IMPACT ASSESSMENT OF ESA EARTH OBSERVATION EARLY R&D ACTIVITIES

Digital Altimeter Integrated Circuit Design

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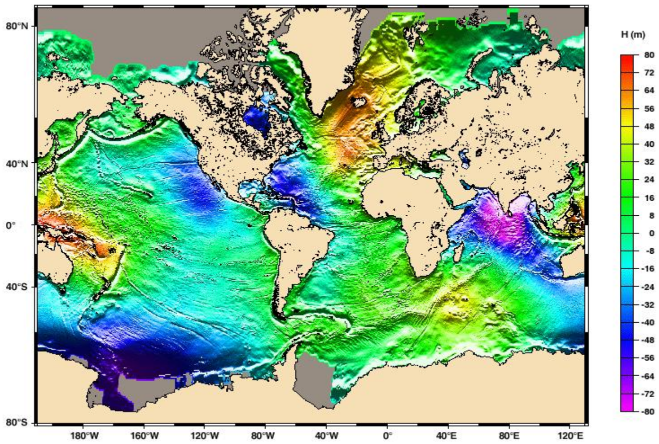
Through the determination of surface elevation over time, satellite altimetry offers invaluable insights into key environmental and geophysical processes …

Satellite altimetry is a pivotal tool in the study of the Earth's surface, offering the ability to measure ocean's surface elevation with a high degree of precision over time. By deploying altimeters - devices that measures altitude by determining the distance above a fixed reference point, such as sea level - from space, scientists and policymakers can gain valuable insights into key environmental and geophysical processes that impact the Earth, including the monitoring of sea level rise and ice sheet dynamics. The European Space Agency (ESA) uses altimeters for this purpose onboard the *Sentinel* missions as part of the Copernicus programme.

The key value of satellite altimetry lies in its ability to provide consistent, global coverage of sea and inland waters surface elevation changes that are central to efforts in identifying long-term trends, and key to detecting variations which may indicate underlying environmental changes. This technology therefore plays an important role in climate science, enabling the assessment of key indicators including the thermal expansion of oceans and the rate of polar ice melt, both of which contribute to global sea level rise. Satellite altimetry also enhances our understanding of ocean dynamics; providing accurate measurements of sea surface height, which can be used to infer currents, wave heights, and the distribution of heat within the ocean.

Figure 1: Example of global mean sea surface height derived from radar altimeter data



Source: ESA[1]

[1] ESA (2005). Taking measure of the world: radar altimetry in spotlight at Venice event. Available at: https://www.esa.int/Applications/Observing_the_Earth/Taking_measure_of_the_world_radar_altimetry_in_spotlight_at_Venice_event

Beyond climate change monitoring, satellite altimetry data can also be harnessed to support several other practical applications. These include disaster management, navigation, and infrastructure planning. For example, accurate elevation data can improve flood modelling and help to develop and validate early warning systems, allowing policymakers and response agencies to prepare for, and mitigate against, the impact of extreme weather events. In geophysical applications, altimetry also contributes to the broader understanding of Earth's gravitational field and tectonic processes. Through the exploitation of altimetry data, and the identification of variations in surface elevation, scientists can develop models detailing subsurface structures and geodynamic phenomena, offering insights into the planet’s tectonic movements, and the distribution of mass across the planet.

Satellite altimetry is therefore an indispensable tool for monitoring and understanding the Earth's changing environment. Its applications span a wide range of domains, providing data that not only contributes to scientific discovery, but also supports environmental management and the development of institutional and community resilience in the face of global challenges.

… and the continued development of cutting-edge digital altimeter technologies, supported by ESA funding can help to sustain European leadership …

