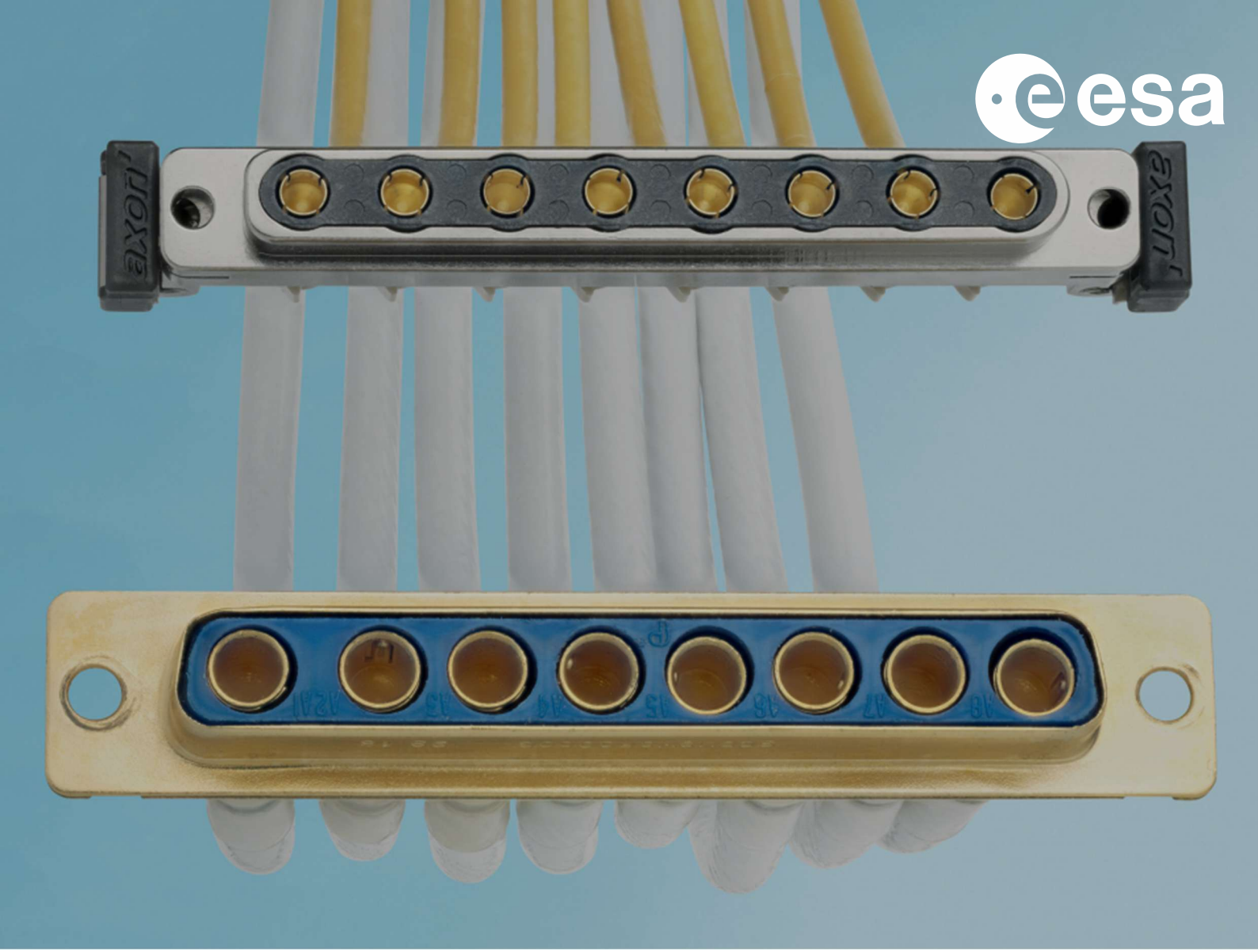


IMPACT ASSESSMENT OF ESA EARLY R&D ACTIVITIES

Miniaturisation of Power/Coaxial Connectors

know.space

March 2025

Outdated electronics drive inefficiencies in space missions …

Radiofrequency (RF) and power electronics are vital for space systems such as satellites, launch vehicles, and payloads.[i] RF electronics enable reliable communication between satellites and ground stations, while power electronics regulate and distribute electrical power from solar panels, ensuring efficient onboard operations. These electronics are notably enabled by space connectors and cables, which are specialised interconnection technologies that link different electronic systems within a satellite. They allow power and data to flow between various parts of the spacecraft, ensuring all systems function reliably.[ii]

