The Oscillator IMP

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Oscillator Instability Measurement Platform

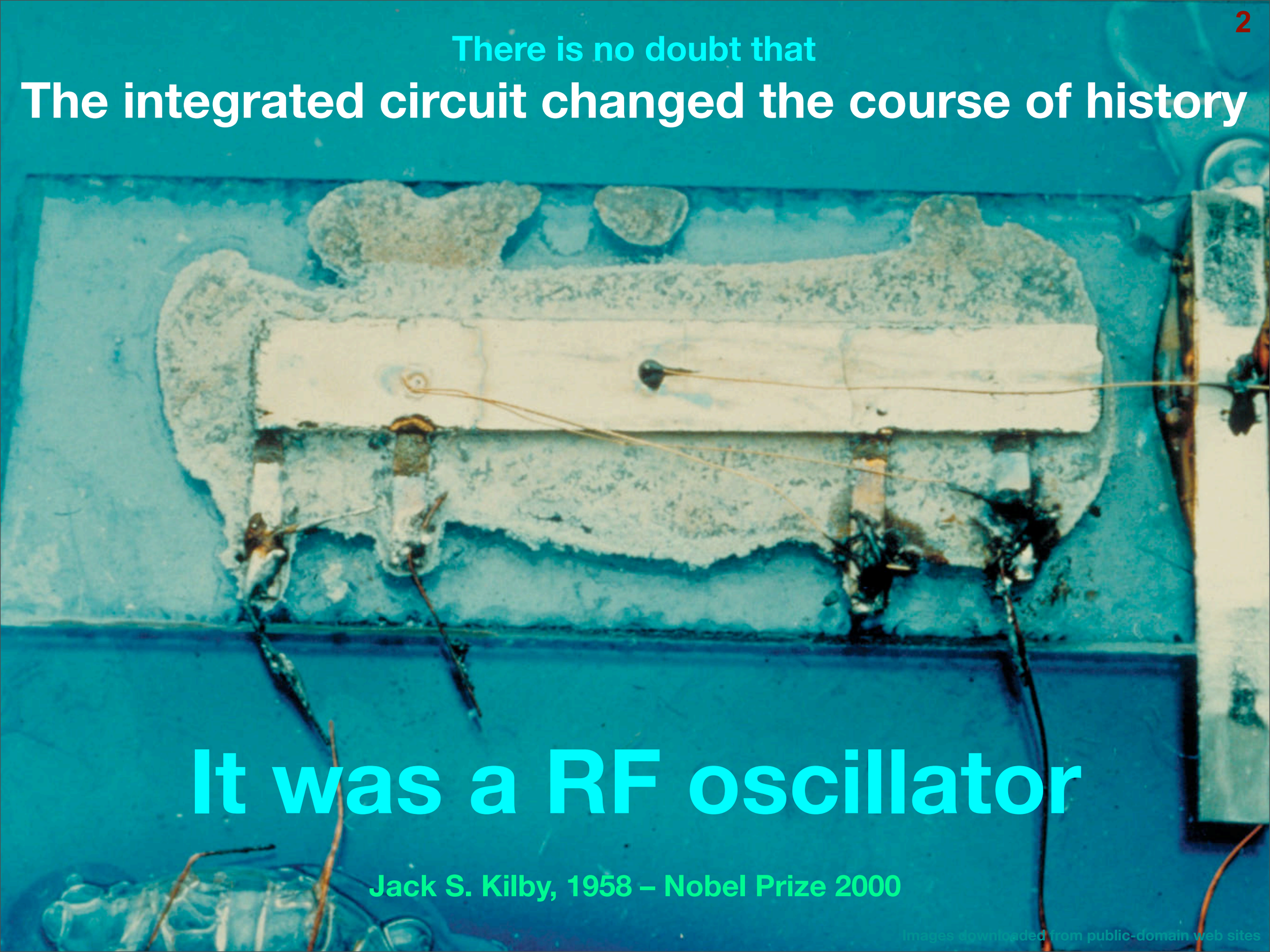
At your choice, P stands for Playground, Playstation or Platform
You can also read Oscillator IMPact

100% Besançon

Web page http://oscillator-imp.com
home page http://rubiola.org

There is no doubt that

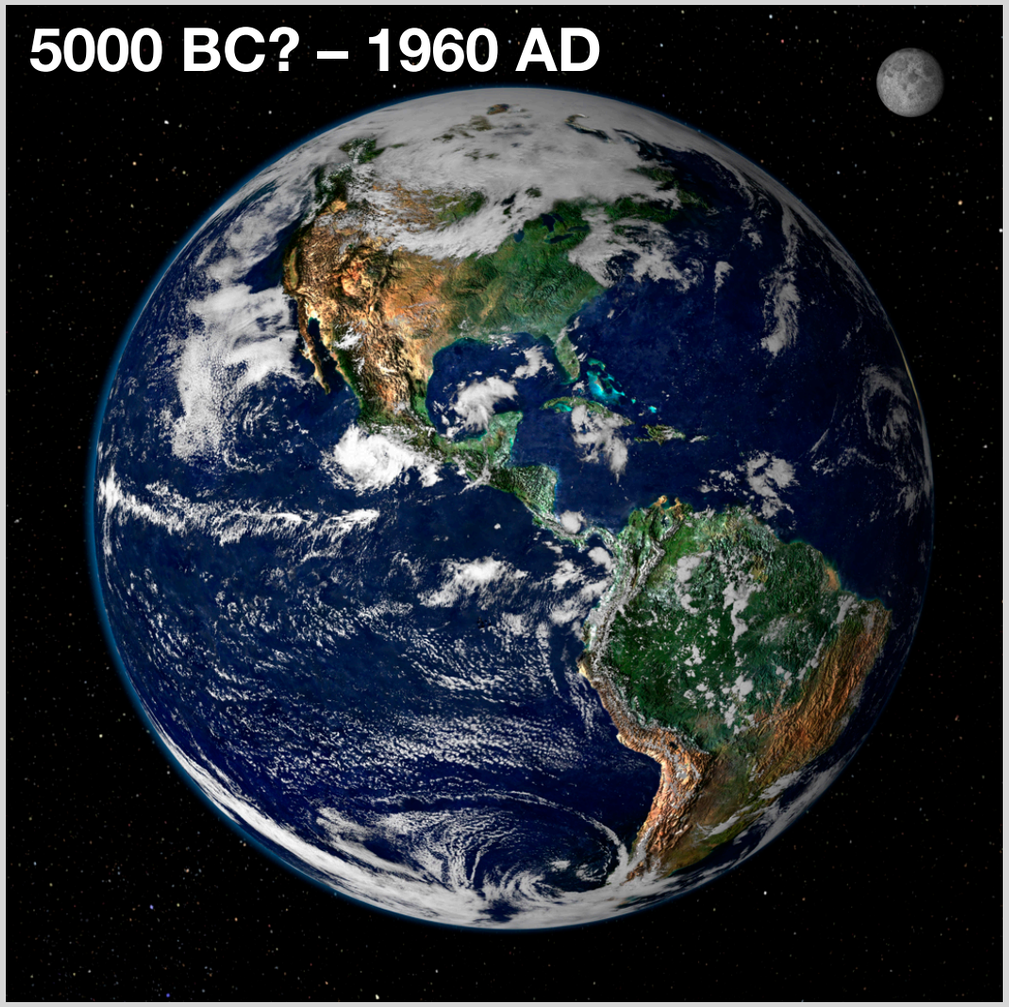
The integrated circuit changed the course of history



