

Precision Manufacturing Activities: Flexure Technology, Additive Manufacturing, Space and Watch Applications

CSEM's Precision Manufacturing activities combine precision engineering, compliant mechanisms, advanced manufacturing technologies, and system integration to develop innovative solutions for high-value industrial sectors. Leveraging expertise in flexure-based mechanisms, MEMS, advanced materials, surface engineering, and additive manufacturing, CSEM addresses demanding challenges in space, watchmaking, scientific instrumentation, and industrial automation. This unique combination of competencies enables the development of highly integrated, lightweight, and reliable systems that enhance the competitiveness of Swiss and European industry.

Precision Manufacturing and Additive Manufacturing at CSEM

A particular strength of CSEM lies in the development of compliant and flexure-based mechanisms, which enable frictionless, wear-free, and highly repeatable motion. Originally developed for scientific instrumentation and space applications, these technologies have also found applications in watchmaking, industrial metrology, and high-precision manufacturing systems.

To address increasingly complex industrial challenges, CSEM combines precision mechanism design with a broad range of manufacturing technologies, including microfabrication, MEMS processes, advanced surface engineering, hybrid integration, and additive manufacturing. This multidisciplinary approach enables the realization of lightweight, highly integrated, and multifunctional systems that are difficult or impossible to manufacture using conventional methods.

The resulting technologies serve a wide spectrum of applications ranging from space instrumentation and scientific observatories to luxury watchmaking, industrial automation, metrology, and next-generation manufacturing equipment. CSEM's activities therefore span the entire innovation chain, from fundamental technology development and prototyping to industrial validation and technology transfer.

CSEM has established a strong competency in metal additive manufacturing, particularly Laser Powder Bed Fusion (LPBF), for producing highly integrated precision mechanisms and multifunctional components. The strategy is not simply to replace conventional machining with 3D printing, but to exploit additive manufacturing to create structures that would otherwise be impossible to manufacture.

Key developments include:

- Topology-optimized lightweight structures
- Additively manufactured compliant mechanisms
- Integrated actuation and sensing functions
- Embedded electrical routing and connectors
- Shape-memory alloy actuators
- Multifunctional structures combining mechanical and sensor functions

CSEM operates several high-precision LPBF platforms and has developed manufacturing processes for stainless steels, titanium alloys, aluminum alloys and shape-memory alloys, enabling the production of complex space-qualified mechanisms and components.

Flexure Technology as a Core Enabling Competence at CSEM

For more than three decades, CSEM has developed high-precision mechanisms based on compliant or flexure technologies for demanding applications in space instrumentation, astrophysics, scientific metrology, and the Swiss watch industry. Flexure-based mechanisms replace traditional bearings and joints by elastic deformation of carefully designed structures. This approach eliminates friction, wear, lubrication requirements, backlash, and particle generation while providing exceptional positioning accuracy and long-term stability.

This expertise has enabled CSEM to deliver flight hardware for major ESA and scientific missions, including precision optical mechanisms, steering mirrors, corner-cube mechanisms, and large-angle flexure pivots. In parallel, the same engineering principles are applied to high-end watchmaking components, oscillators, escapements, and other micro-mechanical systems where long-term precision and reliability are essential.

Today, flexure technology forms a cornerstone of CSEM's Precision Manufacturing research priority, which combines precision mechanisms, additive manufacturing, MEMS technologies, functional surfaces, photonics, and advanced instrumentation. The objective is to develop next-generation manufacturing technologies that provide both extreme precision and integrated functionality.

Space Applications

Space is one of the primary drivers of CSEM's precision mechanism activities. CSEM develops:

- Optical pointing and steering mechanisms
- Beam steering mirrors
- Scientific instrument positioning systems

- LiDAR components
- Precision deployable mechanisms
- High-performance compliant pivots
- Spaceborne metrology systems
- Cryogenic optical mechanisms
- Additively manufactured structures and components

A notable example is the Large Angular Flexible Pivot (LAFP), a flexure pivot capable of achieving $\pm 90^\circ$ rotation while maintaining micrometric center stability and long operational lifetime. Such mechanisms are intended for future scientific payloads and optical communication systems operating in harsh space environments.