The growing accessibility of the space industry and the advent of NewSpace technologies has placed unique requirements on space-graded connectors, driving the need for the miniaturisation of this technology. Connectors and cables for space applications need to be designed with strict size and weight constraints, as satellites have stringent space requirements. For example, the standardised CubeSat form factor (starting at just 10 × 10 × 10 cm) demands high density. Reducing the size and weight of these components can improve fuel efficiency, allowing for additional or more advanced payloads to be integrated onboard the spacecraft. As satellites grow more compact, connector design must balance durability, ease of integration, performance, and optimised size to meet the evolving demands of space missions.[iii] Therefore, this highlights a need for miniaturised connectors that fit within tightly-packed electronics, while also maintaining secure and reliable connections.

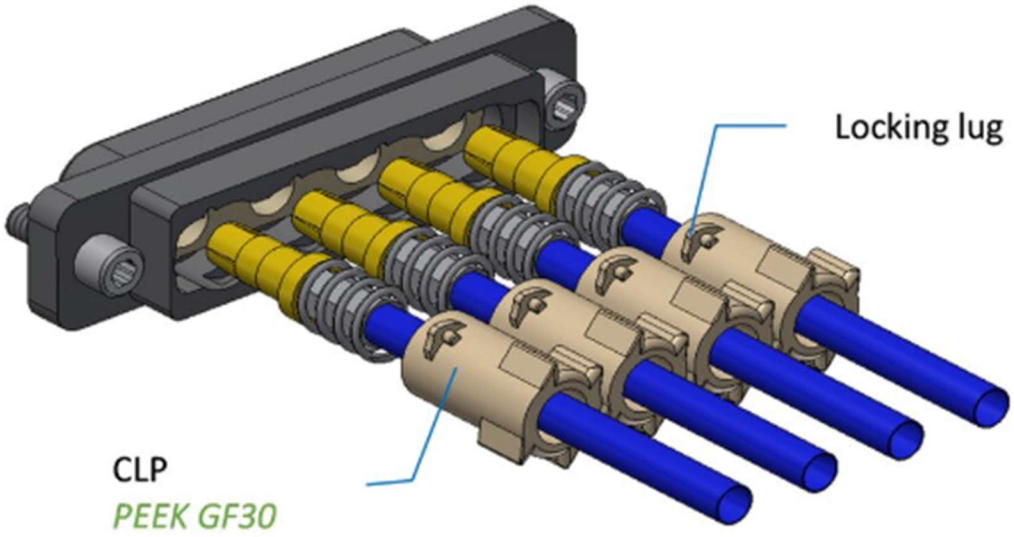
… but the miniaturisation of power and coaxial connectors, funded by ESA, offers a solution …

The 'Miniaturisation of Power/Coaxial Connectors' is a technology development project, which received around €250,000 through ESA's TDE[1] programme. The objective of the project was to design, develop, manufacture, and evaluate European micro-miniature connector solutions for applications requiring power or coaxial (RF) links. This activity was carried over the course of 4 years (2011/12 – 2015) by Axon' Cable, who successfully achieved the design and development of two separate families of connector – one for power and one for RF – driven by user needs, and a complete set of connector and cable assembly.[iv] By the end of the project, the connectors developed reached space qualification

[1] ESA's Technology Development Element (TDE) is a mandatory programme which explores innovative, 'blue-sky' concepts. It supports all ESA fields of activity across various technical disciplines, serving as the foundation for future technological advancements. All ESA Member States contribute to the TDE on a mandatory basis.

and were demonstrated on a large constellation of 650 satellites, to NewSpace industry standards.

Figure 1: Removable connectors design



Source: ESA[v]

Traditionally, applications requiring power or coaxial links used D-SUB connectors and micro-miniature connectors (Micro-D) developed in the 1950s and 1980s. Whilst these connectors are still widely used, new space technologies require a reduction in footprint to minimise the overall volume and mass of equipment, addressing critical space constraints in spacecraft design.[vi] In this project, the miniaturised power/coaxial connectors, derived from the older Micro-D technology, were developed with a fast-locking feature, such that the connectors could be mated (joined together to establish a connection) and locked in place with a single click, without the need for tooling.