It was a RF oscillator

Jack S. Kilby, 1958 – Nobel Prize 2000

Time, Earth and Pendulum



The rotation of the Earth
provides ultimate accuracy
– yet only for timekeeping –

The pendulum is the first instrument
that enables the precise
measurement of a short time interval

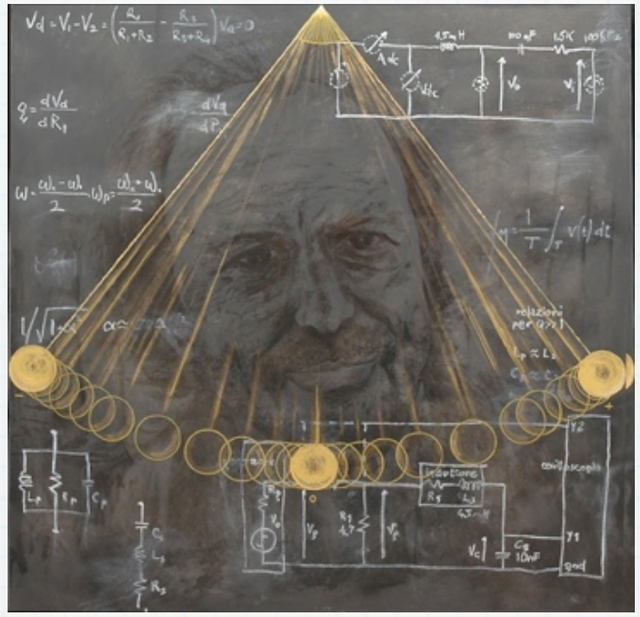
- Science and engineering rely on the pendulum
- The pendulum is steered to the rotation of the Earth

The free land to conquest matches our best skills

Short-term stability – Spectral purity – Jitter

- **Scanning the technology, we notice that virtually all systems relying on time and frequency**
  - need that the oscillator is stable for a suitably short integration time τ
  - the absolute frequency can be provided by an external reference or steered to an atomic time scale.

- **This pattern is found in**
  - **Galileo's pendulum, steered to the Earth rotation ($\tau \le 10^1 \ldots 10^6$ s)**
  - radars ($\tau = 10^{-6} \ldots 10^{-2}$ s)
  - telecommunication systems ($\tau \le 1 \ldots 10^5$ s)
  - computer boards ($\tau < \approx 1$ μs)
  - particle accelerators ($\tau \le \approx 100$ ms)
  - very-large baseline interferometry ($\tau = 10^{-1} \ldots 10^4$ s)
  - space missions ($\tau = 1 \ldots 10^3$ s)
  - GPS/Galileo/Glonass ($\tau \le 10^6$ s, i.e. ≈2 weeks)

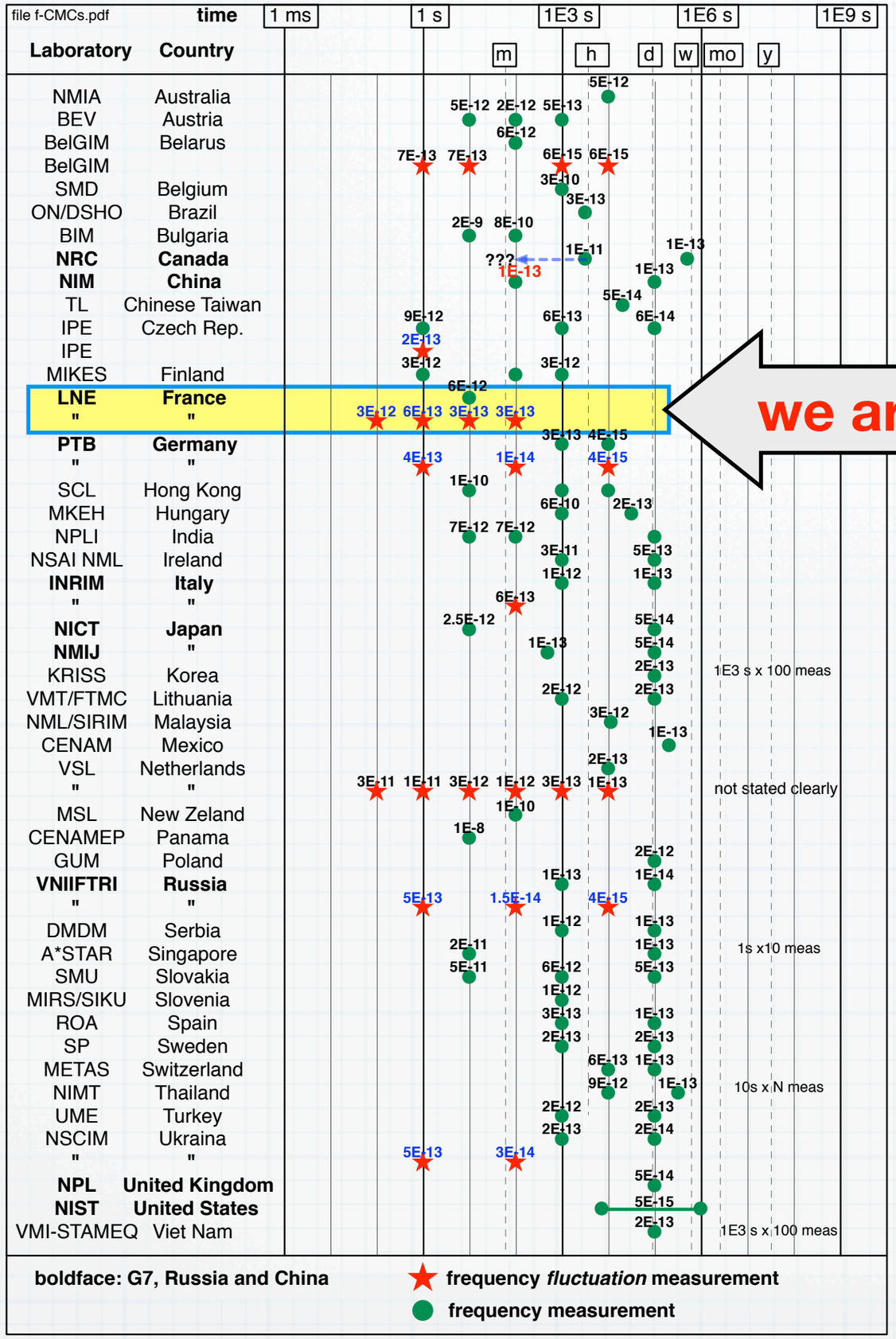


Enrico and the Duffing oscillator, seen by Roberto Bergonzo

- **Emerging domain, the competition is surprisingly low compared to the high relevance**

