

Deployment and Validation of the Frequency and Time Second Generation distribution system in Cebreros ESA Deep Space Antenna

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European Space Agency

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ESA Operation center- Who we are and what we do



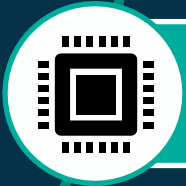
ESA's Mission Control (ESOC): Flying 20+ missions: planetary, Earth observation, navigation.
Coordinating operations across ESA's space assets



Global Ground Network (**ESTRACK**): Deep space & near-Earth stations. Supporting ESA & international partners (NASA, JAXA, etc.)



R&D and Testing in operational representative environment: Compatibility labs & performance validation.



Timing & Frequency Engineering: Designing and maintaining F&T systems.
UTC (ESOC) realisation



The European Space Tracking (ESTRACK) network



ESTRACK – ESA's Global Ground Station Network

- 10+ ground stations worldwide
- Supporting S-, X-, K, Ka bands Frequency
- Enabling 24/7 operations for ESA and partner missions

Mission Types We Support

- Deep Space Missions: e.g., Mars Express, BepiColombo
- Earth Observation: e.g., Swarm, Sentinel series
- Launch & Early Orbit Phase (LEOP)
- Cross-Support: NASA DSN, JAXA, KARI, and others

Operational Readiness & Technology Evolution

- Continuous station upgrades to meet evolving mission requirements
- Preparing for operational deployment of next-generation technologies (e.g, Optical technologies)



ESTRACK Core Network

To replace aging infrastructure and meet growing performance needs, ESA developed a Second-Generation F&T Distribution System. For the first, the system introduces optical signal transmission from a central clock location, driven by redundant hydrogen masers and supported by GNSS receivers for UTC traceability. .

15m Antennas

- **Kourou** - French Guyana
- **Kiruna** - Sweden
- **Redu** - Belgium

Part of the upgrade

35m Antennas (Deep Space Antennas)

- **New Norcia** - Australia
- **Cebreros** - Spain
- **Malargue** - Argentina

5.5m Antenna

- **Santa Maria** – Portugal

Not part of the upgrade



Why Upgrading the Frequency and Timing System ?

Building on the Legacy

- 1st Gen: robust and long-lasting (>20 years), but evolved inconsistently over time
- Result: non-uniform deployments and fragmented versions
- 2nd Gen: unified, maintainable design for the next 20+ years

Address Obsolescence

- Some hardware components are no longer supported or manufacturable
- Upgrade ensures **long-term maintainability** and **lifecycle support**
- 2nd Gen introduces modularity:
 - **Intra-station**: master and remote share common components
 - **Inter-station**: unified design across all deep-space stations