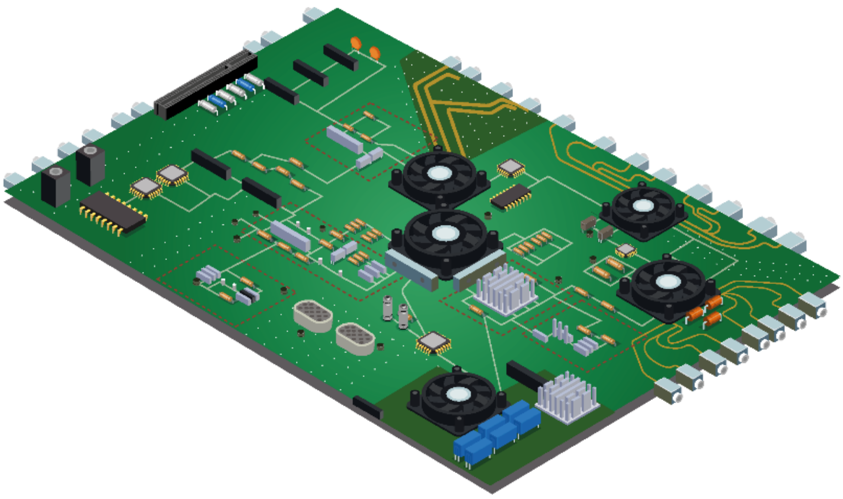
As global competition across the space sector intensifies, Europe's ability to advance technologies such as the digital altimeter will ensure it remains at the forefront of scientific discovery. In doing so, Europe takes a significant step towards strategic autonomy, even though several US components are still necessary for the development of the studied function.

This study, undertaken by Thales Alenia Space France (TAS), received €1 million in funding through the ESA FutureEO programme.[2] Over the course of the study, TAS successfully demonstrated and validated a proof-of-concept for the design of a Digital Altimeter Integrated Circuit Design.

[2] The ESA FutureEO programme is a long-term initiative aimed at developing innovative EO technologies, missions, and applications. It focuses on developing research, including promoting the use of new observation techniques. By supporting early-stage research and development projects, and exploring novel mission ideas, FutureEO seeks to maintain European leadership in EO.

The technology introduces several advancements over traditional altimetry components, primarily through the integration of high-speed digital processing and improved synchronisation. Unlike existing systems that rely on separate analogue and digital components, this approach consolidates functions into a compact and modular Receive and Transmit Module (RT-Module). This modularity allows the system to be adapted for use across a range of radar altimetry applications, including nadir, interferometric and swath altimeters, without requiring extensive redesigns.[3] Its compact design, reduced power consumption, and improved signal clarity set a new standard for high-precision radar altimetry in Earth observation and climate monitoring.

Figure 2: Representative illustration of the Digital Altimeter Integrated Circuit Design



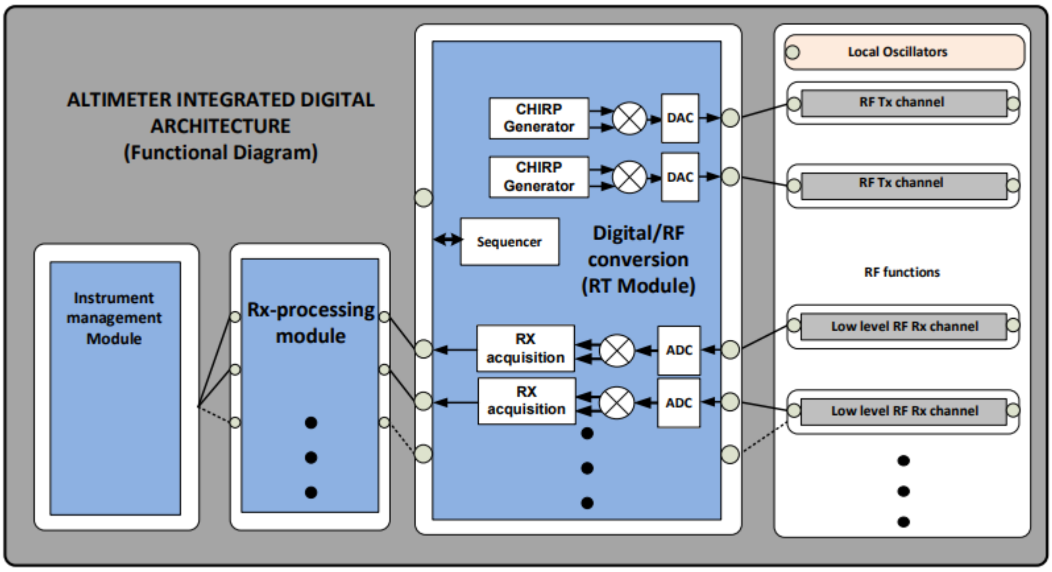
Source: Spatial Design Hub based on Thales Alenia Space image