- **Why? World-class μwave/RF is a blend of engineering, science and art**

BIPM Calibration & Meas. Capabilities



we are already here

The BIPM is on the top of the metrology labs

- **The green spots are the absolute frequency measurements – in total, 70–80 national labs –**
- **The red stars are the frequency fluctuation measurements – in total, 8 national labs –**
- **We are the one and only lab listed by the BIPM for spectral purity, Sϕ(f) or L(f) as you like**

Oscillator IMP – Block diagram

color code

μwave
optics
data

operational | testing | replace | upgrade | new | shared with Refimeve+

2014 First-TF General Assembly

AUX EQUIPMENT -- FEMTO-ST & Observatory

- Frequency synthesis
- OEO (low-noise synthesis)
- Room-temp. sapphire oscillators
- Liquid-N2. sapphire oscillators
- σy(τ) measurement
- Sϕ(f) measurement
- resonator stability measurement
- calibration
- network analyzers
- spectrum analyzers
- power meters
- database

Environment tests -- FEMTO-ST

- vibrating table
- vacuum chamber
- magnetic field equipment
- 20 m2 shielded room & EMC equipment
- large gloveboxes

UTC(OP)P from SYRTE

Cesium-clock ensemble: master, secondary, secondary

Time-transfer: Carrier-phase GPS, RX

measurement equipment & steering algorithms

Observatory

FEMTO-ST

backup power supply

optical link

composite clock

Local copy of UTC(OP) to all users

Distribution: distribution amplifiers → stable frequency

White Rabbit

1.5 km (fiber)
0.5 km (sight)

optical link

ETHERNET

Monitor & distribution: White Rabbit → stable freq.

Time-transfer: RX-TX, TWSTFT two-way μwave

Hydrogen-maser ensemble: three-corner-hat measur. & control; master, secondary, secondary; distrib. ampli

reference frequency

data

composite clock (optional)

Distribution: distribution amplifiers → stable frequency

Shared with REFIMEVE+ Equipex project

RENATER

optical carrier meas.

reference opt. frequency from SYRTE

Stabilized laser comb: FS laser, detector, ULE FP cavity, control

optical frequency

Liquid-He sapphire oscillatos ensemble: three-corner-hat measur. & control; master, secondary, trans-portable; distrib. ampli; ULISS

transportable

Stabilized laser comb: FS laser, detector, small FP cavity, control → optical freq.

transportable

quartz-oscillator ensemble: three-corner-hat measur. & control; master, secondary, secondary; distrib. ampli; battery

Monitor: computer & storage; sensors

environment

Main control unit: phase detectors, data acquisition, down converters, multich. counters, algorithms

backup power supply

Cryogenic CW reference: CW laser, detector, cryo Si cavity, control → optical freq.

Setting up the Oscillator IMP

Quality
S. Ubaldi (all UFC) [M.Mourey]

Project Leader
E.Rubiola [V.Giordano]

Executive Comittee
E.Rubiola,V.Giordano, F.Vernotte

New WP

Microwave Photonics
Y.Kersalé [R.Boudot]

Yann Kersalé
Jacques Millo
Clement Lacroute

Rodolphe Boudot
Emanuel Bigler

Luca Furfaro
Yannick Gruson
Philippe Abbé
David Vernier

Assemble ULE FP etalon
Lock FS laser to ULE-FP
Steer ULE-FP to *μ*wave
Dual-mode lasers

Microwaves & RF
V.Giordano
[P.Y.Bourgeois]

Vincent Giordano
Serge Grop
Benoît Dubois

Pierre-Yves Bourgeois
Roger Bourquin (emeritus)
Rémi Brendel (emeritus)

Yannick Gruson
Cyrus Rocher

Install H masers
3-corner hat
OCXO ensemble
System integration
Measurements

Metrology & Env.
S.Galliou [E.Rubiola]

Serge Galliou
G. Goavec Merou

Sylvain Ballandras
Enrico Rubiola
Joël Imbaud
Marc Mourey
Jean-Jacques Boy
Tomas Baron
Philippe Abbé
Nathalie Cholley

Perturbed environment
Meas. of $S_\varphi(f)$ & $\sigma_y(\tau)$
Install meas.sys. (ΔY etc.)
Quality & accreditations

Time & Statistics
F.Vernotte [F.Meyer]

François Vernotte
Timothée Accadia

Francois Meyer
Eric Meyer
Emmanuel Tisserand

Install TWSTFT
GPS -> CP-GPS
Upgrade time-scale
Run the time scale
3-corner-hat estimation

Digital Electronics
P.-Y. Bourgeois
[E.Rubiola]

P.Y.Bourgeois
E.Rubiola

Timothée Accadia
Benoît Dubois
Nicolas Gautherot
Eric Meyer
Emmanuel Tisserand

Custom hardware
Software
$S_\varphi(f)$ & $\sigma_y(\tau)$
White Rabbit
Computer systems
Installations
Web site

[in brackets] backup, for all the key persons

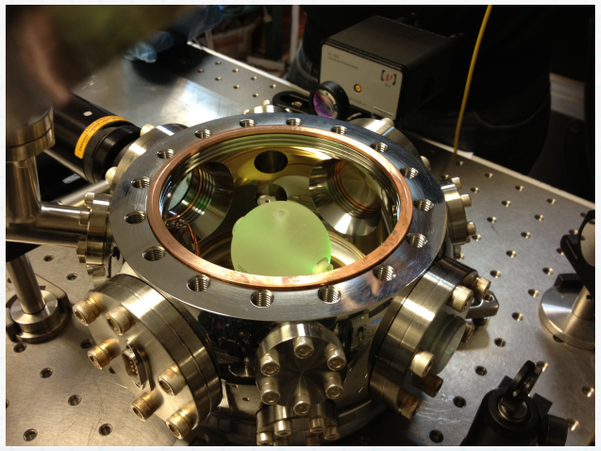
Administration Manager
Aryanne Hicks [F.Cornu]

