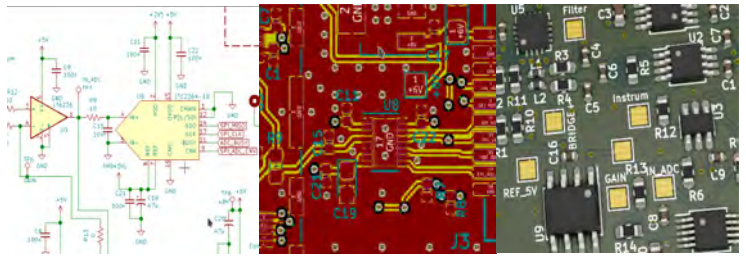
-Développement de logiciels de type OCC (One Class Classifier)

TF à FEMTO Engineering

- Benoît Dubois & Christophe Fluhr

- Cryogenic Sapphire Oscillator
- Synthèse de fréquence
- Electronique bas-bruit
- Instrumentation

Uliss®
ULTRA-LOW INSTABILITY
SIGNAL SOURCE



Actions mises en place en juin 2021

- **FEMTO Engineering est le guichet unique d'accès à la plateforme.**
- Accord cadre FC INNOV / ENSMM (en cours de rédaction) qui défini le méthode de facturation et le règle de responsabilité.
- Définitions des conditions d'accès.
- Convention d'accès à la plateforme Ocillator IMP pour les industriels.
- Grille de tarification.
- Site de réservation en ligne (interne FEMTO-ST).
- Simplification des sites internet.

Développement commercial

- Démarré sur proposition de Tematys à la fin de l'étude de marché
- Définition de l'offre de service
- Identification des clients
- Entretien individuel avec F. Goulven (Innovabilis)
- Prise de contact avec FEMTO Engineering
- Devis

