nauisp Element 1 Work Plan 2023

NAVISP Programmatic Lines

	ELEMENT 1	ELEMENT 2	ELEMENT 3
Content	Generate innovative concepts, techniques, technologies and systems linked to the PNT sector, along the entire value chain.	Ensure the readiness of the industry to effectively respond to emerging market opportunities by focusing its activities on products ready for the commercial or institutional market	Support to MS National Programmes
General principles for implementation of the activities	Competitive tender, 100% ESA funding on the basis of yearly work-plan	Continuous open call, unsolicited proposals, Thematic window, ESA co-funding	Continuous open call, unsolicited proposals, Thematic window, 100% ESA funding
Lead for the definition of the activities	ESA via call for ideas, NAVAC, stakeholders interactions, etc.	Industry	Member States

Vision 2023-2025 Program Manager

- Following the initial phases of the programme (Phase 1 – birth, Phase 2 – consolidation), Phase 3 has now to deliver on the original expectations of the programme: *"Generation of European PNT champions"*
- Element 1 is key to the achievement of this objective by preparing the grounds for Element 2 (commercial) and Element 3 (institutional) activities
- Success in Element 2 and 3 will be measured by the ability to attract external stakeholder to co-invest in the programme
- Consequently, a focus of future EL1 workplans will be to prepare promising PPP's by:
  - Advanced prototyping
  - Larger scale demonstrations
  - Economic studies
- In parallel, support to disruptive technologies will continue

nauisp Element 1 Objectives

Perform feasibility studies and viability analysis for the emergence of new concepts in the PNT world (both upstream and downstream)

Contribute to the formulation and implementation of PNT technology strategies and roadmaps

Prove concept of promising PNT-based services

Work Plan 2023 Fundings and Durations

ID	Name	Funding Required (k€)	Duration (months)
EL1-071	Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning	300	12
EL1-072	Navigation Using Machine Learning Applied to Signals of Opportunity	450	24
EL1-073	Trusted PNT for Unmanned Aerial Systems	400	12
EL1-074	Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre	450	24
EL1-075	Bearer Independent Secure Time Transfer	400	12
EL1-076	Low SWAP optical clock control unit	650	24
EL1-077	Technological Enablers of Cellular Networks for PVT Assurance	600	12
EL1-078	Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime	450	18
EL1-079	Reduced size Antenna for Earth Pulsar navigation	300	12
EL1-080	Miniaturised GNSS/LowRF receiver	450	18
EL1-081	Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics	350	12
EL1-082	Low noise frequency tunable microwave generation using photonic integrated microcombs	700	24
EL1-083	Deployable satellite navigation antenna	400	18
EL1-084	Digital Beamforming for GNSS-R Radio occultation payload	600	18
EL1-085	Navigation technologies for Shield nanosatellite	400	18

Work Plan 2023 Preliminary ITT schedule

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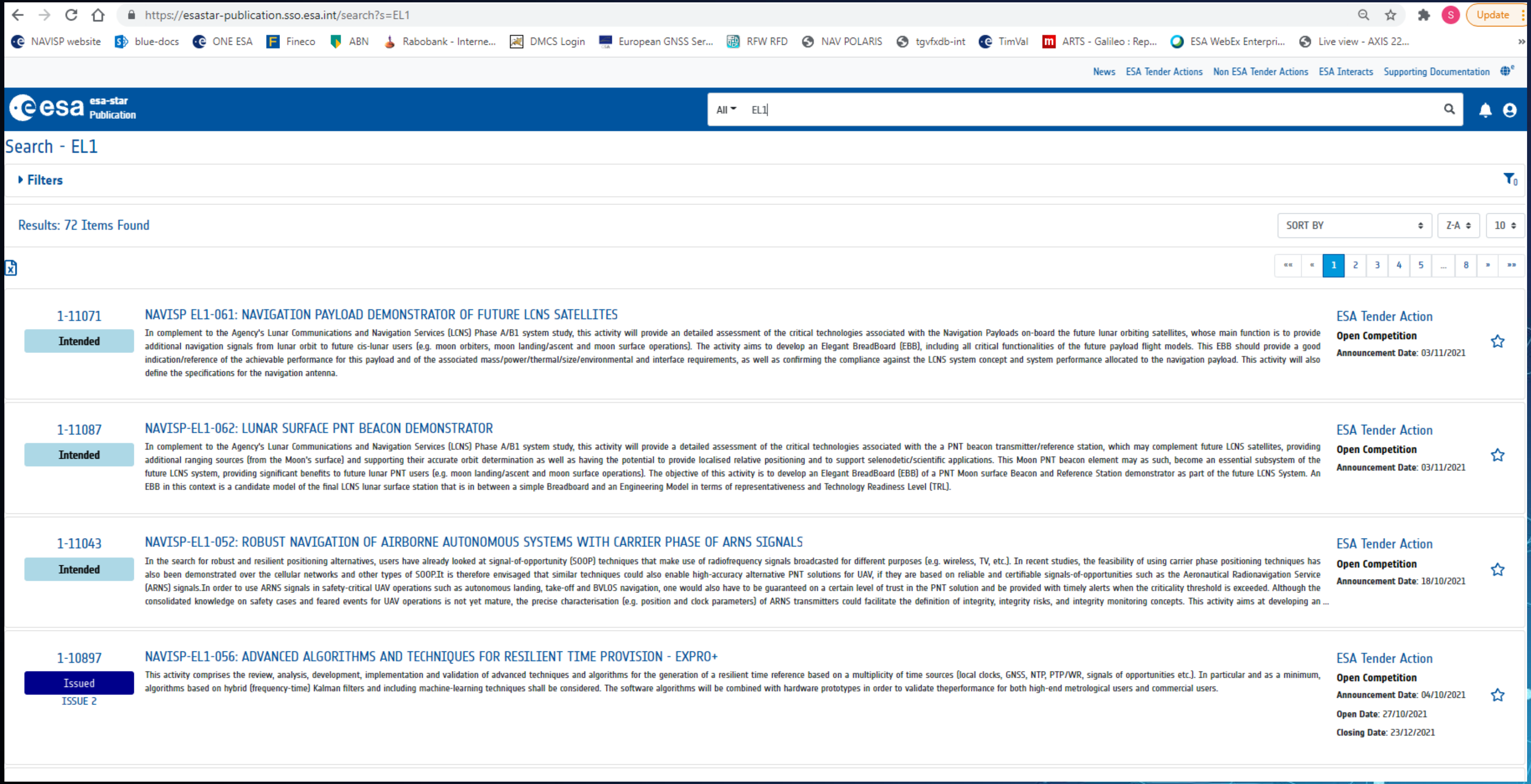
ID	Name	2023				2024				2025			
EL1-071	Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning				ITT								
EL1-072	Navigation Using Machine Learning Applied to Signals of Opportunity	ITT											
EL1-073	Trusted PNT for Unmanned Aerial Systems			ITT									
EL1-074	Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre		ITT										
EL1-075	Bearer Independent Secure Time Transfer	ITT											
EL1-076	Low SWAP optical clock control unit	ITT											
EL1-077	Technological Enablers of Cellular Networks for PVT Assurance				ITT								
EL1-078	Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime			ITT									
EL1-079	Reduced size Antenna for Earth Pulsar navigation				ITT								
EL1-080	Miniaturised GNSS/LowRF receiver		ITT										
EL1-081	Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics	ITT											
EL1-082	Low noise frequency tunable microwave generation using photonic integrated microcombs		ITT										
EL1-083	Deployable satellite navigation antenna			ITT									
EL1-084	Digital Beamforming for GNSS-R Radiooccultation payload		ITT										
EL1-085	Navigation technologies for Shield nanosatellite			ITT									