~~**Computer systems**~~
~~IE CDD [……]~~

Tough: 13.5 years manpower in 2013 – Thanks to all colleagues

femto-st SCIENCES & TECHNOLOGIES

Spherical cavity (commercial CPER-FEDER 100 keuros)



All the stabilization electronics is ready

Laser locked to the cavity

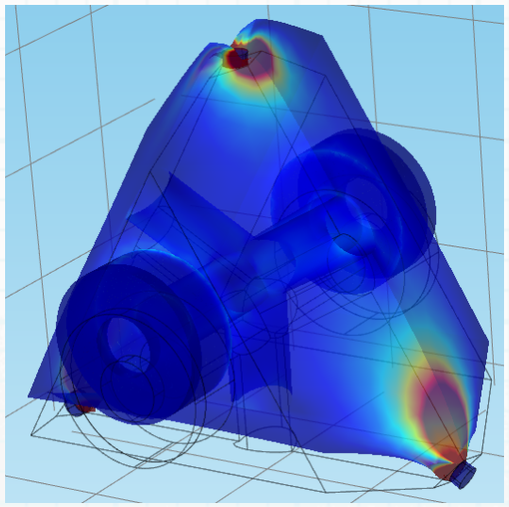
laser frequency stability transfert to the frequency comb

Target : $\sigma_y(\tau) \approx 8\ 10^{-16}$

Ready to used scheduled to mid 2014

OSC-IMP

Compact cavity (CNES 45 keuros)



Design finished

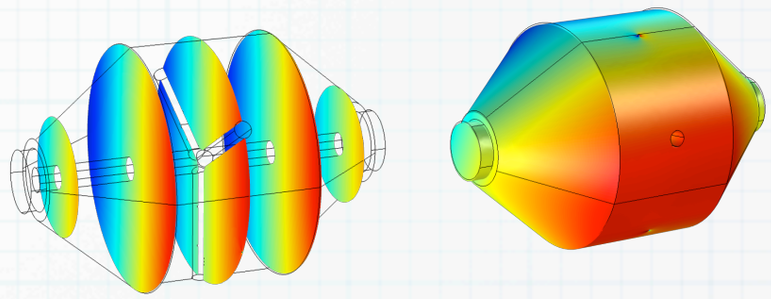
Machining is started

Design of the vaccum chamber and thermal isolation started

Target : $\sigma_y(\tau) \approx 2\ 10^{-15}$

First experiments on this cavity scheduled to beginning 2014

Silicon cavity (Région 70 keuros)