The activity was originally scheduled to take place over 24 months, but was delayed by unforeseen events, including the COVID-19 pandemic. Work commenced in 2019, technical work concluded in 2023, and the project was formally closed at the end of 2024. The activities were structured into three main phases. The first phase involved an assessment of system requirements, component selection, and the identification of design trade-offs to establish the most effective architecture for the RT-Module. Frequency plans, signal processing components, and synchronisation mechanisms were analysed to ensure optimal performance in radar applications such as altimetry and interferometry. This phase resulted in the specification of a robust digital architecture that balances performance, manufacturability, and operational stability. Building on these insights, the second phase

[3] *Nadir altimeters* measure the height of an object above a surface directly below it. They are used in a variety of applications, including oceanography, hydrology, meteorology, and climatology. *Nadir interferometric altimeters* are a type of satellite altimeter that use radar to measure the height of the ocean's surface, whilst *wide-swath altimeters* measure the ocean surface and produce high-resolution images of water surface height.

focused on the design and development of a Proof of Concept (PoC) breadboard, including defining hardware configurations, integrating Field Programmable Gate Arrays (FPGA) based digital processing, and establishing data transfer interfaces. Special attention was given to the layout and routing of signal paths to optimise radio frequency (RF) performance and synchronisation: the result was a prototype ready for manufacturing and initial validation. The final phase involved the fabrication and validation of the PoC breadboard. Rigorous testing was conducted to evaluate the system's transmit and receive functionality, synchronisation stability, and resilience under various environmental conditions. Performance metrics such as signal quality, jitter, and phase stability were also assessed. The successful validation of the PoC confirmed the feasibility of the RT-Module architecture and set the foundation for further refinements towards flight-ready models. The study also validated the viability of the modular architecture based on digital components, enabling the creation of a configurable hardware prototype tailored to the requirements of next-generation Copernicus missions, such as Sentinel-3 Next Generation - Topography (S3NG-T).

Figure 3: Overview of activity



Source: Thales Alenia Space

The success of these activities encourages further refinement of the design and provides a strong foundation for future flight applications. The project's achievements in developing a scalable design pave the way for enhanced altimetry solutions that will contribute to more accurate and reliable EO data.

… and deliver valuable socio-economic benefits.

Notwithstanding the development of a new type of digital altimeter, this study also produced important human capital and knowledge benefits and laid the foundations for potential future operationalisation and commercial exploitation.

Developing a new generation of altimeter

The development of the Integrated Circuit Design marks an advancement in digital altimeter technology, enhancing modularity and adaptability for next-generation radar systems whilst improving performance and accuracy across scientific, commercial, and defence applications.

The development of an Integrated Circuit Design for the Receive and Transmit Module (RT-Module) represents a significant advancement in the field of digital altimeter technologies. By leveraging qualified Field Programmable Gate Arrays (FPGAs) and Digital-to-Analog Conversion (DAC) and Analog-to-Digital Conversion (ADC) components, this approach enhances the modularity, scalability, and adaptability of radar systems across a range of potential applications, including altimetry.

The project advanced the technology readiness level (TRL) from TRL 3 to TRL 5 for the targeted 'Receive and Transmit' function, reducing the potential risks associated with future missions and demonstrating the early indications of maturity required for operational use. The development of this new technology also increases accuracy and efficiency in spaceborne and airborne radar applications. One of the most significant advances lies in how signals are processed. Traditional altimeters typically use intermediate frequency stages for signal conversion, requiring multiple analogue components. The digital altimeter integrated circuit design eliminates much of this complexity by introducing direct sampling at C-band frequencies, using high-performance DACs and ADCs**.** This not only reduces hardware complexity but also enhances precision by minimising sources of error such as phase distortion and unwanted signal artifacts. Synchronisation and stability have also been validated and successfully compared to legacy systems.

Additionally, as a result of its modularity and integrated design, it offers improvements across the design, manufacturing, and validation process associated with the commissioning of new sensor systems, providing opportunities for streamlined and rapid development of the recurring models. This success also marks a step towards the realisation of more sophisticated, high-precision altimetry technologies with potential scientific, commercial, and defence applications.