- ITT expected to be released at the end of the Quarter containing the text "ITT" in the chart
- Expected contract execution as per grey area in the chart
- EL1-075 issued, close date 05/05/23

Where to find Tender Actions

General information: **navisp.esa.int**

Official Tender information **esastar-publication-ext.sso.esa.int/**

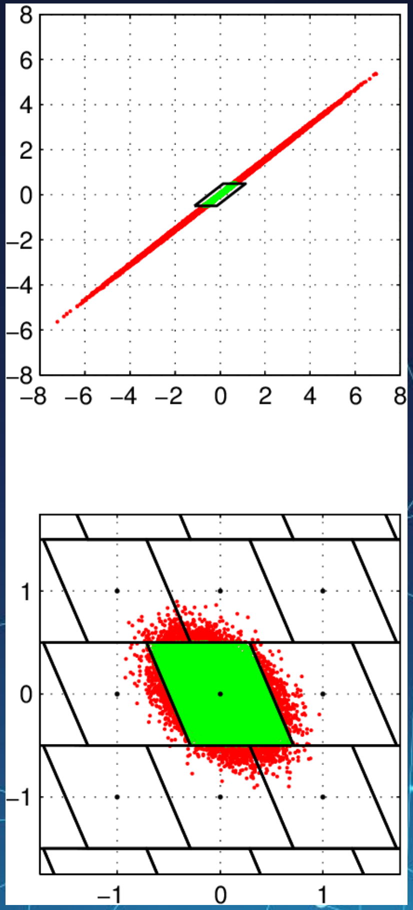


→ THE EUROPEAN SPACE AGENCY

071-Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning

Background and Rationale

- High Accuracy requires usage of phase measurements, which are ambiguous measurements: ambiguities must be fixed to relate phase measurements to ranges.
- Phase Ambiguity Resolution is a stochastic process which needs a minimization search for the correct ambiguities which can require a very large search to find the correct solution: such a search is very time consuming and the search space must be limited to avoid very long time processing, with consequent practical limitation in the reliability of the identified optimal solution.
- This limitation prevents performing integrity processing on high accuracy positioning because any feared event involving wrong ambiguity resolution or interruption of phase measurement would not allow to provide a boundary with a very high probability, as would be required by a reliable, accurate and precise positioning service.



There is the need to improve the AR and precise positioning processes and make them reliable.

071-Technologies for Reliable Ambiguity Resolution (RAR) and Integrity in High Accuracy Positioning

Activity Description

Objective: Apply the Artificial Intelligence (AI) to Ambiguity Resolution (AR) problem on the user side to increase the AR reliability, looking for approaches that focus on multi-frequency and multi-system, which do not necessarily follow the state of the art methodology for AR (float estimation + decorrelation + Integer Least Square).

Description of innovation/Tasks:

- Navigation signal ranging allowing reliable and fast ambiguity resolution in phase measurement.
- Solution for applying AI to AR to improve reliability of high accuracy positioning.
- Review studies on integrity for high accuracy positioning, e.g. TDE Enablers of range-domain rigorous integrity for future safety-critical applications.
- Review state-of-the-art of Ambiguity Resolution.

Expected output:

- Data package (reports, algorithms, results, etc.) providing a complete understanding of achievable capabilities of ambiguity fixing and related positioning performances.
- Real-time board and emulating real-time post-processing software, associated results and user manual.

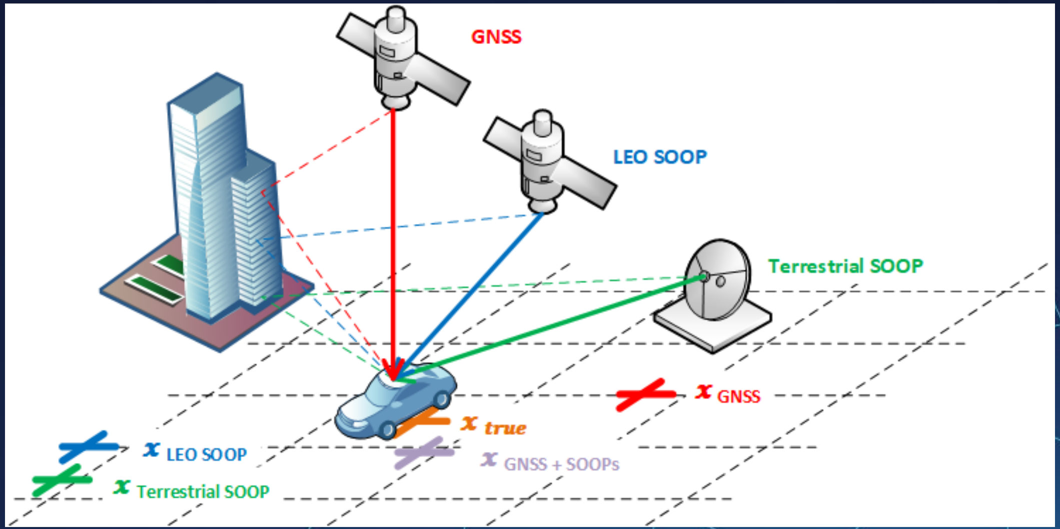
Duration: 12 months **Budget: 300 k€**

072-Navigation Using Machine Learning Applied to Signals of Opportunity

Background and Rationale

- There is an existing need to **optimise navigation** in **challenging environments**, such as deep urban or indoor, and to offer **alternative PNT**. For this purpose, the user may complement the GNSS with space-based (e.g. LEO SatCom) or terrestrial-based (e.g. cellular) **signals of opportunity (SOOP)** to optimise the PNT performance. SOOP could also be exploited similarly in a maritime environment.

- Traditionally, a Kalman Filter is used to integrate the sensor data in the navigation kernel. However, the use of **Machine Learning** may provide numerous benefits when **integrating SOOP** in specific situations:
  a) when the signal characteristics (e.g. modulation, location of transmitter, etc.) are not accurately known;
  b) when the statistical distribution of data is non-Gaussian (e.g. in multipath-rich environments).