The project is led by Axon' Cable[2] (FR), a company that develops interconnect solutions that can adapt to hostile environments. They have extensive experience and heritage in developing space-graded connector and cable assemblies. Through this TDE-funded activity, they successfully carried out the design, development and manufacturing of the European miniature power/coaxial connector.

[2] Henceforth referred to as Axon.

… enabling the efficient transfer of power and signals in space through its compact design …

The principal added-value of the ESA-funded connectors developed by Axon is fast integration, as no tooling is required to incorporate them into space-based systems. This allows for significant time savings, streamlining human resource requirements during on-ground assembly. This technology is 40% smaller and lighter than traditional D-Sub connectors – which can enable streamlined systems and payloads, reducing the cost of the mission. Additionally, the solution developed also exhibits very good RF performances at 40 GHz. These new connectors offer flexibility in their usage due to their improved contacts, enabling quicker replacement and removal, and easy maintenance. This is in contrast to traditional connectors, where contacts were pre-installed and fixed, making them difficult to remove or replace. The miniaturised power/coaxial connectors are also ATOX- resistant (i.e., atomic oxygen, which oxidises and erodes materials quickly in space) and radiation-resistant, enabling long-term durability on space missions and facilitating cost savings.[vii]

These connectors are an enabling technology that play a critical role in a range of high-performance applications where reliability, power efficiency, and miniaturisation are essential. They are widely used in electrical and electronic systems within satellites and spacecraft, supporting both individual missions and satellite mega-constellations that enable global communication and advanced Earth observation (EO). Their scalability extends to any application demanding compact, high-power solutions, making them useful in cutting-edge aerospace and defence technologies.[viii]

… and delivering potentially valuable socio-economic benefits.

Beyond enabling the flight demonstration of the miniaturised power/coaxial connectors on a large commercial constellation, ESA funding has led to some important benefits being realised for the contractors, including strengthening European technological non-dependence, enhanced reputation, and visibility, and securing follow-on missions.

Progressing the maturity of an enabling technology

ESA funding has facilitated the full technological maturation of the first-of-their-kind European miniature power/coaxial connectors by helping Axon progress the technology from an early concept to enabling a (privately funded) flight demonstration on a NewSpace large commercial constellation of satellites.

ESA's TDE investment allowed for the development of an enabling technology offering many attractive features for end-users. For example, the miniaturised power/coaxial connectors developed through this activity are half the size of traditional connectors, whilst generally performing at the same level. An improvement in connector performance was even showcased in their RF feature – previous mini-D connectors were limited to 1GHz, but Axon was able to develop the component to perform all the way up to 50 GHz. Additionally, as highlighted in the introduction, a key innovation of the solution lies in its fast-locking system, which was a nascent concept in space applications at the time of development. The activity was driven by a survey of user needs to ensure that its output would be commercially attractive. This resulted in the development of two separate connectors – one for power connections and one for RF connectors – instead of a combined connector for both uses (which was already in Axon's catalogue).

ESA was pivotal in providing the financial and strategic support necessary to drive forward the technological maturation of the miniaturised power/coaxial connectors. Axon reported raising this technology from Technology Readiness Level (TRL)[3] 1 to TRL 5 within the timeframe of this ESA project, helping the company bridge the 'innovation valley of death'. The Agency's funding and support enabled the de-risking of this technology by validating its potential and reducing early-stage uncertainty, making it more attractive to potential investors. This was instrumental in building trust with commercial end users, helping Axon secure a private flight opportunity for its connectors onboard a commercial constellation, which served to demonstrate them and significantly accelerate TRL progression, reaching TRL 8/9, i.e., flight qualification/proof, at NewSpace industry standards.

[3] Technology Readiness Level (TRL) is a standardised system used to assess the maturity of a technology before it is deployed in operational missions. Defined by the *European Cooperation for Space Standardization* (ECSS) and aligned with NASA's TRL framework, it ranges from TRL 1 (basic principles observed) to TRL 9 (actual system flight-proven in space). For space applications, TRL progression typically involves rigorous analytical studies, laboratory testing, validation in relevant environments, and demonstration in orbit to ensure reliability under extreme conditions.

Securing follow-on opportunities

The successful achievement of Axon in designing and developing miniaturised power/coaxial connectors helped build heritage, with the technology having since been (or set to be) integrated into key commercial and institutional missions. Terrestrial applications are also being investigated.