Watch Industry Applications

Watchmaking remains a strategic application domain for CSEM. The organization leverages expertise developed for space mechanisms and scientific instrumentation to support the Swiss watch industry through:

- Precision micro-mechanisms
- Flexure-based components
- Oscillators and escapements
- Hybrid silicon-based mechanisms
- Additive manufacturing technologies
- Materials characterization and reliability testing

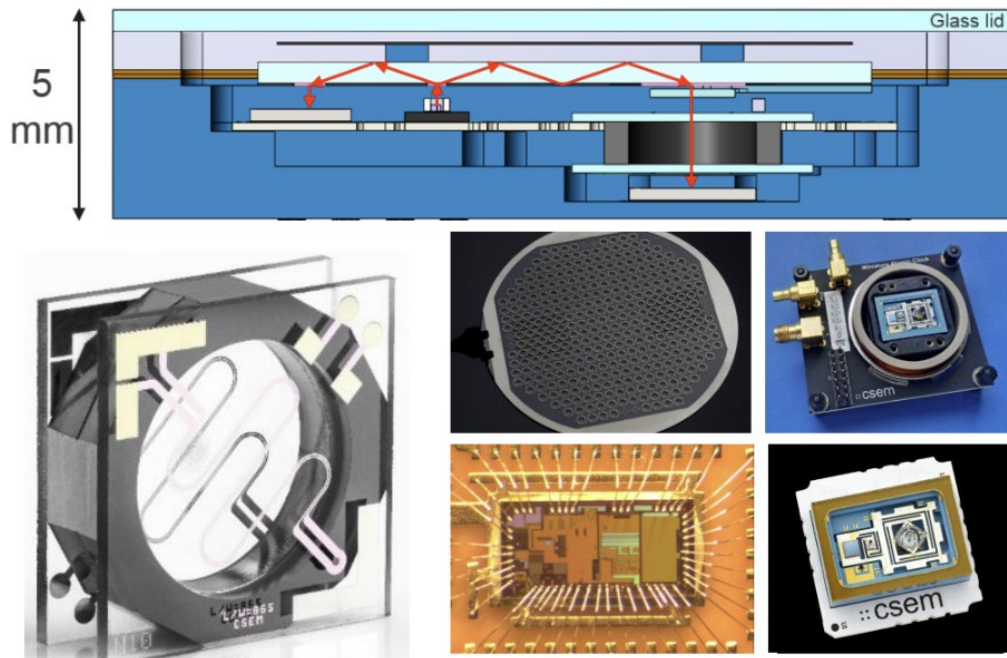
Several senior engineers involved in current space-flexure developments previously worked on high-performance watch mechanisms and the development of compliant mechanical systems for major Swiss watch manufacturers.

Atomic Clocks and Quantum Technologies

Neuchâtel has a long history in precision timekeeping, and BU-I continues this tradition through the development of next-generation atomic clocks and quantum sensors. Atomic clocks are enabling technologies for satellite navigation, telecommunication networks, secure communications, scientific missions, and autonomous space systems operating independently from GNSS signals.

BU-I develops two complementary families of atomic clocks. The first focuses on miniature microwave atomic clocks based on proprietary MEMS rubidium vapour cells and ultra-low-power electronics. These devices offer extremely compact size, low power consumption, and high robustness, making them attractive for small satellites, autonomous spacecraft, and portable timing applications. The second family addresses ultra-high-performance optical atomic clocks based on rubidium two-photon transitions.

These systems provide exceptional frequency stability and represent a promising technology for future navigation systems, precision geodesy, and spaceborne fundamental physics missions.



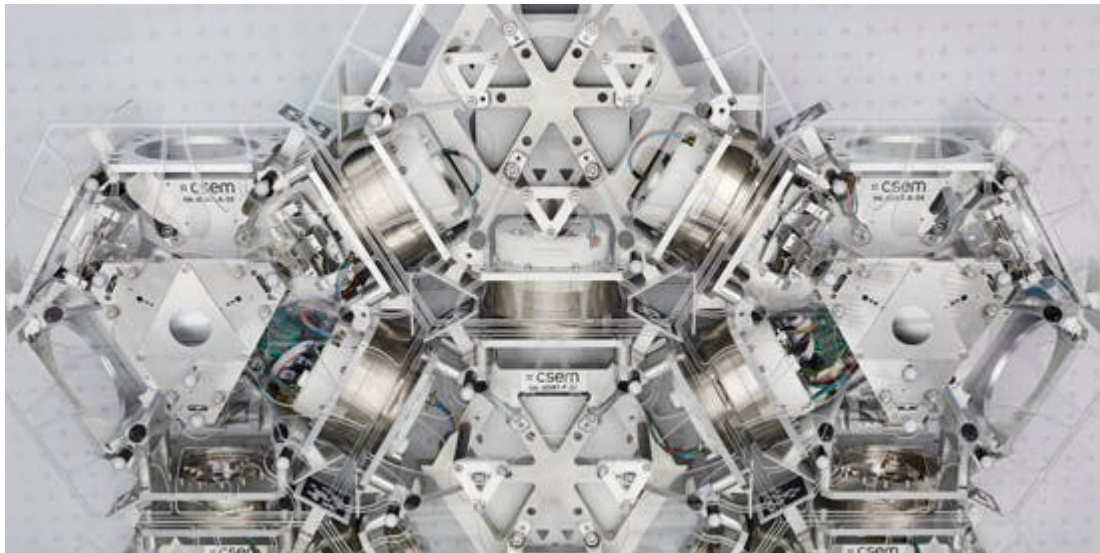
Beyond atomic timing, BU-I is actively developing quantum sensors such as magnetometers, gyroscopes, and radio-frequency sensors based on atomic vapour cells and diamond NV-centre technologies. Quantum sensing promises substantial performance gains for inertial navigation, magnetic field measurements, Earth observation, and spacecraft autonomy. Supporting technologies include MEMS vapour cells, photonic integrated circuits, quantum light sources, compact physics packages, low-phase-noise electronics, and quantum metrology techniques. These developments position CSEM as one of Europe's leading centres for applied quantum engineering and space-oriented quantum instrumentation.