072-Navigation Using Machine Learning Applied to Signals of Opportunity

Activity Description

Objective: To optimize PNT performance in challenging environments and offer alternative PNT. This shall be achieved by integrating GNSS and SOOP, or using SOOP only, applying Machine Learning.

Starting point: Traditional integration techniques (e.g. Kalman Filter), serving as benchmarks.

Description of innovation/Tasks: The activity will explore innovative use of Machine Learning for positioning and sensor integration at user level using SOOP, whose characteristics are not perfectly known, in challenging environments (e.g. road, maritime). The activity is novel as the previous machine learning activities focused on:

- EL1-020 Less challenging maritime environments with well-defined sensor characteristics without SOOP,
- EL1-053 Exploring machine learning at central processing facility level for integrity products and not at user level, also without SOOP.

Expected output: Optimized navigation in challenging environments, alternative PNT, and a better understanding of the benefits and the limitations of Machine Learning for Navigation

Duration: 24 months	Budget: 450 k€

073-Trusted PNT for Unmanned Aerial Systems

Background and Rationale

- Urban Air Mobility is expected to become a reality in Europe within 3-5 years. The first commercial operations are expected to be the delivery of goods by drones and the transport of passengers, initially with a pilot on board. [1]
- Satellite navigation systems and hybridisation with inertial sensors can provide high-accuracy uninterrupted solutions to UAS users (can be used for take-off and landing, or precision mission operations)
- Current failure rates of the aforementioned solutions prevent the adoption of UAS in safety-critical operations, because of the insufficient level of trust.
- SWaP considerations, cost of the components, as well as peculiar UAS dynamics (e.g. limited sky coverage) are key drivers of the PNT solutions.
- Protection level concepts could be defined for different navigation sensors, and thus, an integrity concept relying on hybridisation and/or diversification of sensors could be derived. This aims at investigating the aforementioned concepts.

[1] EASA website - https://www.easa.europa.eu/domains/urban-air-mobility-uam

073-Trusted PNT for Unmanned Aerial Systems
Activity Description

Objective: The objective of the activity is to develop a proof-of-concept of a fused PNT architecture for UAS and showcase safe aerial navigation in the context of crowded and regulated airspaces. The developed system shall exploit hybridisation and diversification of navigation sensors for the determination of a trusted PNT solution.

Starting point:

- State-of-the-art in navigation sensors and PNT architectures for UAS and legacy integrity concepts.
- Urban Air Mobility use cases and associated requirements, and regulatory framework (FAA, EASA).

Description of innovation/Tasks: taking into considerations the outputs of past projects like DELOREAN, SONORA, DEGREE and GEODSEY, and UAV related EU Regulations, propose and develop PNT architectures and integrity concepts for autonomous or safety critical UAS operations, and assess the integrity concepts with respect to navigation performance needs (including time-to-alarm assessment within the proposed architectures logic).

Expected output:

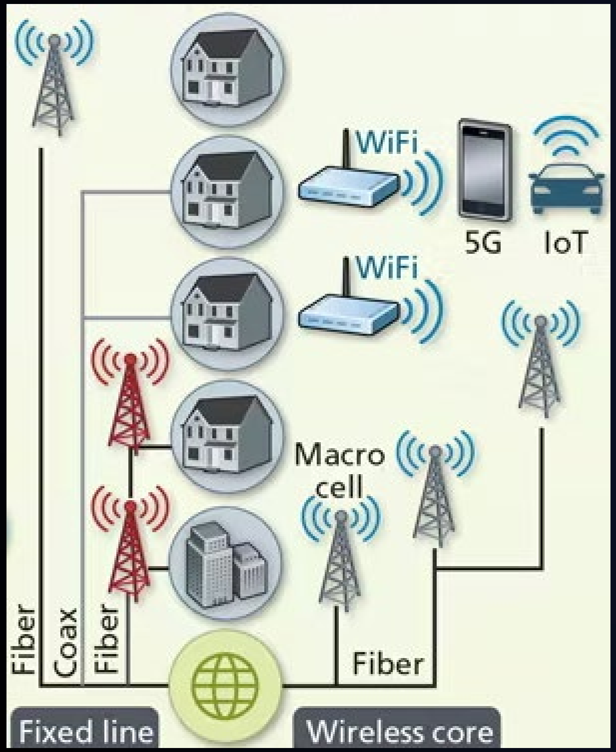
- PNT sensor architectures and associated integrity concepts/Proof of concept.
- Roadmap towards prototyping and a product, paving the way for industrial products, for instance through activities in NAVISP Element 2.

Duration: 12 months **Budget: 400 k€**

074-Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre

Background and Rationale

Telecom

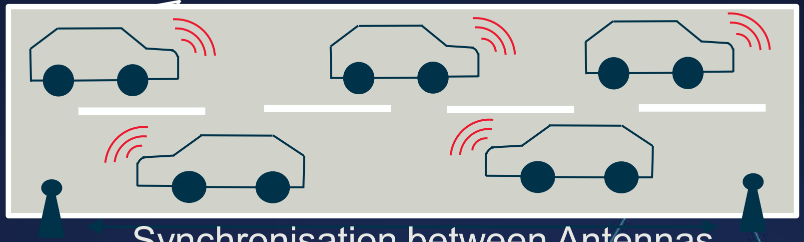


Synchronisation of ground infrastructure

Time synchronisation becomes more and more stringent and widely use on several markets such as telecom, finance, geo-localisation, estimation in real time of the road network, power grid… The performance requirements for time synchronization can reach up to 100 ns.

Nevertheless the performance should not be at cost of the security notably for critical infrastructure. Consequently implementing encryption and/or authentication on high performance time transfer solution over optical fibre would be a good alternative to improve current solution which are not providing high performance and secure time transfer together.

Geo-localisation



Synchronisation between Antennas

Finance

Time stamp shall be traceable to UTC!

074-Assessment of authentication and encryption techniques on high-performance time-transfer over optical fibre

Activity Description

Objective: To develop authentication and/or encryption techniques that are suitable for high performance time transfer over optical fibre, addressing the development of necessary critical building blocks up to a breadboard level.

Description of innovation/Tasks: Time Transfers via GNSS are performant but known for their vulnerability to jamming or spoofing. Alternatively current secure time transfer over optical fiber have low performance (10us accuracy) while high performance time transfer (sub nano-seconds) are not secure.

Combining high performance time transfer over optical fibre with an appropriate authentication and/or encryption method could provide a secure alternative to GNSS. Some timing distribution systems/services on various physical supports exists already (e.g. OPNT/WANTime/Tower), but they don't address fully the authentication and encryption of the information distributed.

