

DELOS : DEformable Lens for Optical Systems in space

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Abstract - The DELOS project addresses the critical cost and structural constraints of Earth observation satellites, stemming from complex ground alignment, heavy thermal management trade-offs, and in-orbit optical degradation, by developing a space-compliant deformable lens for real-time wavefront aberration correction.

The proposed solid-state architecture integrates radiation-tolerant glasses, piezoelectric actuators, and low-outgassing polymers. This design will enable active correction of up to 36 Zernike modes while maintaining structural robustness, a primary eigenfrequency > 140 Hz, and resistance to extreme launch vibrations and thermal cycles. Featuring a low-power charge-control driver (~ 1.5 W) to eliminate piezo hysteresis and sensorless AI algorithms for direct focal-plane wavefront estimation, the lightweight assembly (~ 25 – 50 g, 72 mm clear aperture) aim at relaxing ground assembly constraints, reduces payload mass, and extends the operational lifetime of next-generation small satellites.

Motivations - The deployment of Earth observation satellites has grown exponentially, becoming an indispensable tool for monitoring critical environmental parameters, evaluating the impact of natural disasters, coordinating rescue operations, and ensuring effective territorial surveillance. However, manufacturing and operating these space assets demand large financial and technological commitments. Overall satellite costs remain exceptionally high, driven by mission risk, where failures must be economically compensated by operational missions, and by intricate structural engineering. A major design challenge involves thermal and weight management: engineers must choose between high-cost advanced materials like carbon fiber to achieve both lightness and thermal stability, or heavy alloys to minimize thermal expansion at the expense of added weight. Furthermore, performance degrades over time in orbit as severe thermal and mechanical stresses cause structural misalignments and optical aberrations. Moreover, to mitigate gravitational release effects once deployed, satellites are often intentionally misaligned during ground assembly, a delicate process, which heavily relies on satellite mathematical modeling, that significantly increases production and testing timelines. Together, these demanding trade-offs and complex manufacturing constraints greatly complicate satellite design and increase project costs. To maximize the return on investment and extend mission lifespans, modern aerospace research is increasingly focused on developing advanced dynamic technologies and self-correcting alignment systems capable of autonomously compensating for these spatial distortions.

Objectives - Within the framework of the DELOS project, the primary objective is to overcome these current design limitations by developing a space-compliant deformable lens specifically designed to actively correct optical aberrations in Earth observation satellites. To ensure technological readiness and operational reliability, the project includes the design and

realization of a dedicated test set-up aimed at validating the performance of the deformable lens within a relevant space environment. Furthermore, DELOS will quantitatively evaluate the overall system-level impact of integrating this adaptive optical element into small Earth observation satellites, focusing specifically on mass reduction and the extension of operational mission lifespans. By dynamically compensating for structural misalignments, thermo-mechanical stresses, and orbital degradation in real time, the developed lens promises to relax stringent ground alignment constraints and reduce reliance on heavy, costly materials. Ultimately, DELOS aims to demonstrate how active wavefront control can streamline payload design, decrease launch expenses, and drastically improve the performance density and economic viability of next-generation small satellite platforms.

Key challenges - The realization of a space-compliant adaptive optics lens presents critical engineering challenges across material selection, electrical driving, and mechanical design, all framed by stringent environmental constraints. First, candidate materials must withstand accumulated total radiation doses ranging from 15 up to 50 krad without undergoing degradation in their optical, electrical, or mechanical properties. Furthermore, components must remain vacuum-compatible under operating pressures down to 10^{-5} hPa; they must strictly limit outgassing—targeting a Total Mass Loss (TML) $\leq 1\%$ and Collected Volatile Condensable Material (CVCN) $\leq 0.1\%$, to prevent volatile vapors from depositing on and contaminating adjacent optics. Second, the electronic architecture requires a fundamental overhaul: standard piezoelectric actuators are typically voltage-driven, which introduces creeping and hysteresis (where the system must target tight specifications such as $\leq 2\%$ hysteresis and 99% linearity); switching to current-based control architectures is essential to mitigate these non-linearities and achieve required long-term open-loop stability. Finally, the mechanical structure must survive severe environmental profiles, including sinusoidal vibrations up to 10g, random vibrations of 8 g_{RMS} , mechanical shocks reaching 700g, thermal cycling spanning non-operating ranges of 100 K to 323 K, which restricts to 273 K to 313 K when operating, and maintain a lowest eigenfrequency above 140 Hz, while simultaneously providing the structural flexibility needed for the active optical elements to deform and correct up to 36 Zernike modes.

Preliminary design - The proposed design for the deformable lens within the DELOS project is based on integrating piezoelectric actuators, glass membranes, and a polymer assembly. This combination creates a solid-state structure with no loose moving parts, providing high robustness and high resonance frequencies to withstand launch loads. The baseline configuration features a thin, soft polymer layer sandwiched between a CTE-compensated glass membrane and a thick glass base substrate. The thin membrane is actuated by concentric piezoelectric rings bonded symmetrically on both sides to intrinsically compensate for thermal expansion mismatches. The outer non-segmented rings handle defocus and thermal offset compensation, while the inner segmented rings apply local deformations to correct higher-order aberrations. To mitigate the hysteresis and non-linearities typical of piezoelectric actuators without using space/mass-consuming wavefront sensors, the driver system adopts a charge-control strategy by introducing series capacitors [1]. The power and control electronics feature a high-voltage DC-DC converter (up to 150V–250V) built with radiation-tolerant components and GaN switches, capable of driving up to 32 channels with low power

consumption (~ 1.5 W). In addition, to withstand the space radiation environment (up to 50 krad TID), material selection focuses on radiation-tolerant glass substrates (such as fused silica or titanium and cerium oxides doped silicates) and space-qualified low-outgassing elastomers (e.g., Dow Sylgard 93-500 or CV4-2500) [2,3]. The integrated unit (with an estimated lens mass of only ~ 25 – 50 g and a clear aperture of 72 mm) also enables Tip-Tilt modulation for extended exposure times during staring modes. For in-orbit wavefront correction, sensorless AI algorithms will estimate and correct Zernike coefficients directly from the focal plane images captured by the payload sensor [4].

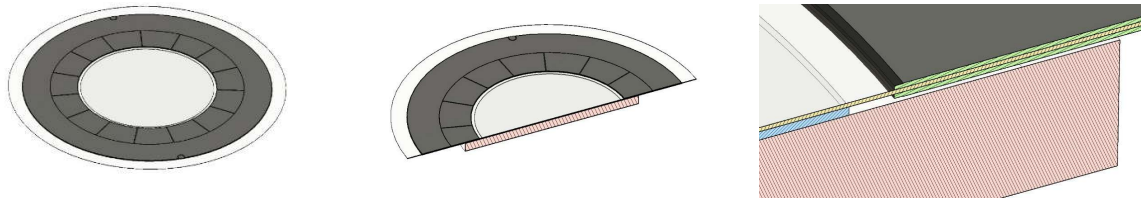


Figure 1- Sketch of the preliminary lens design

References

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