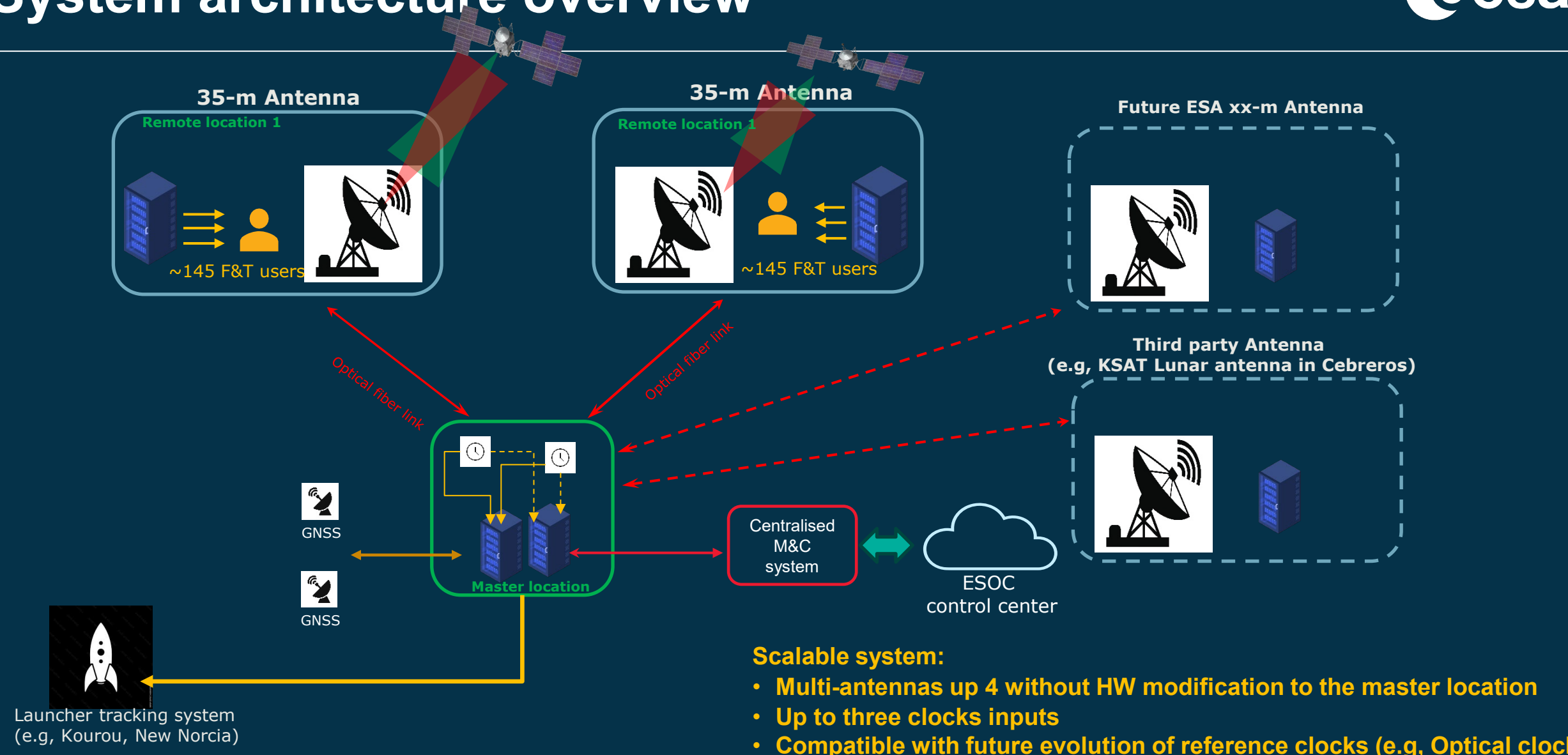
Introduce Advanced Technologies in a Controlled Way

- Enables integration of **optical technologies** (e.g. stabilized links, mode-locked lasers)
- All tested and qualified within an operational environment, **not just in lab!**

Ensure Scalability and Future Compatibility

- Modular and harmonised design usable across all ESA deep-space stations
- Agnostic to clock type and compatible with both current and next-gen missions' requirement