Expected output:

- 2 integrated breadboards (master and slave demonstrators) including software and firmware
- report : trade off, design, manufacturing and test documentation and final report
- demonstration of secure time transfer over optical link with improved performance w.r.t current secure time transfer

Duration: 24 months	Budget: 450 k€

075-Bearer Independent Secure Time Transfer

Background and Rationale

A common requirement for achieving an assured Position, Velocity and Time (PVT) service is to securely initialize the receiver with coarse time synchronization.

For additional security, this information can be provided periodically during the mission.

A space-based infrastructure is the most attractive option to achieve a global service coverage.

Relying on external network provider might be difficult for some use case (e.g. limited coverage, cross border operations, different Quality of Service commitment).

Several telecommunication constellations are already operative and standardization is undergoing for the next generation (e.g. 5G non-terrestrial networks - NTN).

075-Bearer Independent Secure Time Transfer
Activity Description

Objective: To demonstrate the efficient provision of ubiquitous secure time transfer service relying on satcom constellations using standardized protocols and RF technologies.

Description of innovation/Tasks: The activity will investigate the feasibility to efficiently provide an ubiquitous and secure time transfer service relying on satcom constellations using a combination of:

- standardized protocols, guaranteeing the authentication and encryption (if needed) of the process (e.g. NTS, a version of Secure NTP, Roughtime, a coarse network synchronisation designed by a major IT company, TWSTFT, a satellite-based synchronisation protocol)
- radio frequency common communication technologies (e.g. WiFi, 5G, UWB).

Furthermore, the activity will investigate the possibility to opportunistically combine satellite and terrestrial infrastructure in order to increase the capacity (limited in case of satellite-only usage), as well as efficient handover strategies.

Expected output:

- Survey of state of the art on secure time transfer protocols technologies
- Breadboard and test report
- Roadmap for commercialization, including potential NAVISP-EL2 activities

Duration: 12 months **Budget: 400 k€**

076-Low SWAP Optical Control Unit

Background and Rationale

The need for high-accuracy, resilient holdover techniques to be available in the event of GNSS signal denial has been widely emphasised. Whilst current microwave GNSS satellite clocks, and best-in-class commercial microwave clocks, provide holdover for relatively short periods in situations where GNSS system disciplining is lost, it is clear that future resilient PNT systems will need to maintain improved accuracies over longer fly-wheeling intervals. One solution for this is to develop robust low-SWaP optical oscillators and clocks with better accuracies than microwave systems. Significantly higher accuracies (by factors of up to x100) have already been demonstrated by the best national metrology laboratory-based optical clocks.

Solutions focussed on future optically-augmented PNT applications include the use of high TRL optical reference cavities capable of operating either in space or in terrestrial mobile environments. Optical cavity-stabilised lasers, where the cavity material is ultra-low-expansion (ULE) glass, have demonstrated very low and well-characterised frequency drift at the level of 1 part in 10^{15}, where the frequency drift can be removed by opto-electronic feed-forward techniques.

Compared to other approaches (e.g. Horizon) where one single laser wavelength, or none, is foreseen, this Optical Control Unit is based on the requirement for the control of multiple laser sources: wavelength knowledge, wavelength drift control and duty cycle. For Strontium optical frequency standard/clock there are 6 wavelengths. With multiple wavelength requirements, additional complexity comes, but also vastly enhanced performance.

076-Low SWAP Optical Control Unit
Activity Description

Objective: to develop a dual-axis cavity clock control unit to TRL 6/7. In particular, developing this key component of an optical atomic clock, such that a fully integrated unit is available with appropriate size, weight and power consumption for terrestrial mobile applications. The unit should also be developed to have robustness to vibration, shock and radiation conditions consistent with launch and relevant orbit conditions for use in space applications.

Description of innovation/Tasks: ULE glass dual-axis cubic cavity is the leading vibration- and force-insensitive optical reference cavity technology for operation in any orientation, in normal gravity or micro-gravity in space. It can provide complete frequency stabilisation control of the optical clock laser (clock transition) and auxiliary lasers needed for an optical clock via dual axes of the cube, which will offer high accuracy, robustness, resilience and extended holdover times for PNT systems.

The main tasks to be performed will be:

- characterisation of ULE glass material growth orthogonal axes, optimal mounting arrangements and mirror finesses across the dual axes (very high finesse low thermal noise coating on clock axis, medium broadband finesse on auxiliary axis),
- performance testing (vibration insensitivity, frequency stability and long-term drift) and environmental testing (vibration/shock, thermal vacuum and radiation hardness), digital opto-electronic servo system with components that have space-compatible equivalents.

Expected output: Fully functional and environmentally-tested cubic cavity in vacuum chamber with thermal and frequency stabilisation at world-leading performance for a space-deployable cavity, which is a critical component for ultra-high-stability lasers and high accuracy optical atomic clocks (the other components being the physics package, the laser and the frequency comb).

Duration: 24 months **Budget: 650 k€**

Background and Rationale

Cellular networks have various built-in security features including access control, mutual authentication, and key management, which could be evolved to provide technological enablers for PVT assurance.

An efficient solution to protect from PVT spoofing is the use of symmetric cryptographic mechanisms to render the ranging signal unpredictable to the potential attacker.

The concept requires sophisticated key management systems or frequent rekeying for scenarios in which the users cannot be trusted.

These workarounds could be facilitated by cellular networks technologies. In addition, cellular networks themselves have become relevant sources of PNT, using unencrypted signals.

077-Technological Enablers of Cellular Networks for PVT Assurance

Activity Description

Objective: To study, design, and demonstrate the use of the cellular networks technologies for PVT assurance and encryption of ranging signals, considering robustness against post-quantum cryptography.

Description of innovation/Tasks: The activity will study, design, and demonstrate the use of cryptographic information securely stored on the SIM card or secure element for the encryption of GNSS ranging signals and the provision of native encryption of cellular networks PNT signals to support PVT assurance.
The feasibility of post-quantum cryptography for the aforementioned security solutions (e.g. delivery of longer cryptographic keys by cellular networks) also needs to be investigated.

Expected output:

- Survey of state of the art on cellular network technologies for cryptographic operations
- Breadboard and test report
- Roadmap for commercialization, including potential Navisp EL2 activities

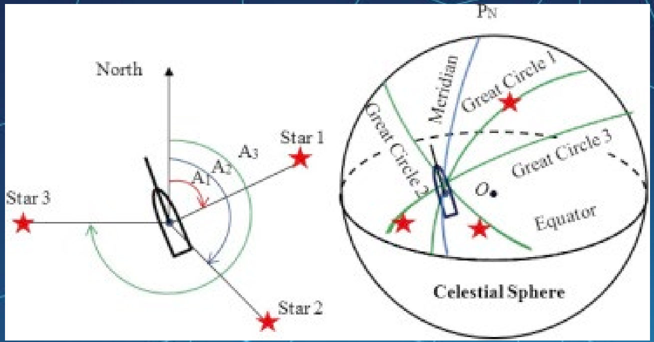
Duration: 12 months **Budget: 600 k€**

078-Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime Background and Rationales

These days, GNSS is fundamental for navigating but it is still fragile: it can be spoofed or jammed.