Design finished

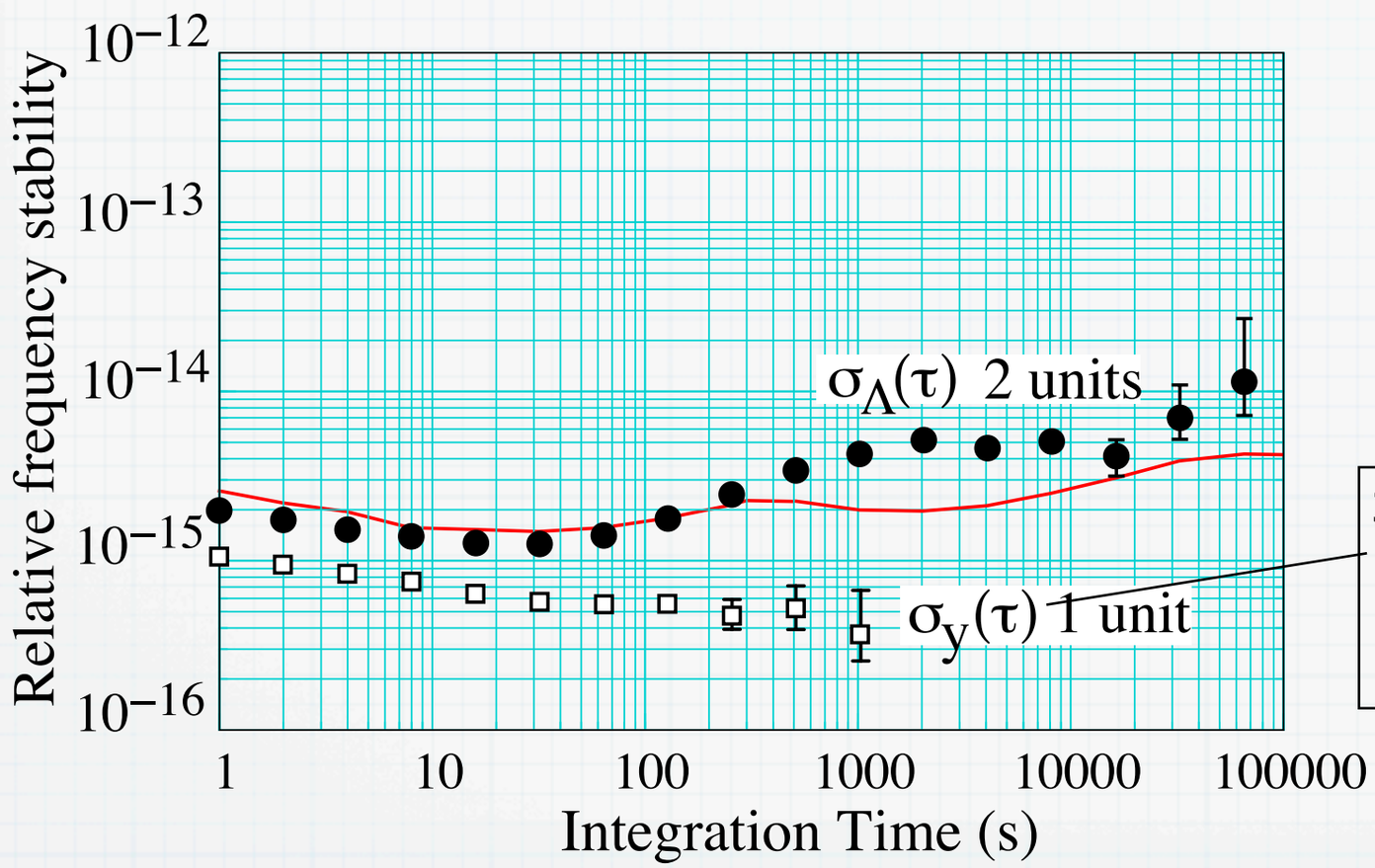
Machining is started

Design of an ultra low vibrations cryocooler started

Target : $\sigma_y(\tau) \approx 3\ 10^{-17}$

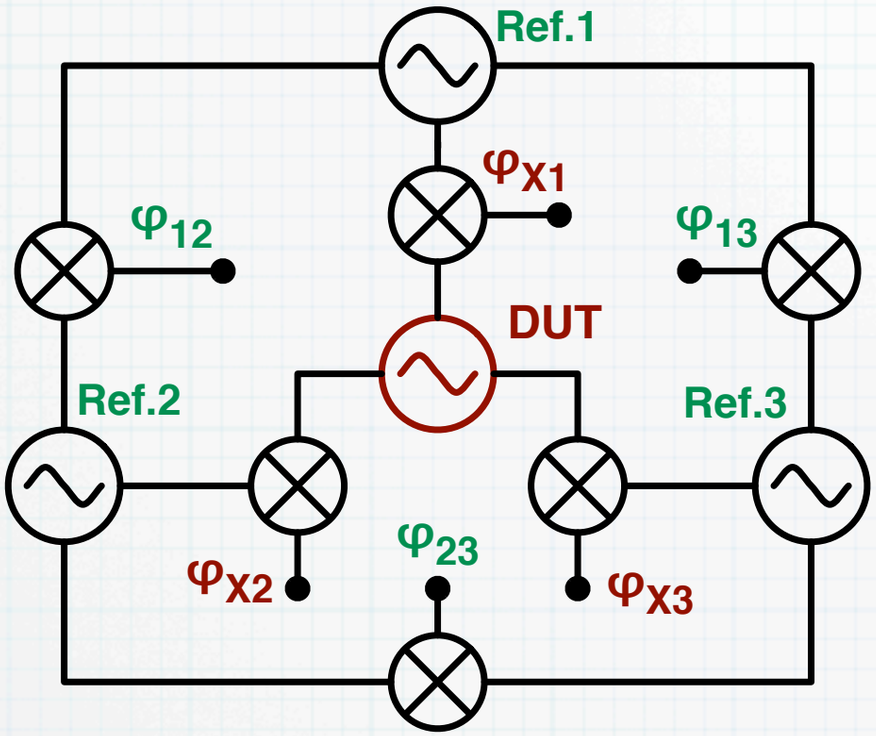
First experiments on this cavity scheduled to mid 2014

Test ULISS before and after travelling

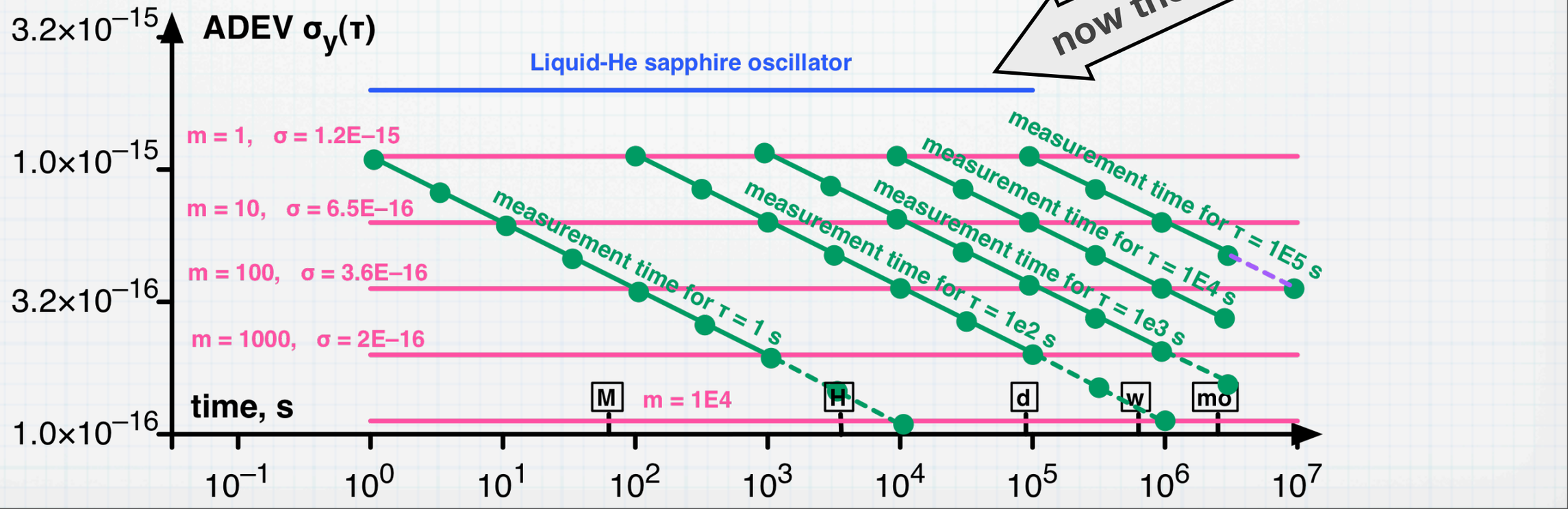


3 hours extracted from the entire data set
- Quiet environment, nighttime
- Take away 3dB for two equal units
- Λ-counter compensated: for flicker: $\sigma_\Lambda(\tau) \simeq 1.3 \times \sigma_y(\tau)$

Three-cornered hat



- Three reference oscillators
- Heavy statistics
- … And go digital !