Reinforcing national and European leadership in altimeter design

TAS is a European leader in altimeter design and manufacturing, combining decades of innovation and mission success. Through this established partnership, the project helps reduce risks and costs for ESA through reliable, high-performing solutions and technological advancements.

TAS stands as a European leader in the design and manufacture of altimeters; a position underpinned by decades of innovation and mission success. Building on its existing portfolio of altimetry solutions already deployed on EO missions – such as the Poseidon-4 altimeter equipped on *Sentinel-6A*, and on *Sentinel-6B* (to be launched in 2025) and planned for deployment on Sentinel-6C – TAS has earned the trust of key stakeholders, including ESA and national space agencies across Europe. The company's leadership in the field is well established, and TAS is regarded as a 'go-to' partner for altimetry requirements.

The project harnesses this expertise and provides new opportunities to develop knowledge and experience in not only digital altimetry, but also in the development of modular integrated circuit designs. In harnessing this expertise, and by collaborating with ESA, the project contributes to France's existing leadership, heritage and capabilities within the field, whilst opening up further opportunities for development (e.g. through future phases of this project, and ultimately, the operational deployment of the altimeter).

In addition to this market leadership, TAS' continued development of altimetry technologies reduce system-level risks and costs for ESA missions through iteration and experience. By leveraging this experience, and pre-existing knowledge and components, TAS offers reliable, high-performing altimetry systems while optimising lifecycle costs – costs which could ultimately be further reduced with the introduction of the integrated circuit design. This focus not only ensures the success of existing missions but also supports ESA's ambition to achieve cost-effective, scalable solutions for future EO and programmes.

Harnessing existing partnerships and collaborations

The collaboration between TAS and ESA leveraged their long-standing partnership to exchange knowledge, align perspectives, and develop a sustainable altimeter solution that balanced immediate needs with long-term adaptability, while strengthening TAS' expertise, supplier relationships, and internal capabilities.

The collaboration between TAS and ESA to deliver this project harnessed a well-established relationship between the two stakeholders. While TAS possessed the knowledge to develop the altimeter on their own, ESA's involvement provided a platform for knowledge exchange and strategic guidance that influenced the final outcome. The initial project concept envisioned a more advanced generation of altimeters employing a powerful ASIC (Application-Specific Integrated Circuit) with integrated digital-analogue conversion. As a result of direct negotiations and discussions between ESA and TAS, it became evident that there was an opportunity to explore new technical solutions. This partnership led to the development of the integrated circuit design, utilising existing components while remaining adaptable for future applications. This decision underscored the strength of the TAS-ESA partnership, demonstrating how aligning perspectives and sharing technical insights can steer a project toward a more sustainable solution with long-term applicability.

More broadly, these activities enabled TAS to access and integrate skills and capabilities from other TAS product lines and teams, such as their software and firmware development teams, allowing it to draw on a broader base of expertise and resources. The project also allowed TAS to strengthen its ties with its existing suppliers, including Teledyne e2v, a leading European supplier of DAC/ADC technologies. The use of European-manufactured components, such as Teledyne e2v's ADCs and DAC components, enhances the autonomy and long-term reliability of the system.

Developing a robust and skilled talent pipeline

The digital altimeter project team blended experienced professionals with junior members, helping to develop experience in software development, project management, and programme delivery.

The development of the digital altimeter supported approximately 5 jobs at TAS. Though many of those involved had significant experience in altimetry technology development, the activity also provided opportunities to develop and nurture junior team members. These team members were predominately employed on software development tasks, gaining 'hands on' experience in technology development whilst working alongside experienced professionals. More broadly, involvement in this project exposed these junior team members to ESA 'ways of working' and developed their understanding of ESA standards and project management approaches.

Beyond individual career growth, this ongoing development not only strengthens TAS' institutional capabilities but also contributes to the broader French and European space ecosystems. By investing in upskilling and knowledge-sharing, this project also supports to the continued futureproofing of the workforce and helps to sustain a highly skilled talent pipeline that contributes to Europe's leadership in space technology.

Supporting the next generation of high-profile Copernicus missions

This activity successfully advanced technology readiness, delivering a modular, configurable hardware solution with potential for operational deployment, while positioning TAS for future altimetry and EO missions.