Using a sextant to determine a star position relative to the horizon, sailors have marked ship locations for centuries using Celestial Navigation (CN). Nowadays technology would allow automatic adoption of this technique, extending its utilization to daylight and exploiting not only stars, but also artificial satellites as reference sources. The technology is being revisited for maritime use cases (e.g. DARPA). The technology can consider other celestial bodies as well as the sensing in non-visible spectrum to increase availability during daytime or in cloudy conditions.

Similarly to GNSS, CN can then be combined with different sensors, e.g. inertial sensors, to mitigate the drawbacks of each single technique, e.g. exploiting the CN for calibrating bias and drift of the inertial sensors while using inertial sensors to predict the motion in the short term.



The exploitation of Celestial Navigation with sensors allowing weather and light independent measurements for Absolute Autonomous Navigation and Timing for autonomous vessels can provide a safe and robust alternative to GNSS.

078-Autonomous Alternative Absolute Navigation (AAAN) technologies for maritime Activity Description

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Objective: This activity aims to study and demonstrate new concepts for absolute autonomous PNT for the maritime environment, in particular for autonomous vessels in open seas.

It will include a detailed assessment, trade-off and demonstration via prototyping, of the tangible benefits provided by adopting Celestial Navigation with multi-band sensors for detecting natural and artificial celestial targets during night and day independently of the meteorologically conditions.

Description of innovation/Tasks:

- **At technological level:** modernisation of CN and comprehensive hybridisation of alternative technologies, with target accuracy better than the existing CN devices (<100m, TBC).
- **At the level of the vertical:** for the maritime, AAAN could become a fundamental resource for autonomous vessels, for resisting spoofing and jamming attacks, complementing and being an alternative backup solution to GNSS with Inertial/Visual Navigation.
- Review studies on autonomous vessels, e.g. NAVISP-EL1-020 Maritime AI-NAV
- Review state-of-the-art of APNT and CN for Maritime
- Develop absolute navigation solution alternative to GNSS adaptable to very different ship sizes.

Expected output:

- Autonomous continuous robust absolute navigation for autonomous vessels in open sea (depending on the achievable accuracy, could also support artic navigation). Spin-off could benefit many more users (civil aviation, aid to Search&Rescue, etc.).

Duration: 18 months **Budget: 450 k€**

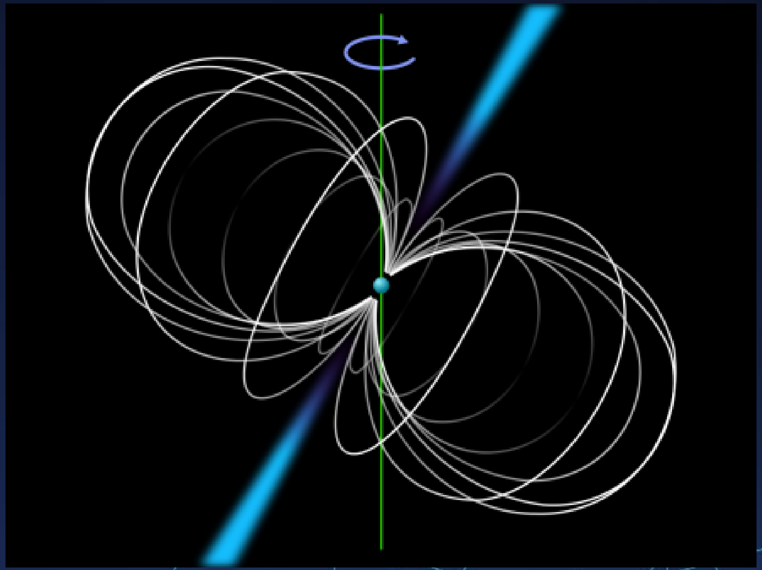
079-Reduced size Antenna for Earth Pulsar navigation

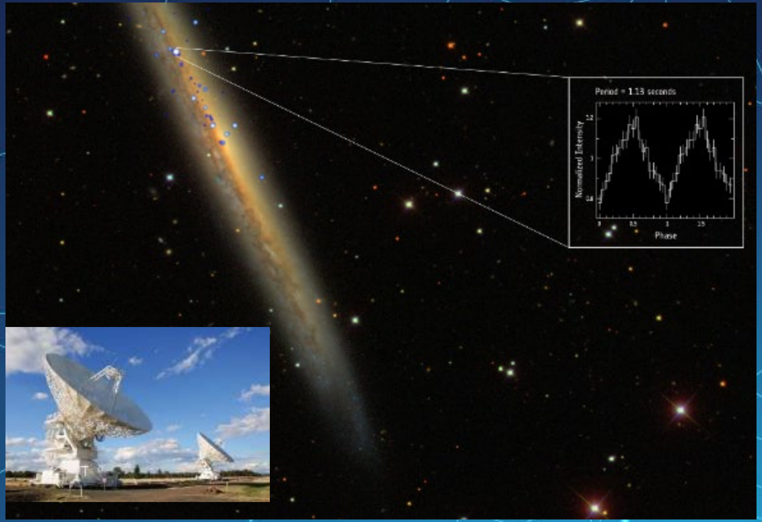
Background and Rationale

Pulsar are rapidly rotating neutron stars emitting beams of radiation periodically, some with very high stability.

Since every pulsar has a different frequency, they can be used in a navigation system like beacons, and in timing (see EL1-006).

Emission occurs in all spectrum (infrared, visible, RF, X-ray). For space navigation, detectors in X-ray are preferred for their size, but detectors in the visual range could also be used; on ground RF is preferred for accuracy, but this requires big RF telescopes.





Researchers also discuss current detector technologies such as silicon pore optics, silicon drift detectors and “active pixel sensors” that might be used in missions that would adopt the pulsar navigation.

The need for an autonomous navigation system and a pulsar’s natural time-keeping abilities will probably lead to pulsar navigation in the future.