WP METROLOGY

Equipment

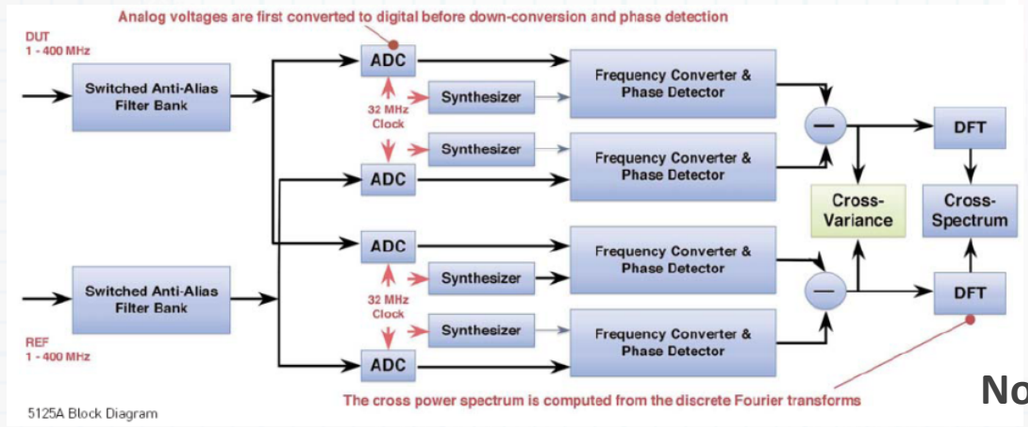


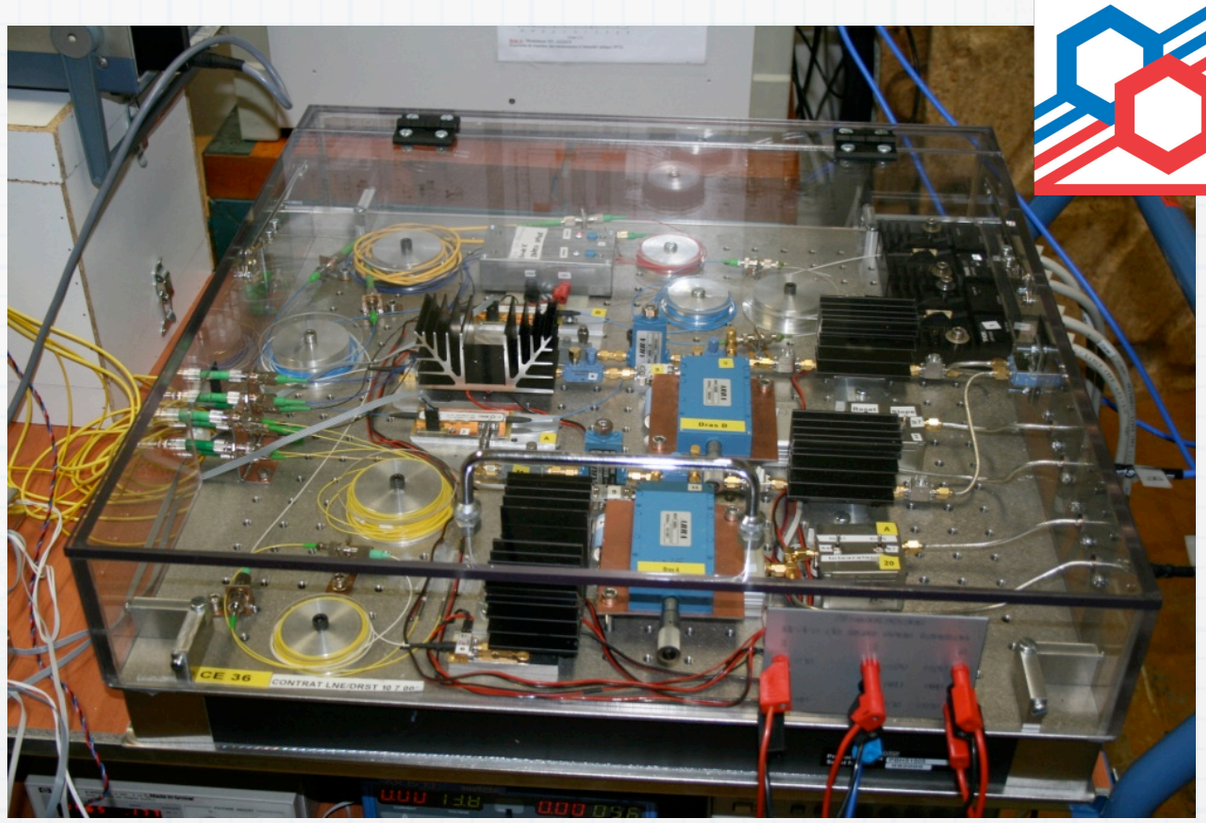
Image from Symmetricom web site

No longer must the reference and DUT beat at the same frequency

LNE
Le progrès, une passion à partager

Dual delay line X-band Bench

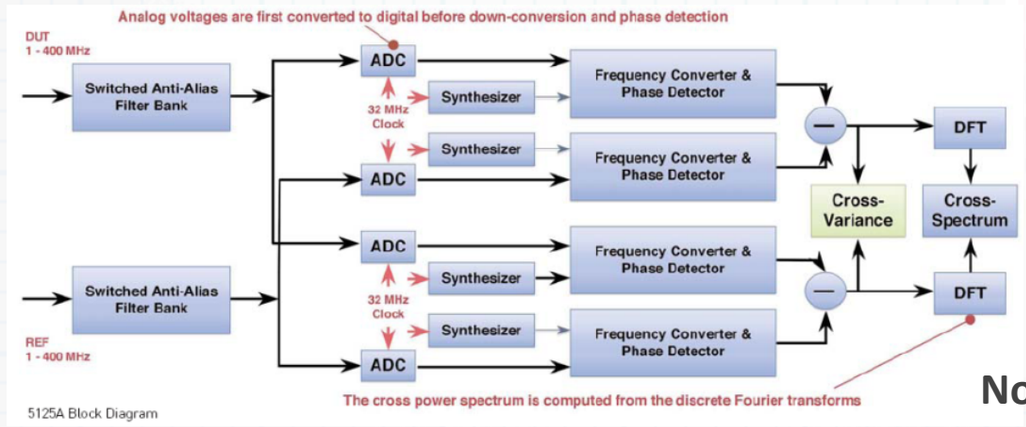
cofrac



Institut UTINAM

WP METROLOGY