The project has successfully demonstrated a Proof of Concept that has the potential to contribute to future missions within the *Sentinel* programme, including the *Sentinel-3* Next Generation Topography (S3NGT) mission. This mission seeks to provide continuity of initial first-generation observations and increasing the quantity and quality of radar altimetry services. This would be achieved through the POSEIDON-5 radar altimeter, a nadir-viewing altimeter which is currently under development for deployment on the *S3NGT-A* and *-B* missions in 2033 and 2035 respectively. Building upon the legacy of its predecessors, such as Poseidon-4 – due for deployment as part of the *Sentinel-6C* mission in 2030 – it employs dual-frequency radar technology to achieve high-precision altimetry measurements. This dual-frequency approach allows for the correction of ionospheric path delays, enhancing the accuracy of the data collected.

More broadly, this study enabled the development of a preliminary, configurable, hardware solution that meets modular architecture requirement, derisking the technology for future operationalisation. The success of this activity is, therefore, not only a technological milestone: it is also a strategic one for both TAS and ESA. The ability to demonstrate a validated and flight-ready technology positions TAS favourably to contribute to further phases the *Sentinel* programme, such as S3NGT, as well as in other future Copernicus missions. This achievement marks a significant contribution towards ensuring the long-term sustainability and competitiveness of European space capabilities in the domain of EO and altimetry.

Potential for future commercial uses

The digital altimeter, particularly its integrated circuit board, has a range of potential applications beyond future *Sentinel* missions.

Beyond likely deployments as part of future *Sentinel* missions, the digital altimeter – and the integrated circuit board in particular – has the potential to expand into a variety of other applications and domains. The global digital integrated circuit market, for example, has been estimated at approximately €171 billion (US$176 billion) in 2024, and is expected to reach approximately €539 billion (US$554 billion) by 2037.[4]

In the rapidly growing commercial space industry, for example, the technology could be adopted by private satellite operators for precise altitude control in small satellites or constellations, ensuring efficient deployment and orbital station-keeping. The compact and integrated nature of the design also makes it a candidate for CubeSats and nanosatellites considering size and weight, even if power consumption remains a mandatory improvement. In defence-oriented applications, meanwhile, the technology could also bring significant enhancements.

Would these benefits have been realised without ESA?

The joint effort from ESA and Thales Alenia Space has made this successful development possible. ESA's involvement in particular is credited as instrumental in shaping the direction of the study, aligning it with the specific technology requirements for the Copernicus programmes altimetry requirements, and help to further develop European non-dependence and leadership in EO technologies.

> *"The joint effort from ESA and TAS made the design of this technology successful. The ESA funding, and the technical knowledge shared between us and the Agency, has helped us to develop a new, adaptable approach to altimetry which is world-leading and helping us to de-risk the technology for future operationalisation."* – Thales Alenia Space

The outcome of the study has evolved significantly from its original concept. Initially envisaged as a straightforward technical development effort, the project has been transformed through ongoing knowledge exchange and collaboration with ESA. This process has led to the realisation of an innovative technology that had not been foreseen at project inception. ESA's emphasis on long-term sustainability, and adherence to stringent performance standards has driven the project towards outcomes that better serve the broader goals of European space policy and EO requirements.[5]

[4] Research Nester (2025). *Digital Integrated Circuit Global Market Size, Forecast, and Trend Highlights Over 2025-2037.* Available at: www.researchnester.com/reports/digital-integrated-circuit-market/6950?utm_source=chatgpt.com