079-Reduced size Antenna for Earth Pulsar navigation
Activity Description

Objective: Design a prototype reduced-size RF antenna, or antenna array, for usage with pulsars on Earth

Description of innovation/Tasks:

- Pulsar detection on Earth is limited in X-ray (atmosphere is opaque in that range), and RF detectors are currently large (typically 25m or more in diameter):
  - a novel way to focus EM energy at RF (around 200-1600MHz) on a newly shaped antenna, or onto an array of suitable antennas (exploiting for example aperture synthesis interferometric processing, see the Very Large Array), should allow to obtain a decent signal to noise ratio for the pulsar pulse train, at least for an appropriate class of pulsars
  - tradeoff will include high gain steerable for single pulsar observations, wide beam array for multi pulsar observations, and inputs for higher navigation processing operational concept
- survey the current Pulsar detectors technologies state-of-the-art
- identify potential use cases for application (maritime freight transport, military ships,…)
- design, develop and verify the prototype RF antenna, install it in a realistic environment and perform validation tests with real Pulsar data

Expected output:

Prototype antenna, or antenna array, with associated design and verification report based on real data collected on Earth, demonstrating the recovery of pulsar pulses with adequate signal to noise ratio

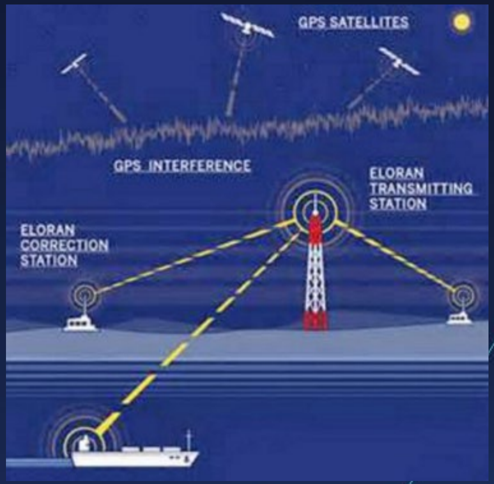
Duration: 12 months **Budget: 300 k€**

080-Miniaturised integrated GNSS and Low Frequency Navigation Receiver

Background and Rationale

GNSSs are typically operating from MEO, using spread spectrum techniques and having a large coverage by each satellite, therefore the user receiver signal power received on ground is extremely low, 'buried' under the thermal noise level.

Because of that, the GNSSs susceptibility to RFI interference, both generated locally with inexpensive means like Personal Privacy Devices or more regionally with state-level RF counter-measures, is relatively high.



In this context, the complementary usage of Low Frequency navigation systems, with a completely different system design, performance and weakness, helps reducing the current societal dependability on GNSSs.

Enhanced-LORAN (eLoRAN) is the latest of the low-frequency LOng-Range Navigation (LORAN) hyperbolic systems, and provides a PNT service for use by all modes of transport (land, maritime and aeronautic).

New eLoran infrastructure is being installed in a number of regions around the globe and there is renewed activity and interest in Europe.

080- Miniaturised integrated GNSS and Low Frequency Navigation Receiver

Activity Description

Objective: Enhance geo-security and precision timekeeping with e-LORAN, through its jam- and spoof-resistant signal characteristics of high transmit power and low carrier frequency.

Description of innovation/Tasks:

- NAVISP-EL1-065 will develop a prototype eLoran miniaturised antenna for handheld applications; to complement and enhance this upcoming EL1 activity, it will be valuable to have a professional market, handheld, prototype miniaturised integrated GNSS and eLoran receiver.
- Taking stock of other activities on combining Medium Frequency DGNSS, AIS, and eLoran, design, develop and verify a prototype miniaturised integrated GNSS and eLoran receiver to investigate feasibility of a complete professional handheld low size, weight and power (SWAP) GNSS/eLoran terminal.

Expected output:

"Proof-of-concept" prototype miniaturised integrated GNSS and eLoran receiver with associated documentation.

Duration: 18 months **Budget: 450 k€**

081- Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics Background & rationale

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Recent advances in both the development and heterogeneous integration of Lithium Niobate ($LiNbO_3$) on Silicon Nitride for high-speed modulators have brough with it the possibility to combine several functionalities on a compliant heterogeneous platform. In the progress towards higher efficiencies, a reduction in system complexity and enhanced reliability for system critical applications such as navigation and PNT, can be envisaged. Navigation by RF techniques and timing can all benefit at system level, but some development first needs to be implemented.

Other transmitter/receiver and detector components are also facilitated directly by this technology. Frequency sampling, a substantial element of the Analogue to Digital Conversion (ADC) process, has been facilitated by the development of short pulse (mode-locked) devices. However no efficient mechanism and technological platform has been available to transform ADC, direct RF sampling to an adequate level of maturity, until now. With the level of heterogeneous integration now possible, and continually being enhanced, the possibility to include optical intersatellite communication and ranging in both the optical as well as RF frequency domain becomes possible.

$LiNbO_3$ modulators are the workhorse for the modulation of laser light, and key components in optical coherent communications systems and for microwave photonics. Triggered by the development of $LiNbO_3$ on insulator in China by NanoLN, ridge waveguide based integrated modulators that operate with CMOS levels have been demonstrated, that are now commercialized via Hyperlight in the US. These modulators have half voltages below commercial $LiNbO_3$ and can transform integrated photonics by offering a material with the highest Pockels coefficient.

However, to date, despite impressive advances, it is not possible to manufacture conventional photonic IC in this material due to the lack of suitable etching techniques. In addition, the losses are x10 higher than today's commercial foundry level silicon nitride, and a corresponding Process Design Kit (PDK) is not available. One can view the PDK as the design guidelines from which the entire photonic chip design can be simulated, virtually created, fabricated with high lithographic precision, and even virtually tested. Viewed more broadly Europe lacks a $LiNbO_3$ integrated photonics technology and foundry.

081- Lithium Niobate Photonic integrated circuit based high speed, low voltage modulators for microwave photonics Activity description

esa

Objective: Based on a recent patented breakthrough (EPFL), it has been possible to deep etch $LiNbO_3$ with excellent optical losses and high lithographic precision based on a diamond hard mask. This process opens the route to a PDK that includes also complex photonic circuitry and a path towards commercial foundry scale deployment. The goal of this activity is to develop a full suite of high-speed devices, IQ (Quadrature) modulators, Mach-Zehnder (MZM) modulators, splitters and delay lines based on $LiNbO_3$ integrated photonics.

Description of innovation/Tasks:

- Develop a Process Design Kit (PDK) for $LiNbO_3$ integrated photonic strip waveguides to enable design methodologies to be implemented
- Demonstrate 100 GHz MZ modulator with half voltage below 2 Volts
- Demonstrated 100 GHz IQ modulators with large power handling and half voltage below 2 Volts
- Establish low loss coupling interfaces with 3dB fiber-chip-fiber losses
- Transfer the technology to a high-tech startup for foundry

Expected output:

The output of the project would be the development of a PDK for $LiNbO_3$ for the development of high-speed low voltage modulators for uses in PNT. Additionally, the development of MZ and IQ modulators shall also be functionally verified in domains of primary relevance to PNT.

Duration: 12 months **Budget: 350 k€**

082- Low Noise Frequency Tunable microwave generation using photonic integrated microcombs

Background and Rationale

Ground based optical free space communication experiments have enabled >1 Tb/second communication links based on the multitude of carriers that are individually modulated to carry information. Optical frequency combs with line spacings that match the ITU grid have potential to implement free space communications in space.