Beyond serving as a flight demonstration at NewSpace industry standards, Axon's supply of the miniaturised connectors for the 650-satellite commercial constellation helped improve the technology through the company's close collaboration with the spacecraft manufacturer, a key European prime contractor. This opportunity also enabled Axon to build heritage for the technology.

The successful demonstration (and associated heritage) of the miniaturised power/coaxial connectors has since catalysed various opportunities with both institutional and commercial organisations. For example, the connectors are set to be integrated into the NASA-ESA Mars Sample Return mission, scheduled to launch in 2027 or 2028[ix], which would demonstrate it to institutional standards, unless an earlier ESA flight opportunity is secured. This technology is now also integral to many missions led by industry across Europe, with more in development.

Beyond the space segment, Axon are currently seeking terrestrial opportunities, especially in the aeronautical sector. The connectors developed under this TDE contract are currently undergoing qualification so that they can be leveraged for defence and civil applications. A military mission opportunity was secured, starting in June 2025.

The wide-ranging follow-on opportunities demonstrate the value and practicality of the miniaturised power/coaxial connectors developed through this ESA TDE-funded project. Its ability to scale and adapt to different needs highlights its versatility, and ensures its relevance across various application areas.

Strengthening European non-dependence and technological leadership

ESA funding for the development of the miniaturised power/coaxial connectors has enabled Europe to maintain non-dependence and capture technological leadership in the space-grade connectors domain.

Traditionally, space-grade D-Sub connectors were the primary choice. However, their limited form factor and relatively low pin count restricted flexibility and led to long integration times. Therefore, ESA sought to improve the technology through a first-of-its-kind development of miniaturised power/coaxial connectors. Axon's solution provided a compact (and flexible)

form factor, removable contacts, and fast-locking technology, with increased RF performances. This helped establish European technological leadership in the domain.

The miniaturised power/coaxial connectors, at the time of development, were some of the most advanced components of their type available. While there are now emerging competitors in the US offering similar solutions, the continued usage of Axon's components in space technologies underscores Europe's ability to maintain a competitive edge and non-dependence in enabling technologies.

Additionally, the 'removable contact' aspect of the miniaturised connectors technology is patented. This not only safeguards Axon's intellectual property and strengthens their position in the industry, but it also provides a unique advantage in the market, preventing competitors from replicating this innovative approach, and reinforcing Europe's technological leadership.

Upskilling the workforce and knowledge spillovers

The design and development of the miniature power/coaxial connectors has enabled the upskilling of Axon's workforce, including through knowledge transfer from ESA experts and spillover of technical expertise that enabled the development of other connectors in Axon's portfolio.

ESA TDE funding for the miniaturisation of power/coaxial connectors has enabled the upskilling of the contractor's workforce in this unique capability. Axon noted that the project team enhanced their technical know-how, specifically through efforts to lower the resistance of the connector and problem-solving to ensure that there were no mechanical errors. The company also highlighted that ESA's feedback was crucial in the process of refining this technology, leveraging the Agency's expertise through various review processes and discussions. This allowed for issues to be identified and addressed effectively, and for user needs to be fully understood and integrated into the design of the technology. The input from ESA was described as essential in ensuring that technological developments aligned with industry standards and best practices. This collaborative approach was key to driving continuous improvement and successful outcomes.

The knowledge gained during the TDE contract for the miniaturised power/coaxial connectors has had a notable spillover effect, benefiting the development of other connectors in Axon's portfolio. The insights and technical expertise acquired were directly applied to enhance the design and functionality of subsequent connectors, streamlining the technology development process. This has enabled Axon to position themselves as a leading organisation in the European space-grade connectors market, further solidifying their expertise.

Overall, this upskilling benefit helps build a highly capable European workforce and supply chain in a strategically important technology area for the space sector.

Enhancing reputation and visibility

Through this ESA TDE-funded project, Axon was able to strengthen their reputation as one of the leading suppliers of connectors and cable technology in Europe, benefiting from the ESA 'stamp of approval' that can foster visibility and commercial and institutional opportunities.