Equipment



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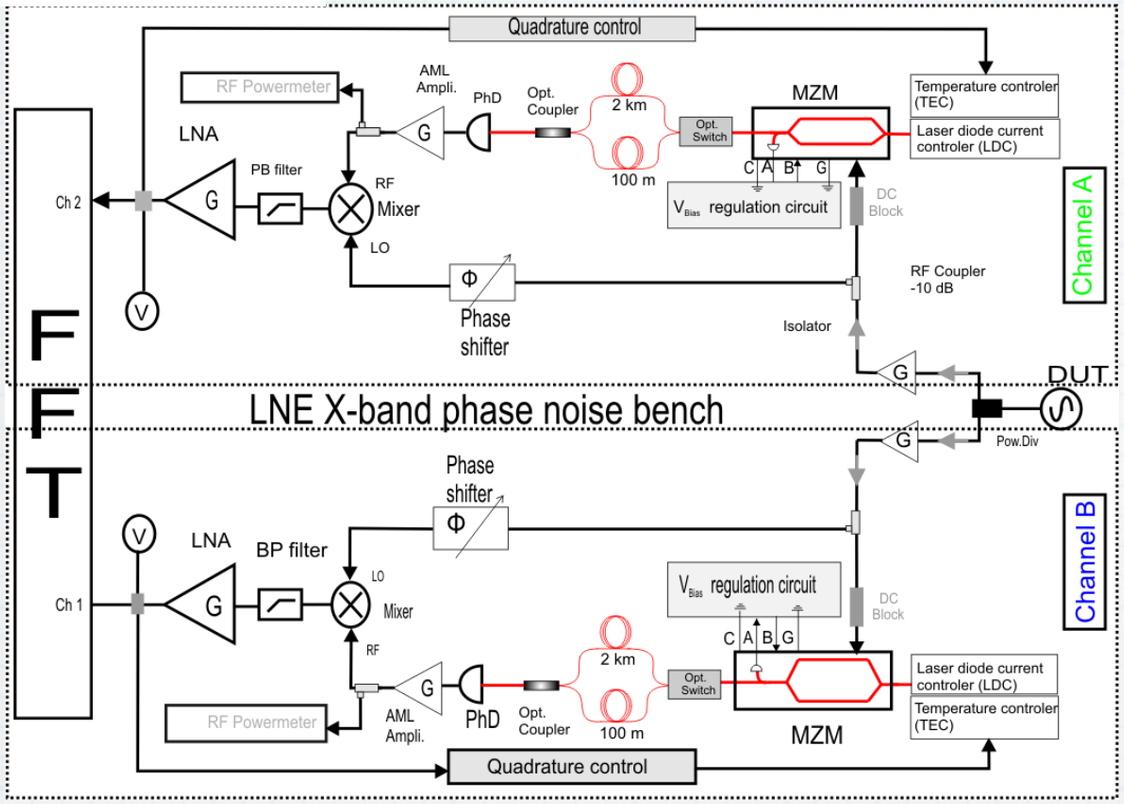
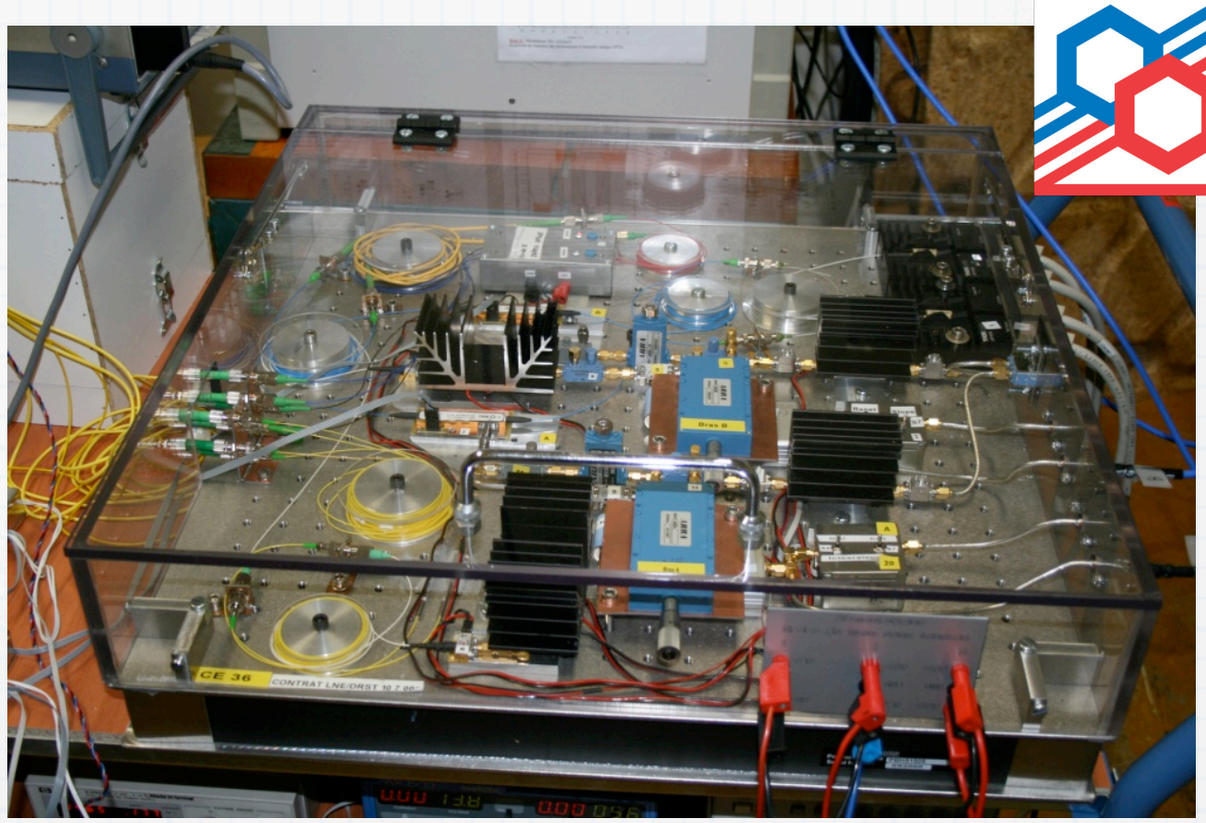




Environment tests

Frequency stability, phase noise and jitter are to be validated in real environmental conditions

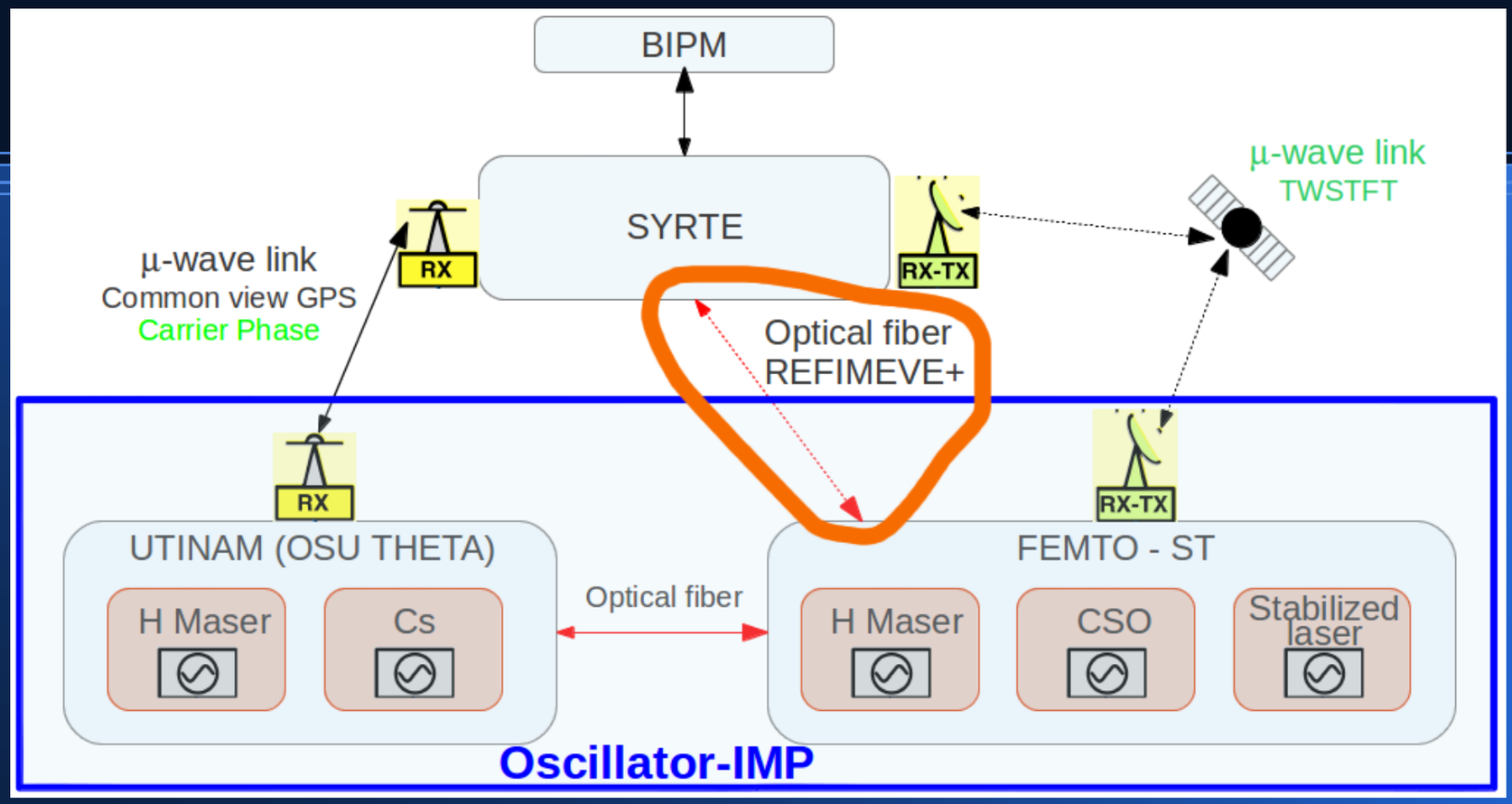
Main concerns for industry and customers