These advances utilize the unique features of microcombs: in contrast to conventional mode locked lasers, microcombs (also called Kerr frequency combs) can operate with line spacings directly in the microwave range, relevant to optical communications, can accommodate clock signals, and can output spectra that cover a full optical octave, which are necessary for coherent microwave-to-optical frequency links. Despite major advances in microcombs, a challenge has been to develop microcombs that have sufficient power for direct use of the individual comb lines for free space-based communications, which necessitates the integration of amplifiers. Recent advances in both the development of heterogeneous integration of Lithium Niobate on Silicon Nitride for high-speed modulators, as well as the development of erbium on chip amplifiers, make high power transceivers that combine on a single die, or use multiple dies, to realize a wafer scale, foundry compatible, and low Size Weight & Power (SWaP) and power efficient transmitters and receivers.

Today's lowest noise optoelectronic oscillators achieve exceptionally low phase noise and are based on optical frequency division using femtosecond laser combs. However, these high performing solutions sacrifice spectral purity for size, weight, and power as well as environmental sensitivity, which makes them unsuitable for space applications. Over the past decade a new technology for frequency comb generation, soliton micro-combs, has emerged. The miniaturization and integration of frequency combs through lithographic microelectronic fabrication have established a new paradigm in optical microsystem capability, cost, performance, and manufacturability.

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Activity Description (1)

Objective: One objective shall be to demonstrate the advantages of photonic integrated micro-combs and develop integrated laser sources with ultra-low phase noise performance to explore the implementation possibilities within PNT applications.

As a preliminary step the phase noise performance shall meet or exceed that of the best discrete oscillator modules yet occupy a compact volume typical of a far noisier chip-scale voltage-controlled oscillators (VCO).

The proposed development also requires a demonstration of wafer scale (manufacturable) photonic microwave generation systems. These shall provide low noise microwaves, based on the conversion of a soliton pulse stream into a microwave signal using direct detection with fast commercial diodes. The approach shall be based on recent advances that have demonstrated that soliton microcombs can generate low noise X- and K-band microwaves and the demonstration of hybrid and heterogeneous integration of this technology.

The platform, based on the ultra-low loss integrated photonics circuits based on Silicon Nitride shall also include MEMS based Aluminium Nitride (AlN) technology for ultrafast tuning of the generated microwaves over >25% of the carrier frequency for fast frequency reconfiguration. Together a demonstration of a new class of low noise microwave oscillators based on photonic integrated circuits based micro-combs shall be developed.

Finally, the capability of this type of platform to perform both transmission and receiver functions shall be included to position this technical approach for applications in free-space optical communication and ranging.

Description of innovation: The proposed project approach is to lay the foundation for space based optical communications in a navigation context, by developing a frequency comb-based transmitter for coherent optical telecommunication, which is space compatible, compact and in which all key components are based on photonic integrated circuits.

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Activity Description (2)

Tasks: Demonstrate:

1. Greater than 1Tb/second data rate in a laboratory communication experiment
2. Optical Analogue to Digital Conversion (ADC) and Photonic assisted ADC
3. The transmission and detection capabilities for typical free space applications in LEO/MEO
4. Optical Oscillators delivering low jitter clock signals (Photonic Integrated Low Noise Microwave generation)
5. Photonic sampling (photonic RADAR and subnoise detection)
6. Laser oscillators using hybrid integrated III-V lasers (including laser integration and photonic packaging)

Expected output of Activity

The main output shall be the demonstration of the capability of photonically integrated optical frequency combs in the receiver and transmitter path for implementation in PNT systems for Optical ADC, low jitter clock signals and photonic assisted detection systems.

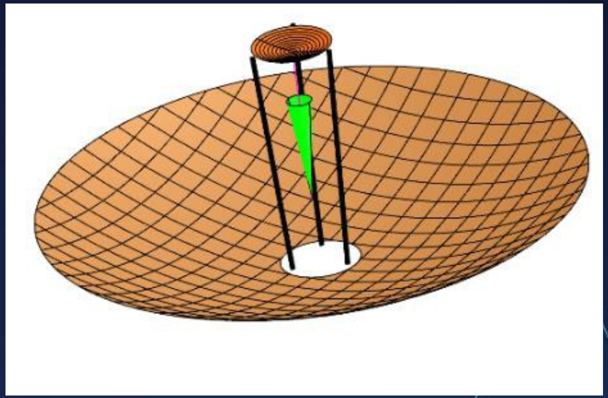
Duration: 24 months **Budget: 700 k€**

083- Deployable satellite navigation antenna
Background and Rationale

The flourishing of utilisation of small and nano satellites in LEO orbit, and the need for ever better navigation accuracy, suggests the study of (relatively) high gain deployable navigation receiver antennas, in new frequency bands, that can be stowed at launch.

In a small satellite, this antenna should allow to achieve better performance when deployed than equivalent non-deployable patch, (double-)helix or array antennas with similar size and weight at launch. In other words, a deployable antenna provides an increased antenna size compared to the size of the spacecraft, however with minimum impact on spacecraft weight.

With (relatively) higher gain, this antenna could also find application on satellites in cis-lunar regions and, if more antennas are deployed jointly, find application also for attitude determination.



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083- Deployable satellite navigation antenna

Activity Description

Objective: Design a prototype deployable satellite navigation antenna in X/Ku-Ka band

Description of innovation/Tasks:

- application of existing X-band satcom technology to satellite navigation
- review the state-of-the-art regarding deployable antennas
- identify possible use cases for the usage of deployable antennas on small satellites for the navigation function
- tradeoff different design solutions. Shapes could be paraboloids for high gain, high directivity antennas, but could be also different helix wider beam antennas, to avoid the need for pointing mechanisms. Appropriate attention to be placed on critical navigation requirements like phase stability, group delay stability and cross-polar attenuation.
- design, develop and verify the deployable antenna in a laboratory environment.