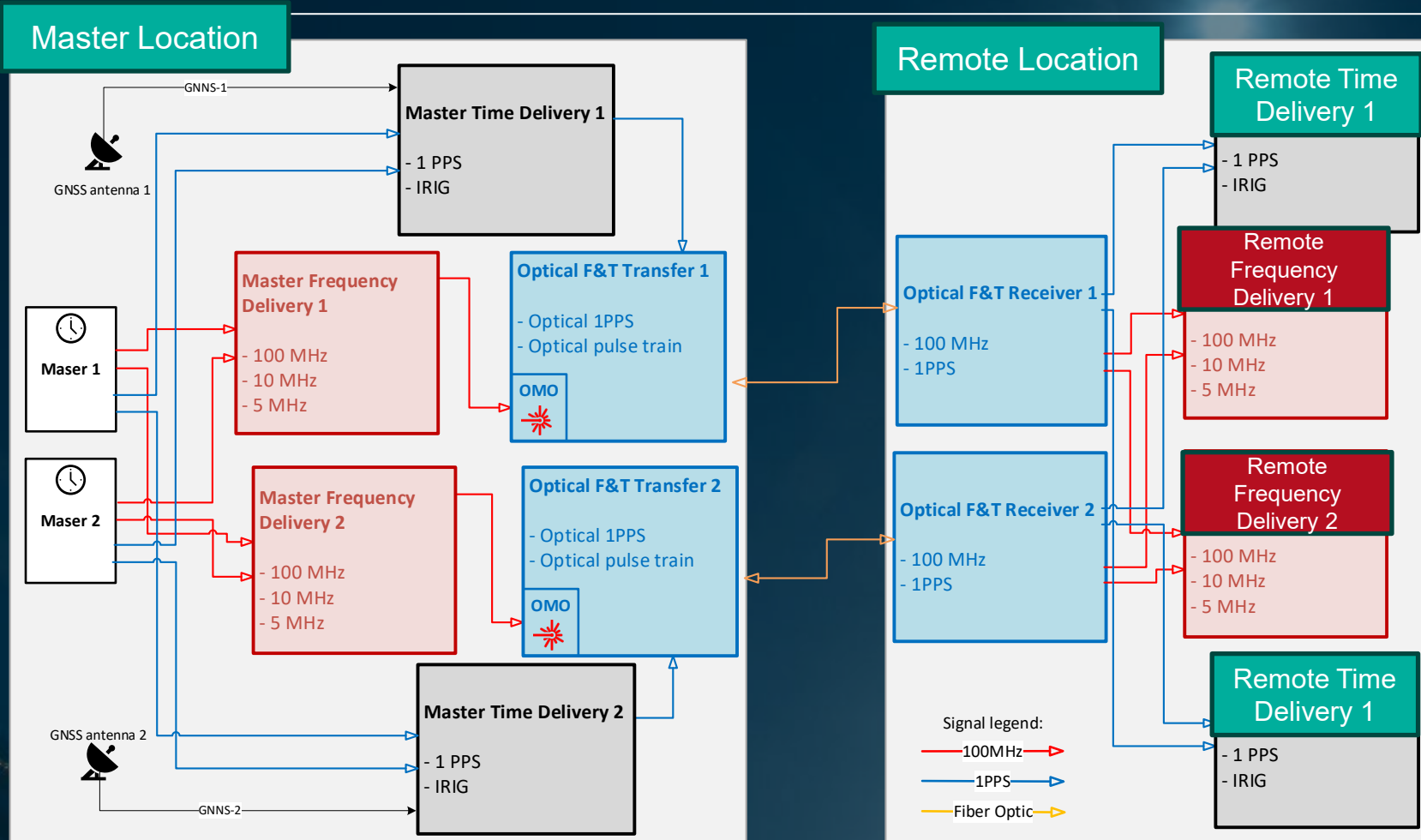
System architecture overview



Scalable system:

- Multi-antennas up 4 without HW modification to the master location
- Up to three clocks inputs
- Compatible with future evolution of reference clocks (e.g, Optical clock)

Key technologies



2nd Gen F&T System Layout:

- ✓ Completely redundant architecture
- Two redundant masers providing F&T signal (100 MHz and 1PPS).
- Two redundant F&T signal chains based on pulsed optical distribution
- ✓ Mode-locked laser-based optical links
- ✓ Enables femtosecond-level synchronization over fiber with active path stabilization

Optical Frequency and Timing Distribution System for ESA Deep Space Tracking Stations K. Şafak, A. Dai, M. Hagemann and S. Mejri, EFTF-IFCS 2023, Toyama JAPAN, 16.05.2023

A Pulsed-Optical Frequency and Timing Distribution System for Deep Space Antennas, K. Şafak, A. Dai¹, F. X. Kärtner, B. Rudin, F. Emaury, O. Lange, W. Lange and S. Mejri, EFTF-IFCS 2022, Paris, 27.04.2022

2nd GEN F&T Implementation Roadmap

2020	2021	2022	2023	2024	2025	2026	2027
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- **Operational Deployment at Cebberos (Spain)**
- **Sequential deployment in NNO (Australia) and MLG (Argentina)**
- **15-meters class antennas deployment will start in 2026**

CEBREROS F&T 2nd gen upgrade

Key issues:

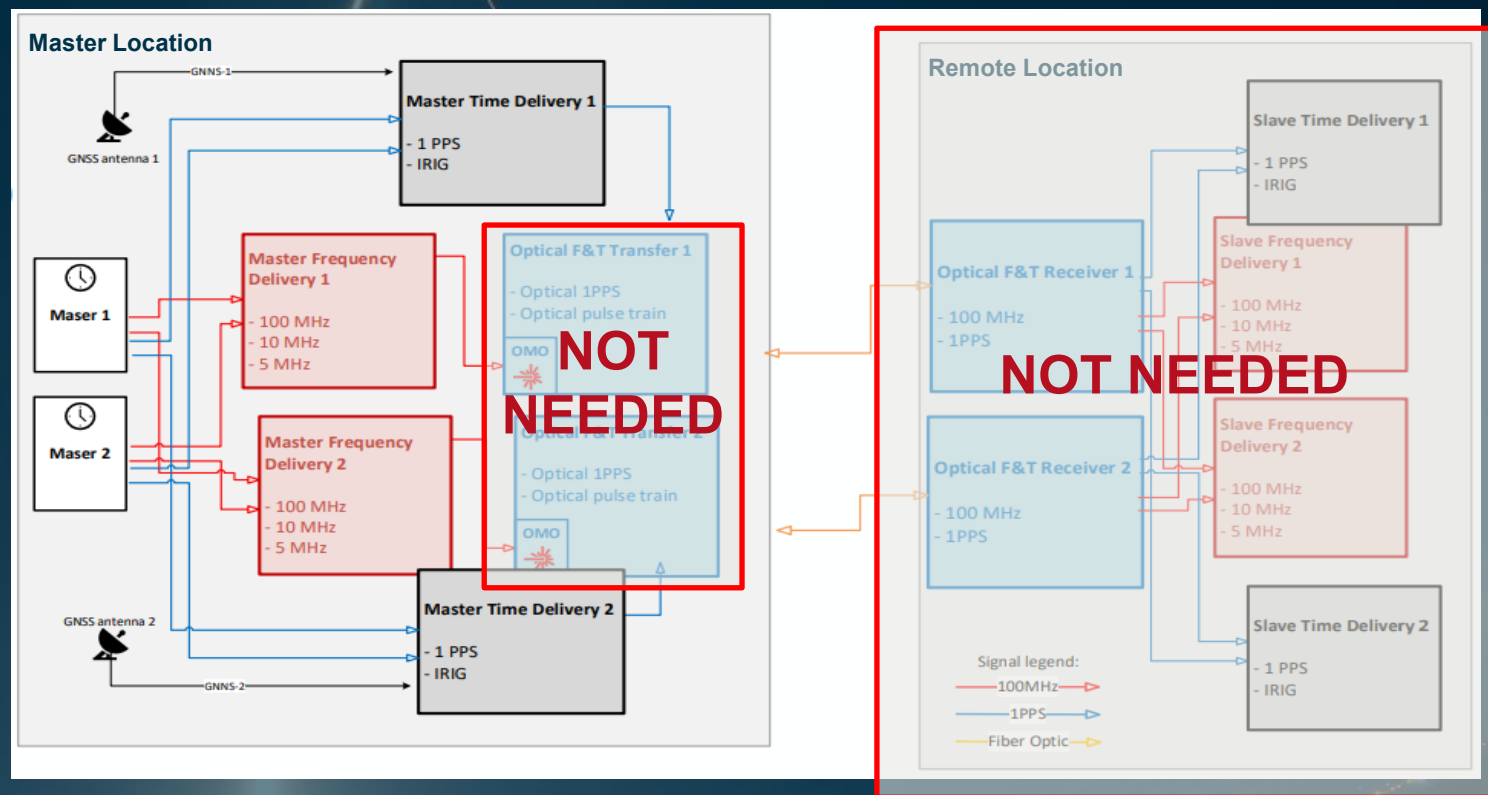
- Obsolescence of the current system: **difficult to maintain.**
- Unilateral decision of TimeTech GmbH **not to extend** the Frame Contract

Main feature:

- Two fully redundant F&T chains
- Compatible with ESTRACK masers signals
- Cross-site via Fiber link
- Possibility to support up to four remote location thanks to the ultralow noise Mode Lock lasers
- Enable centralized distribution structure for multiple antennas per site

1st gen and 2nd gen **TOGETHER**

- Same masers, same references
- Similar interface
- Validation period, systems in parallel