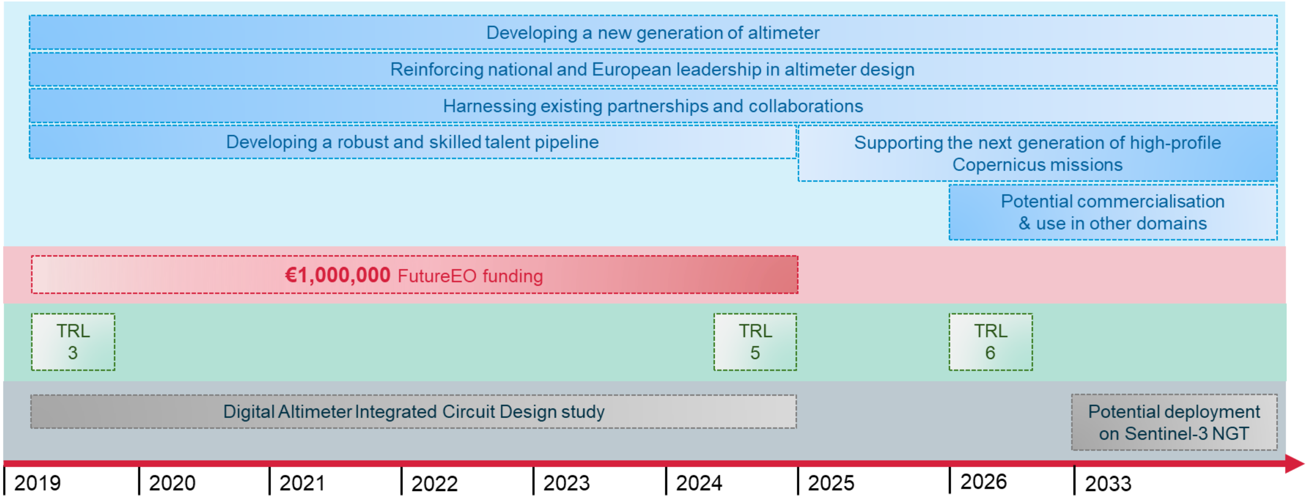
[5] ESA published a new EO Science Strategy, *Earth Science in Action for Tomorrow's World* in September 2024. Though this activity predates the publication of this strategy, these early activities contribute to the overarching objective to harness satellite data to develop "our collective understanding of the Earth system as a whole". The new strategy is available at: www.esa.int/Applications/Observing_the_Earth/ESA_releases_new_strategy_for_Earth_observation

Next steps: Further development, further benefits

The Digital Altimeter Integrated Circuit Design represents a significant advancement in altimetry technology and demonstrates early potential for inclusion in future *Sentinel* missions. The success of this activity has laid the foundations for the Digital Altimeter technology to fly as a potential payload on high-profile missions such as *Sentinel-3 Next Generation Topography* (NGT), scheduled to launch in 2033. These missions represent critical milestones in the evolution of ESA's EO programme, and the inclusion of this technology could provide enhanced altimetry data for subsequent exploitation by users on Earth. Altimetry data is strategically important, as it can provide precise, near-real-time measurements of sea level, ice sheet dynamics, and terrestrial water bodies, enabling exploitation across a number of areas, including climate monitoring, maritime navigation, disaster response, and defence operations, enabling and supporting informed decision-making.

Realising this potential will require continued development of the design to meet the rigorous standards necessary for operational deployment in space. Ensuring readiness for these missions will depend on sustained investment, as well as continued close collaboration with ESA. The experience of TAS within the area of altimeter production in Europe positions it to drive further development of the digital altimeter, and the integrated circuit design in general, and explore its broader applications. In addition to its direct application in future Copernicus missions, the modular nature of the design opens the door to potential alternate uses. These could include deployment in smaller EO missions, commercial satellite constellations, or applications including marine and ice monitoring for climate research. By capitalising on its existing leadership, TAS is well-positioned to expand the impact and utility of this technology across both established and emerging sectors.

Figure 4: Overview of the timeline of the progress, and subsequent benefit realisation, of the Digital Altimeter Integrated Circuit Design project



Source: know.space based on Thales Alenia Space and ESA data

Key priority indicators

Programme	FutureEO
Country	France
Activity cost	€1,000,000
Duration	The activity was originally scheduled to take place over 24 months, but was delayed by unforeseen events, including the COVID-19 pandemic. Work commenced in 2019, technical work concluded in 2023, and the project was formally closed at the end of 2024
Lead contractor	Thales Alenia Space (TAS) France
Sub-contractors	-
TRL progression	From TRL 3 to TRL 5
Spin-in into the space sector	-
Jobs supported	5 full-time staff at TAS
New/strengthened collaboration with ESA	TAS France (strengthened)
Partnerships created/ strengthened	Strengthened existing ties Teledyne e2v, a leading European supplier of DAC/ADC technologies.
Follow-on funding applied/ secured	Potential involvement in the Copernicus programme, with opportunities for contracts to supply altimetry equipment to the *Sentinel-3 (NG-T)* missions.