Oscillator Instability Measurement Platform

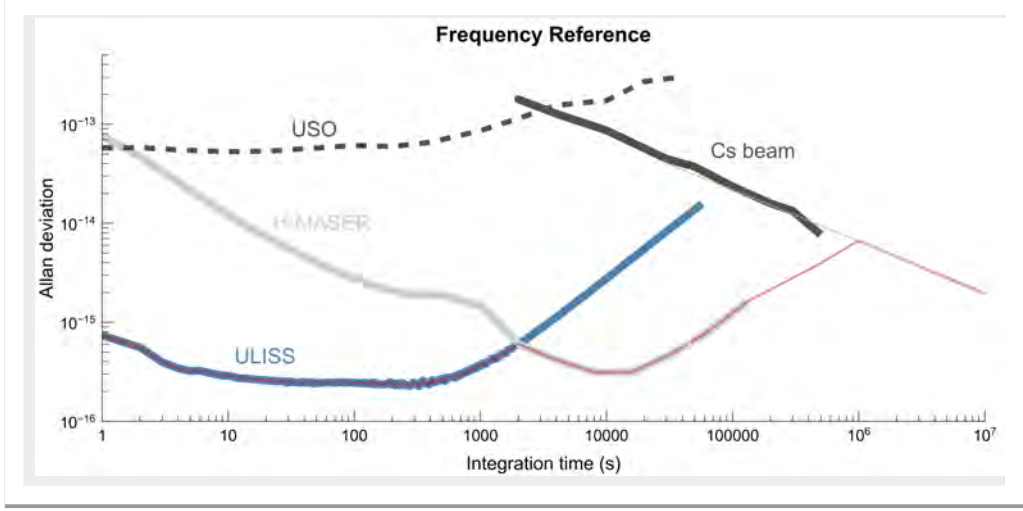
Christophe Fluhr

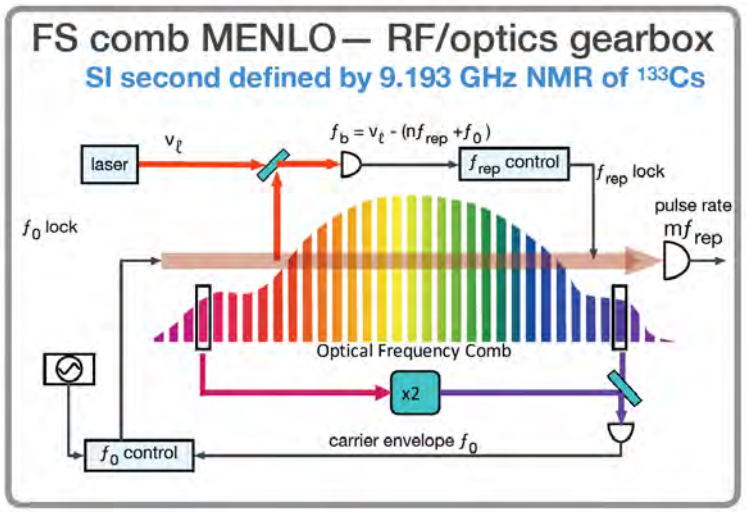
Fabrice Goulven

10/19/22

Femto Engineering Services

- Phase noise and frequency stability measurement
  - Time-Frequency characterization of actives & passives
  - Phase noise, electronic noise, short term stability
  - Electronic system design and characterization
  - Expertise in test bench design and manufacturing
- RF/microwave
  - 1 MHz to 26 GHz, ADEV 3E-15 up to 100k+ s (maser-locked CSO)
  - Measurement over 2+ weeks; temperature range -40 to 125°C
  - Controlled environment: temperature 24±0.5°C, humidity 50±10%
- RF/optical
  - Cavity-stabilized lasers ADEV 2E-15 at τ = 1 second
  - Optical to RF conversion through optical frequency comb





Frequency Sources & Measurement Equipment

COFRAC certifications at LNE LTFB

5 MHz – 26 GHz 5 MHz – 1 GHz

Phase noise measurement

Rohde & Schwarz FSWP

Microchip 5125A/53100A

Frequency sources

Cesium beam

Hydrogen-masers UTC(OP)

Ultra-Stable Quartz Oscillators

Cryogenic Sapphire Oscillators (CSO)