New system design



CEB (2023)						
	5 MHz	10 MHz	100 MHz	IRIG B 1KHz	IRIG B 5MHz	1 PPS
AER	SPAN1	LL RFTG XFRC POLAR Rx (NASA) GPS Antenna MLRFTG POLAR Synth	XDC2 XDC3 TTCP2 XDC4 KDC XUC1 IMBU1 TTCP1 IMBU2 XDC1 KaDC XUC2	NTP1 Radiometer NTP2 ACU		GPS TTCP2 POLAR Rx (NASA) TTCP1
MER	It is confirmed that no users exist anymore in the MER					

One rack system in AER

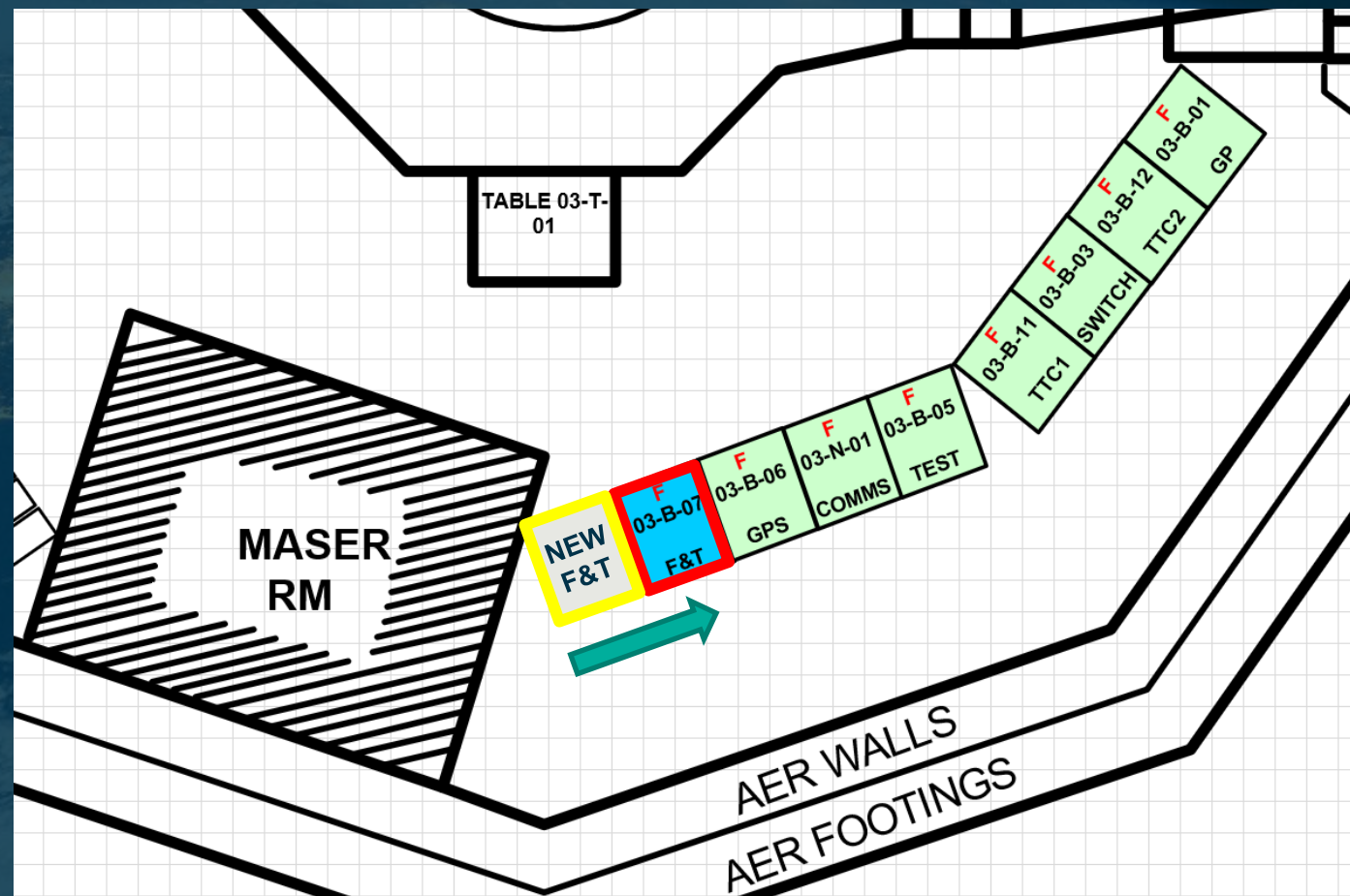
Only the electronic rack will be delivered