- Electromagnetic compatibility
- Vibrations and shocks
- Temperature range, and thermal shocks
- Power supply
- Vacuum, and atmospheric pressure fluctuations
- Magnetic fields
- Aging
- Radiation

The Oscillator-IMP will do all this

(yet radiation tests rely on external collaborations)

Work Package: Time Scale

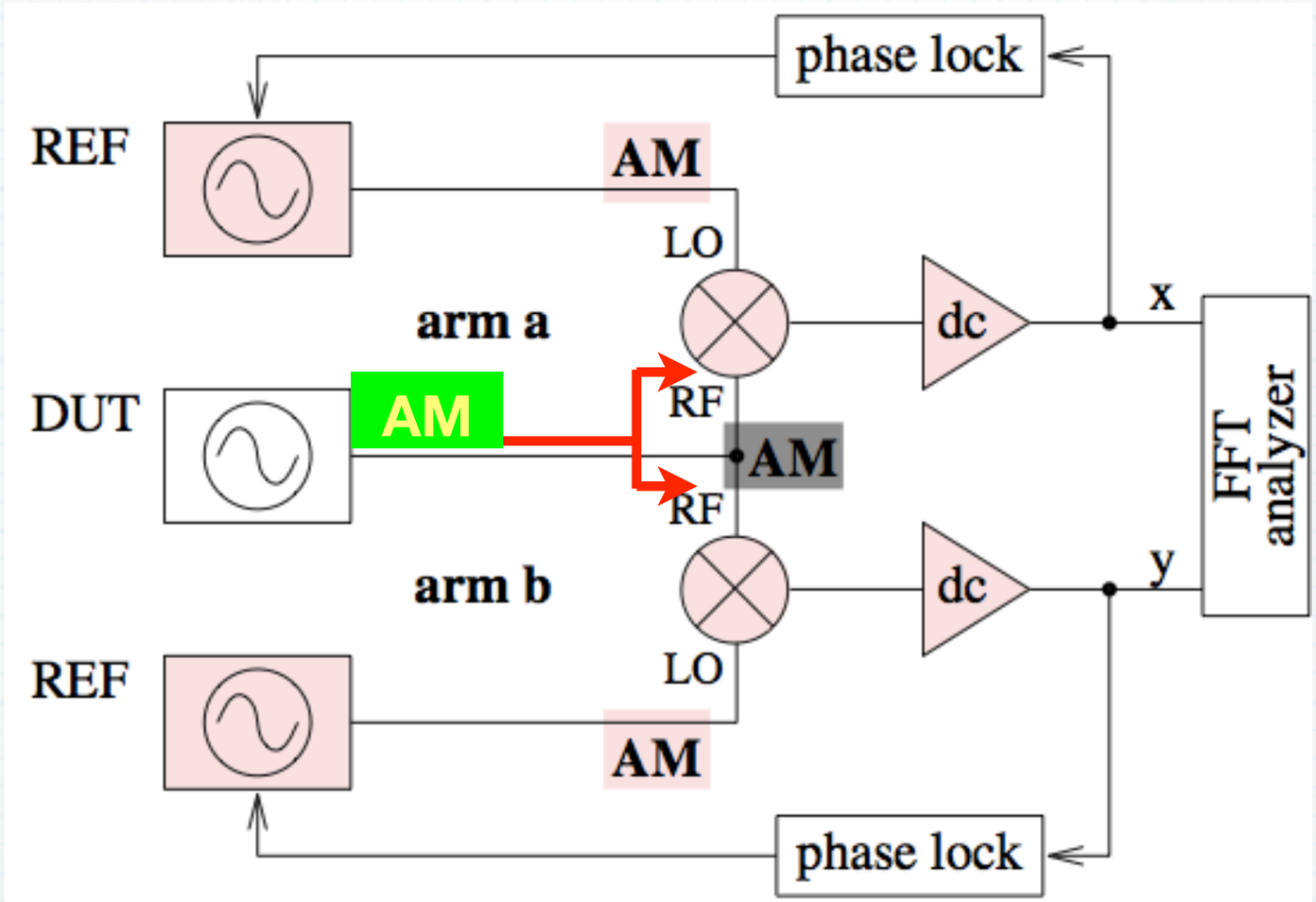


3 main goals:

- External 2-Way Satellite link with SYRTE
- Internal fiber link ENSMM-Observatory
- Time transfer with SYRTE via REFIMEVE+

The AM noise in a correlation system

Average cross-spectrum is used to reject the single-channel noise



Why we need a digital system under full control

- The effect of the DUT AM noise is fully (anti-)correlated
- Over- (under-) estimation of the DUT noise
- 12–15 dB spread has been reported

Budget, M€

Phase 1 years 1-3	microwave photonics	0.57		
	microwaves & RF	1.15		
	metrology & env testd	2.06		
	time scale	0.42		
	education and valorization	0.13		
	management	0.31		
	total phase 1	4.64	3.5	75%
Phase 2 years 3-10	6% of the investment for 8 years Contribution to running cost			
	total phase 2	1.25	0.7	56%
	Grand total	5,89	4.2	71%
	requested		funded	

- ENSMM: 250 m2, one engineer position (scheduled)
- Region Franche-Comte: 1.5 M€ in 2012-13 (3X), 2014-15…

Completed: 25% of the platform