ESA TDE funding has enabled Axon to build on their established heritage of developing connector and cable technology and, in turn, position themselves as one of the trusted suppliers for both the European and global market. This could help them capture a greater share of the global space-grade connectors market – which is currently growing at a CAGR of approximately 7.2% and is expected to reach a value of €2.29bn ($2.4bn) by 2034.[x]

Axon have a long history of collaboration with ESA. For example, they successfully provided data transmission harnesses for scientific satellites, such as Gaia, and Earth Observation satellites, including Proba-V and Sentinel. Axon also supplied the main cabling for the ESA ExoMars Rover.[xi] Their successes on this TDE-funded activity further enhanced their reputation and visibility within the Agency, allowing for deepened trust and collaboration between the two entities. This has helped Axon gain the ESA 'stamp of approval', which increases potential customers' confidence in the company and its capabilities. While the organisation is already prominent within Europe, they found that this 'proof of quality' was most impactful in expanding their visibility beyond the continent, particularly in South America.

As international stakeholders can access a curated list of NASA and ESA (e.g., through ESCC[4]) qualified components, Axon highlighted their plans to have the miniaturised power/coaxial connectors become officially 'institutionally qualified'. Indeed, as highlighted earlier, Axon integrated their technology on board a large commercial constellation, serving as a flight demonstration under NewSpace industry standards. Further qualifying the miniaturised power/coaxial connectors with more stringent ESA or NASA specifications would allow it to be institutionally flight-demonstrated, and published to the curated list. This could lead to increased customer confidence and interest, and help further enhance Axon's credibility within the more 'traditional' space segment. Unless an earlier opportunity arises, institutional qualification is expected in 2027/28, as the connectors are planned for use in the NASA-ESA Mars Sample Return mission.

[4] European Space Components Coordination (ESCC) - The goal of the ESCC is to enhance the availability of high-performance, cost-effective electrical, electronic, and electro-mechanical space components for both institutional and commercial space programmes.

Would these benefits have been realised without ESA?

ESA funding was crucial in the development of this miniaturised power/coaxial connector technology, as it provided valuable expertise and essential funding to support early-stage R&D. This TDE activity was critical in building trust within industry and enabling Axon to secure a private flight opportunity to accelerate the development of the technology and demonstrate it to NewSpace industry standard onboard a large commercial constellation.

ESA funding played a catalysing role in the development of an enabling and (at the time) state-of-the-art technology of significant strategic importance for European space activities. Through this TDE activity, the Agency has contributed to building non-dependence and technological leadership, strengthening the resilience and growth of the European space sector.

"Working with ESA has enabled us to benefit from the best possible publicity in Europe and even outside Europe. This ensures a certain methodology and quality in the developments carried out, thanks to the numerous reviews and collaborative meetings. Obtaining a TDE contract forces the beneficiary to carry out a real survey and thus better understand our customers' needs". – Gilles Rouchaud, Axon' Cable

The contractor reported that working with the Agency reinforced its credibility and reputation through benefiting from an 'ESA stamp of approval', which fosters commercial competitiveness, and has helped secure follow-on institutional and industrial flight opportunities. Space represents approximately 10% of the company's overall operations, which includes space-grade connectors. The ESA-funded miniaturised power/coaxial connectors stand among their top five connector focuses. This underscores the importance of the space market and the connector products within the broader framework of Axon's business. The increase in the company's capabilities was also driven by the upskilling of its workforce and knowledge spillovers to other parts of the business attributable to this activity.