No optical F&T transfer, hence no optical rack required*

Integration approach

Deployment of F&T 2nd Generation
 Electronic rack next to the legacy F&T rack

- Less intrusive installation
- Only few days of partial downtime required
- Less modification on documentation

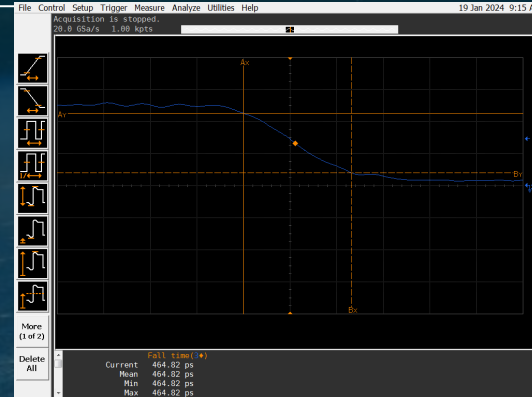
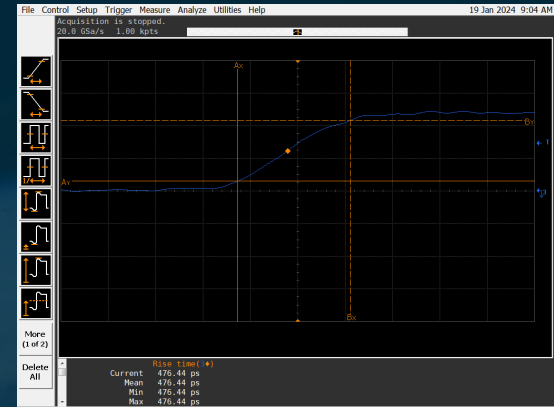


Cebreros Deployment Highlights

- ✓ Installed a new racks with redundant frequency and timing units
- ✓ Laid new cross-site fiber infrastructure
- ✓ New redundant GNSS antennas System
- ✓ Dedicated maser room environment sensors
- ✓ All work conducted without interrupting station operations, requiring careful coordination during live mission support

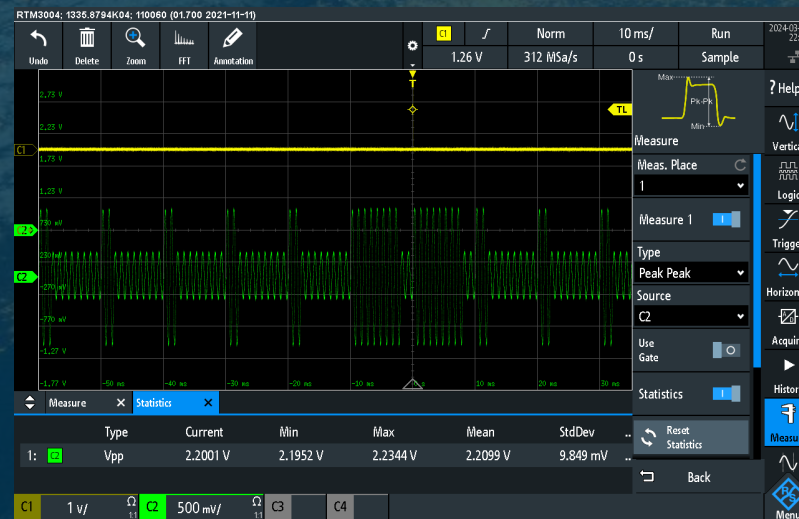
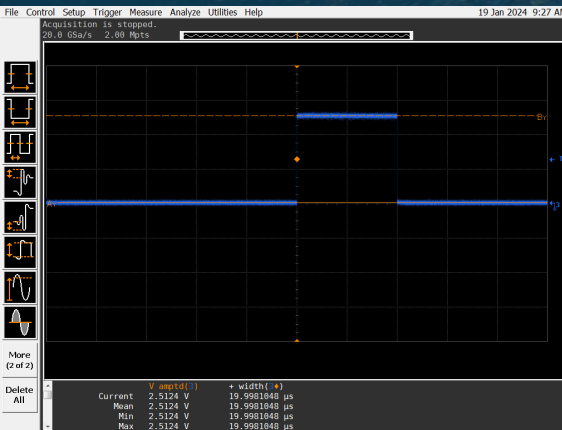