Cavity-stabilized lasers

Optical frequency combs

Frequency stability measurement

Time interval analyzer 5110A

Frequency counter 53132A

Signal generation, spectrum analysis & VNA

S-parameter measurement

Impedance matching

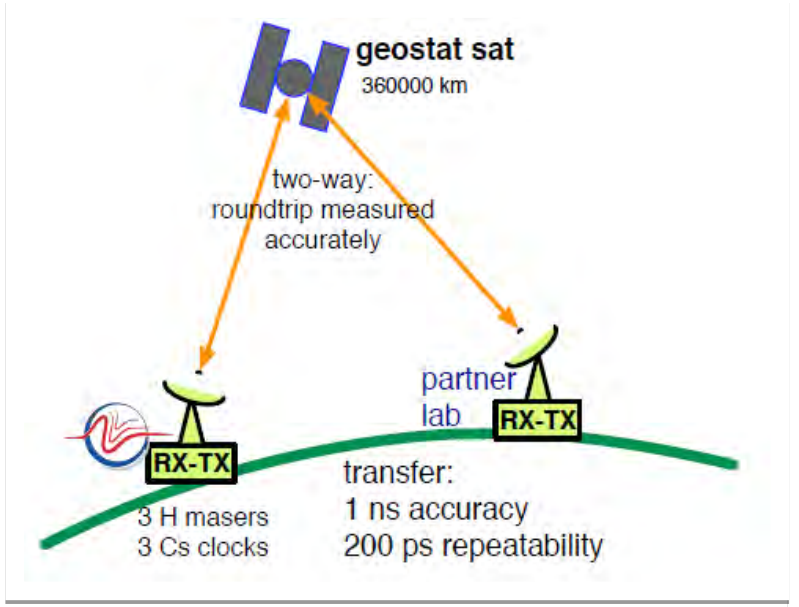
EMI/EMC & controlled environment

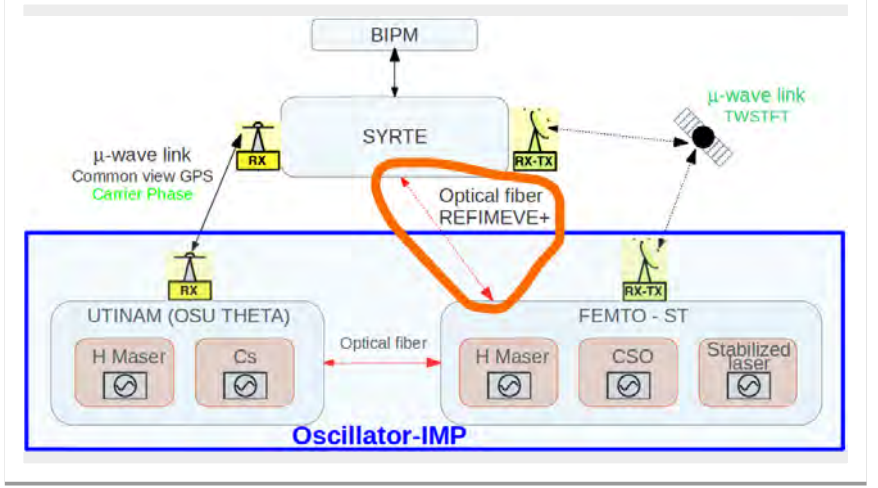
EMI test receiver

Faraday cage

Frequency Sources & Local Time Scale

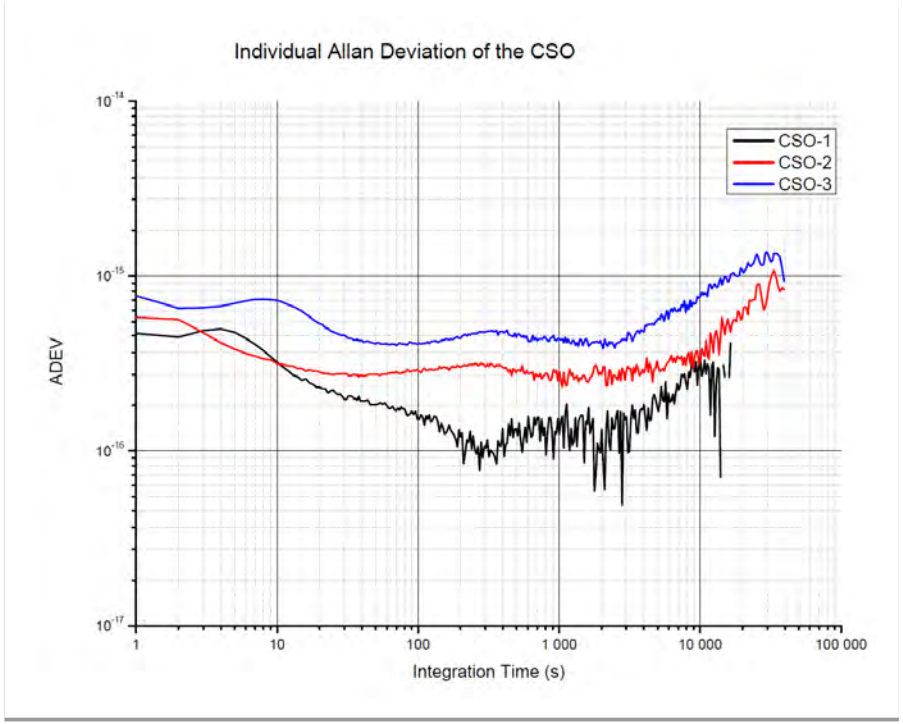
- Cs beam, H-masers UTC(OP) & CSO frequency standards
- TWSTFT (Two-Way Satellite Time & Frequency Transfer)
  - Synchronization through 2-way satellite link with SYRTE (OP)
  - UTC(OP) is the basis of French legal time
  - Local time scale compared with OP, INRIM, NPL, PTB & Greenwich
- SI traceability due to clock comparison system (SYREF)
  - Comparison measurements allows us to generate accurate local time scale
  - Common-view GPS system available for SI traceability on Customer site





Cryogenic Sapphire Oscillator

- The most stable MW source at short integration time
  - ADEV ≤ 3E-15 from 1 to 10,000 seconds; < 1E-14 per day
- Low noise frequency synthesis generating ultra-stable signals
  - 10 GHz, 100 MHz, 10 MHz, 5 MHz & custom
- Internal Direct Digital Synthesizer
  - Relative frequency resolution: 1E-16
- Phase Comparator available
  - To lock CSO output signals to external 100 MHz reference
- CSO available for rental on your premises
  - ULISS (Ultra Low Instability Signal Source)



Phase Noise Measurement

- Rohde & Schwarz FSWP8 and FSWP26 up to 26.5 GHz
  - Simultaneous measurement of phase noise & amplitude noise
  - Phase noise below -166 dBc/Hz at 10 kHz offset, 1 GHz input
- Microchip (Symmetricom) 5125A up to 400 MHz
  - Simultaneous phase noise & ADEV measurements
  - Phase noise below -170 dBc/Hz at 10 kHz offset, 10 MHz input
- Microchip 53100A (phase station) up to 200 MHz
  - Available for rental on your premises
  - Noise floor below -175 dBc/Hz with 10 MHz input
  - Three cornered hat measurement using 3 reference oscillators