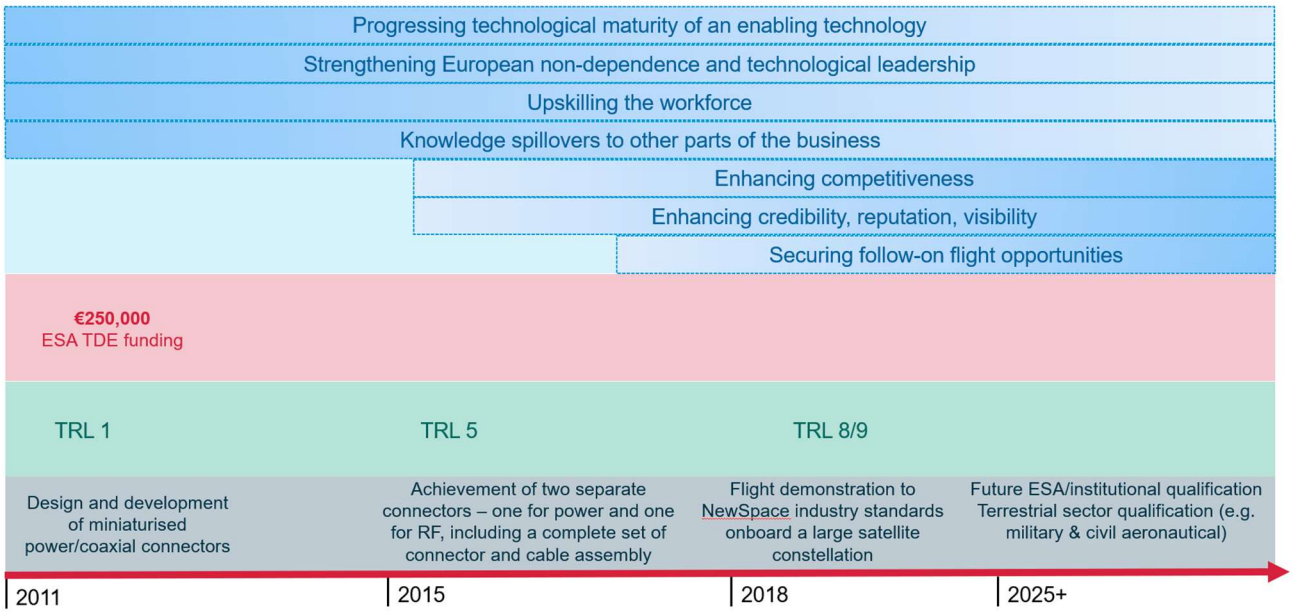
Next steps: Further development, further benefits

The immediate next step for Axon is to secure ESA (or other institutional) qualification of the miniaturised power/coaxial connectors, which would likely enable increased commercial and institutional interest and catalyse further flight opportunities and revenue. Unless an earlier opportunity is secured, this will be achieved in 2027/28, as the connectors are set to be used on the NASA-ESA Mars Sample Return mission. Terrestrial applications in the aeronautical sector are also being investigated, with Axon seeking to qualify its technology for both defence and civil use. A military mission opportunity is set to begin in June 2025. The contractor will continue to pursue opportunities to supply its miniaturised power/coaxial

connectors both for space and terrestrial applications, building flight heritage and increasing revenue.

A preliminary timeline overview of the TDE-funded 'Miniaturisation of Power/Coaxial Connectors' project and associated potential benefits is provided below. However, some of these next steps and their impact are dependent on the availability and timeliness of funding and flight opportunities.

Figure 2: Overview of the timeline of the progress, and subsequent benefit realisation, of the miniaturisation of power/coaxial connectors project



Source: know.space based on Axon' Cable and ESA data

Key priority indicators

Programme	TDE
Country	France
Duration	4 years (2011/12 – 2015)
Lead contractor	Axon' Cable
Sub-contractors	-
TRL progression	TRL 1 (start) to TRL 5 (finish) under the TDE contract. Reached TRL 8/9 upon flight demonstration on a large commercial constellation.
Spin-in into the space sector	-
Jobs supported	-
New collaboration with ESA	-
Partnerships created	-
Follow-on funding applied/secured	• Flight demonstration at NewSpace industry standard of the miniature power/coaxial connectors on a large commercial constellation of 650 satellites. • Securing military qualification to fly on a military mission launching in June 2025. • Seeking ESA/institutional qualification opportunity (before the Mars Sample Return mission opportunity already secured, launching in 2027/28).

[i] Spectrum Control (2020). Space-faring RF Component & Device Applications. Available at: https://blog.spectrumcontrol.com/blog/space-rf-component-applications
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[iv] The European Space Agency (2017). Miniaturization of Power/Coaxial Connectors. Available at: https://www.esa.int/Miniaturization_of_Power_Coaxial_Connectors
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[vi] The European Space Agency (2017). Miniaturization of Power/Coaxial Connectors. Available at: https://www.esa.int/Miniaturization_of_Power_Coaxial_Connectors
[vii] Axon' Cable (n.d). Power miniature connectors Versatys®. Available at: https://www.Axon' Cable-cable.com/en/power-miniature-connectors-versatys
[viii] Axon' Cable (n.d). Power miniature connectors Versatys®. Available at: https://www.Axon' Cable-cable.com/en/power-miniature-connectors-versatys
[ix] J. Foust (2022). SpaceNews: NASA to delay Mars Sample Return, switch to dual-lander approach. Available at: https://spacenews.com/nasa-to-delay-mars-sample-return-switch-to-dual-lander-approach/
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