Expected output:

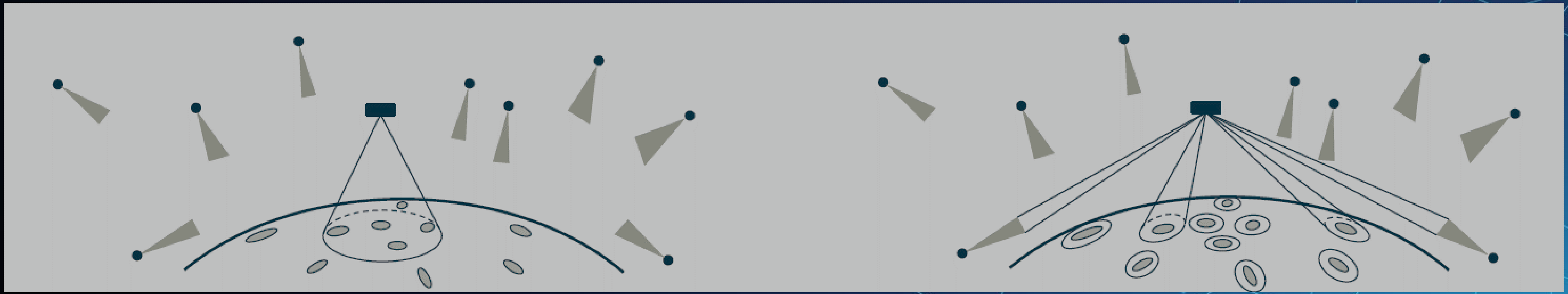
Prototype antenna with associated design and verification report based on laboratory data, demonstrating the reception of navigation signals with adequate signal to noise ratio.

Duration: 18 months **Budget: 400 k€**

084- Digital beamforming for New Space GNSS-R and Radio Occultation payloads

Rationale

- GNSS Radio Occultation is a well-established technique while the younger GNSS Reflectometry has seen a rapid evolution around the world, in particular, after the launch UK-DMC satellite in 2003
- Some examples of GNSS-R missions flying today are: the NASA's CyGNSS 8-satellite constellation, the Spire Global cubesat constellation, the FSSCat cubesat, the Chinese Bufeng 1 Twin Satellites and China's FengYun-3E (FY3E) polar-orbiting meteorological satellite series
- ESA has plans to launch the PRETTY cubesat end of 2022 and HydroGNSS Scout mission end of 2024
- However, none of the GNSS-R and Radio Occultation payloads can take full advantage of the potential given by the many reflection points available from all GNSS transmitters, the reason being limited field of view coverage: a high performant beamformer would be a game changer.



State-of-the-art - Single beam = high gain but poor coverage
Only some reflections or radio-occultations received.
If large coverage is wanted, then SNR achieved is poor

Digital Beamformer = high gain and wide coverage
Many reflections and radio-occultations received,
High accuracy achieved

084- Digital beamforming for New Space GNSS-R and Radio Occultation payloads

Activity Description

Objective: to design and prototype a digital beamforming processor, suitable for new space payloads for small/nano platforms, capable of generating multiple simultaneous beams for GNSS-R and Radio Occultation applications

Description of Innovation/Tasks: First time development of on-board autonomous digital beamforming of multiple beams for small/compact new space payloads, with medium/large number of channels supported. The innovation also relies on large number of channels, dynamic beamforming, low power.

The activity shall initially review the digital beamforming requirements for GNSS-R and Radio Occultation payloads, define a digital processor implemented in a power-efficient manner, develop power resource efficient digital beamforming techniques and algorithms and demonstrate the function in a representative breadboard.

Expected output

This activity will deliver a representative breadboard demonstrating:

1) Compact, New space compatible payloads with much higher measurement accuracy, thanks to highly improved signal-to-noise ratio,
2) Increased field-of-view per satellite

Duration: 18 months **Budget: 600 k€**

085- Navigation technologies for a Shield nanosatellite

Background and Rationale

One of the ESA's accelerators for the usage of space is:

- PROTECTION OF SPACE ASSETS, to ensure resilient availability and functioning of space infrastructure on which Europe's economy and society relies for day-to-day life.

According to the DoD Space Surveillance Network, there are ~34,000 pieces of orbital debris with diameter greater than 10cm. This is the portion of objects "tracked".

There are also ~900,000 objects between 1 and 10 cm and ~128 million pieces smaller than 1 cm. Due to the extremely high orbital velocities (26,000km/h), the debris poses a high risk not only for human space flight, but also for satellite operations in general.

The usual measure, against the risk of collision with 10cm objects, is to perform a collision avoidance manouvre. ISS is also protected against non-tracked 1 cm objects by shielding (with "Whipple shields").

Complementary to the efforts of the Space Safety Program to deploy a constellation of satellites to statistically monitor the debris that cannot be detected from ground, in general, for the smaller objects, local dynamic protection could be established, taking inspiration from anti-missile protection weaponry (e.g. Patriot), UAV's automated navigation technologies and sixth generation fighters "loyal wingman" conceptual design.

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085- Navigation technologies for a Shield nanosatellite
Activity Description

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Objective: Perform a system study on the navigation technologies enabling the design of a nano satellite that accompanies a master satellite, shielding it from small debris

Description of innovation/Tasks:

Instead of making the entire satellite mechanically more resilient (impacting heavily the mass budget), implement sturdiness on a small moving and agile small companion, assuming availability, in the near future, of suitable materials and shapes to ensure that unacceptable fragmentation does not occur after the impact.

Study the design, development, operations of a (set of) slave inexpensive nanosatellite(s) which would fly along with a master satellite.

Main functions:

- Formation flying with master satellite, communicate with it, maneuver to put themselves in the trajectory of the debris, calculated with imaging and processing done on board, integrating the latest automation, navigation and communication means from drone technology
- Key features of nano-satellites (for which best effort assumptions will be taken in the study): sturdiness (composite, or other material, shield), rely on deflection or absorption, whichever provides more effective protection, maneuverability (gas jet only) also after being hit, capability to de-orbit or graveyarding, stripped-down to minimum, inexpensive

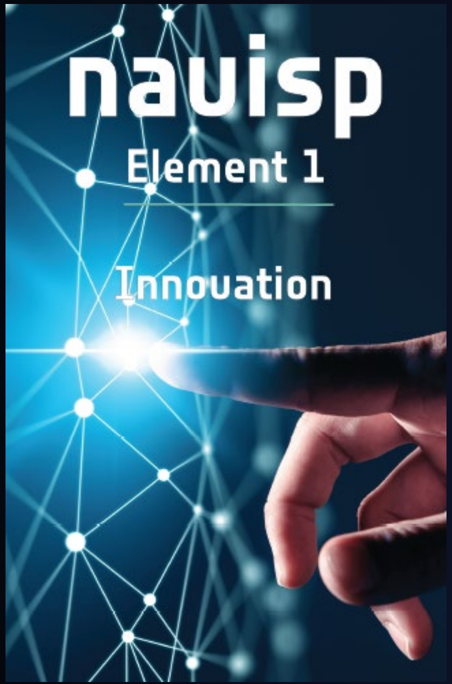
The main PNT technologies to be designed are: time synchronization with the master, formation flying (relative attitude/positioning and navigation determination and control), perception of the surrounding environment, impact trajectory and relative attitude calculation, maneuvers execution, de-orbiting/graveyarding

Expected output:

Report identifying use cases, navigation technologies required for the function, design of shield nanosatellite and master satellite data interface, cost and schedule estimates. Contract will be implemented in Phases.

Duration: 18 months **Budget: 400 k€**

Thanks for your attention!



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