Other Measurement Equipment

- Signal generators up to 67 GHz
  - Rohde & Schwarz SMA100A
  - Keysight PSG E8257D
- Vector network analyzers up to 100 GHz+
- Spectrum analyzers up to 26 GHz
  - Available for rental on your premises
- Time interval analyzer and frequency counter
  - TSC 5110A
  - Keysight 53132A
- COFRAC certifications: introduction to LNE LTFB
  - Phase noise, ADEV 1 to 100 s, frequency, time interval

Equipment Rental Conditions

- Customer's corporate liability insurance to cover equipment on Customer or Femto site
  - If the equipment is booked on Customer site, Customer commits to return the rented equipment at the end of the booked period in the same condition as when it was rented
  - If the equipment is booked on Femto site, Customer commits to release the rented equipment at the end of the booked period in the same condition as when it was rented, and to provide the list of persons using the equipment on site
- Transport options:
  - By default: Femto provides transportation (including insurance), to be invoiced additionally
  - Upon request: Customer can choose carrier or pick up equipment at Femto, if covered by insurance
- A specific training may be required to use the rented equipment
- For additional information, please contact christophe.fluhr@femto-engineering.fr

Bilan 2021-2022

11 commandes

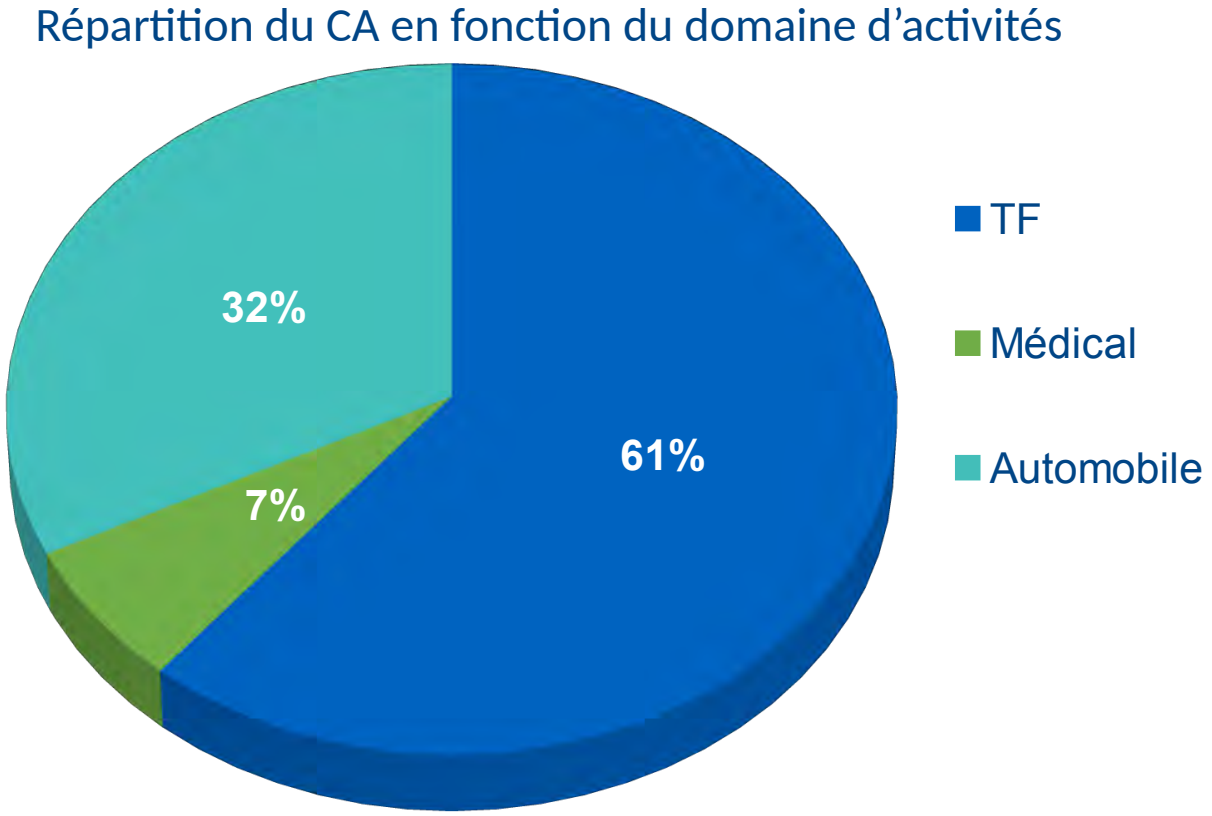
4 entreprises

CA 12 k€

Location intruments (47 %)

Cage de Faraday (32 %)

Caractérisation (21 %)



Phase 2 du développement commercial débutée en septembre 2022