Performance Results of the subsystem- Timing signals



✓ 1PPS: very precise synchronization without Time-of-Day information

✓ Time-of-Day information is received via NTP



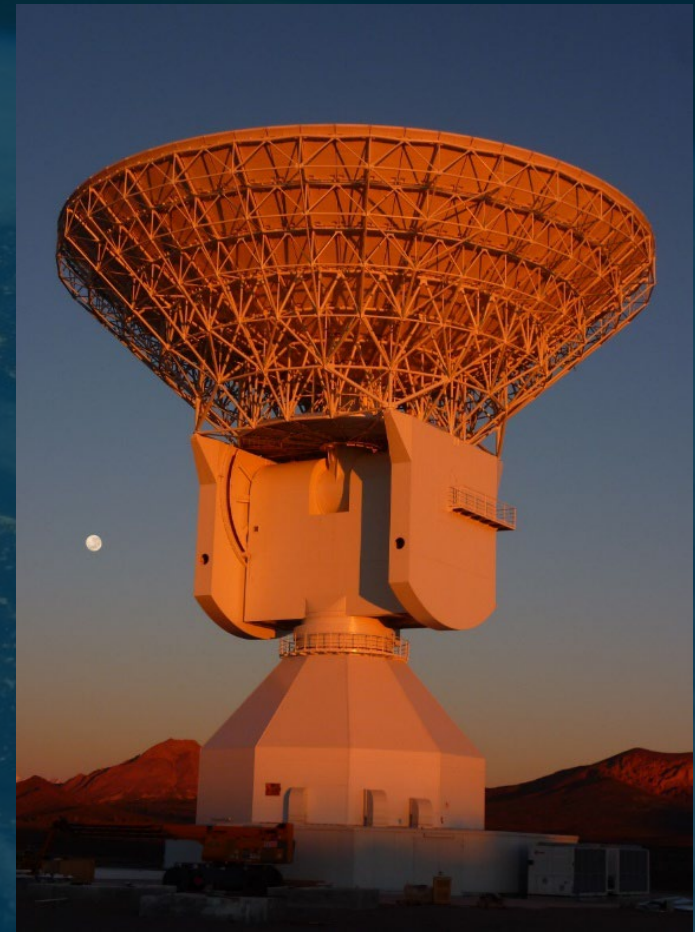
✓ Combination 1PPS + NTP provides very precise timing information

✓ IRIG-B(1kHz):Time-of-Day information + synchronization combined in one signal

End-to-End testing of the antenna with 2nd GEN F&T

- ✓ **Antenna Controller Unit Test:** Performed using spacecraft shadow tracks to validate ground station pointing accuracy.
- ✓ **Shadow tracking of BepiColombo with X- and Ka-band downlink**
- ✓ **Downlink/Uplink Testing:** Verified pointing by comparing expected vs. measured downlink SNR from link budget analysis
- ✓ **Signal Characterization:** Assessed uplink spectral purity and phase noise using mission frequency plans (e.g., GAIA, BepiColombo)

After successful End-to-End testing of the Antenna, the system was declared operational and handed over to operations.



Next Step: New Norcia deployment June 2025



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Conclusion and Acknowledgement

- The 2nd GEN F&T system is **successfully deployed** at Cebreros Deep Space Antenna, and running **24/7 with full redundancy**, supporting operational mission.
- **F&T signal extension** to a **KSAT antenna** for future Lunar support is in progress at Cebreros
- **Next** deployment and testing planned at **New Norcia (Australia)**:
 - **Two Deep space Antennas** and,
 - **Fast-tracking antenna** for Ariane Launcher support
- Foreseen the use the **1st GEN All-European Maser (GAHM)** as maser input for the New Norcia system
- **Special thanks to our industrial partners and the multi-disciplinary ESA team (Flight Dynamics, Antenna experts, Ground Operation engineers,...)**



If you are developing advanced time/frequency technologies and want to validate them in an operational ground infrastructure, get in touch—we're open for collaboration under ESA R&D programmes.

• Thank you!

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