Project PULSAR

PULSAR is a European Horizon 2020 space program aimed at developing technologies for future segmented space telescopes.

Within this project, CSEM contributed to the development of the Single Mirror Tile demonstrator, including the design, manufacture, assembly, and testing of a precision tripod mechanism supporting a segmented telescope mirror.

The project showcased CSEM's ability to design ultra-stable precision mechanisms capable of operating within the stringent dimensional and optical stability requirements of future space observatories. It also strengthened CSEM's expertise in system engineering, opto-mechanics, precision assembly, environmental testing, and space mechanism qualification.



Project CRTM

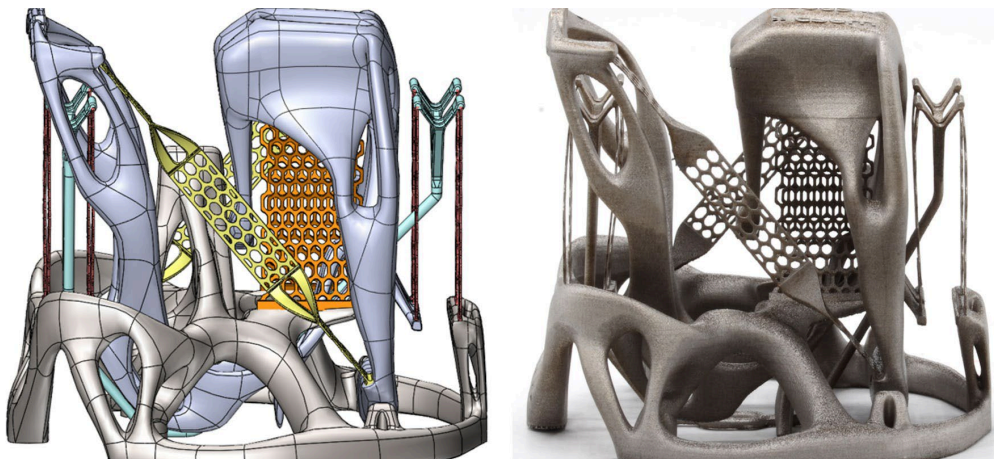
The Compliant Rotation Translation Mechanism (CRTM) originated from the ESA GSTP project COMAM and represents one of CSEM's flagship developments in additively manufactured compliant mechanisms.

CRTM belongs to the family of motion-transformation compliant mechanisms and enables coupled rotational and translational motion through a monolithic flexure structure. During COMAM, it emerged as one of the most promising concepts evaluated and subsequently became the focus of further internal R&D and ESA-funded development activities.

The project enabled CSEM to:

- Design compliant mechanisms specifically optimized for additive manufacturing
- Develop manufacturing recipes for LPBF production
- Master the production of compliant structures in 17-4 PH stainless steel
- Establish process validation methodologies
- Produce and test multiple CRTM breadboards
- Characterize fatigue, tensile behaviour, and microstructure of printed compliant systems

CRTM is therefore a key demonstration of how additive manufacturing can be exploited to realize complex, lightweight, highly integrated precision mechanisms that are impractical using conventional manufacturing techniques.



Project AHEAD

AHEAD is a European ATTRACT / Horizon 2020 project focused on the integration of sensing functions into additively manufactured components.

The project investigated the integration of temperature sensing and heating capabilities directly into metal additively manufactured structures. One demonstrator was a spacecraft pipe segment incorporating:

- Additively manufactured heating elements
- Integrated temperature sensors
- Built-in electrical connectors
- Plug-and-play functionality
- Minimal assembly requirements

AHEAD explored advanced manufacturing methods including:

- Aerosol Jet Printing (AJP)
- Laser Powder Bed Fusion (LPBF)
- Embedded sensor integration
- Functional component printing

One major outcome was the successful integration of commercial temperature sensors directly into LPBF-produced structures using printed clips and embedded electrical interfaces. This demonstrated a practical pathway toward multifunctional smart structures for space applications.

The project also generated valuable know-how regarding the opportunities and limitations of directly printed sensors, guiding future developments toward more reliable integrated sensing solutions.

