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ENGINEERING MODEL OF THE OPTICAL SPACE CS CLOCK

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INTRODUCTION

Thales Electron Devices and OEI Opto AG (subsidiary of RUAG AG) currently develop the engineering model of the Optical Space Cs Clock (OSCC) in the framework of an ESA/CNES project. Recent progress of the project is reported. Emphasis is put on the implementation of an isolator-free optics subsystem and on the space evaluation of the seeding DFB laser and the fluorescence detecting large area photodiode.

DEVELOPMENT CONTEXT

The optical pumping of the Cs hyperfine state was identified many years ago as a suitable technology candidate for an atomic clock to operate in GNSS, and in particular in Galileo. Related industrial activities currently develop this technology with focus on ground applications [1, 2]. The current OSCC project phase develops the engineering model (EM) with a foreseen validation in 2017 [3].
At the end of the elegant breadboard development phase in 2013, a short-term frequency stability of 3E-12$\tau^{-1/2}$ was demonstrated. The target of the present phase is 1E-12$\tau^{-1/2}$ with a flicker floor of 1E-14. Further new design constraints are: 12l volume, 10kg mass, 30W power consumption and 12 years lifetime in medium earth orbit.

DESIGN OF THE ENGINEERING MODEL

The functional architecture was consolidated in former development phases. As shown in Fig. 1, left, the clock is composed by the Laser and Optics (L&O) sub-system (s/s), the Atomic Resonator (AR) s/s and the Electronic Package (EP) s/s. The thermal Caesium beam is contained in the high-vacuum AR.
The engineering model of the clock is shown in Fig. 1, right. It demonstrates the feasibility of a highly integrated clock. All sub-systems were re-designed to fit with weight and volume constraints. The laser and optics (L&O) sub-system is of 500g at 1l volume. The concept of the EP was modified using multiplexing technologies to reduce the number of components. Oversampling approaches are implemented to reach the

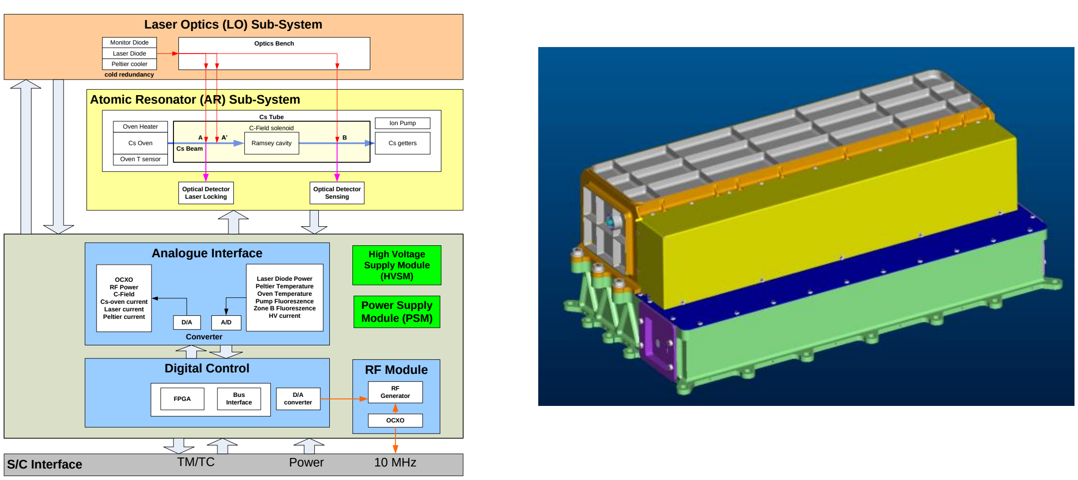

Fig. 1. Left: Functional Architecture of the optically pumped Cs clock, Right: View of the engineering model of the clock – below the housing of the electronics package (EP), above the atomic resonator (AR) and the laser and optics sub-system (L&O).

necessary signal conversion resolutions while maintaining low power consumption through low bit-number AD/DA converters. The over-all housing is optimized in order to withstand the vibrational constraints at satellite launch while still providing the necessary thermal conductivity. The material baseline is Titanium for the Atomic Resonator and Aluminium for the remaining structure.

THE LASER AND OPTICS SUB-SYSTEM

The Optics Bench

The laser and optics sub-system concept is shown in Fig.2, it consists of a DFB laser diode source, laser light polarization management and optical power distribution into three light-atom interaction zones. The over-all physically necessary power is 5mW of laser light locked to the Cs D1 4-3' transition at 894nm [3]. The laser diode collimation lens is implemented using dynamic alignment and low-retraction glue. Although the expected lifetime of the laser diodes exceeds the system lifetime, two laser sources are mounted in cold redundancy. A polarization asymmetry is introduced between the two laser diodes for this purpose. Indeed, the laser light is spatially depolarized for the interaction with the Cs atoms. As such, any linear seed polarization is acceptable. In contrast to a 50/50 beam-splitter redundancy, this approach leads to a lower required laser diode optical power increasing the expected laser lifetime. All optical elements are implemented on specially designed aluminium mounts. Shims provide at the same time initial tunability and mechanical stability. The current design does not contain an optical isolator. To avoid perturbation direct back-reflection into the DFB lasers [4], all optical elements are implemented under a slight angle against the optical axis. A partially representative prototype has been validated through a clock stability measurement [3].

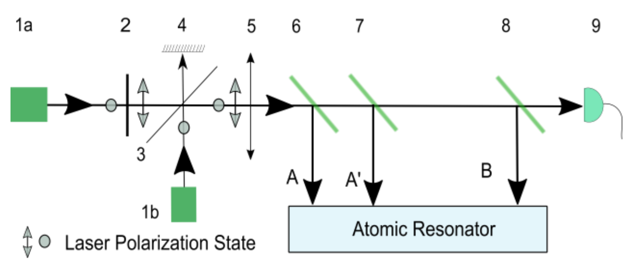

Fig. 2. Functional implementation of the Laser & Optics sub-system, with the components 1 Laser Diode, 2 waveplate, 3 polarizing beamsplitter, 4 beam absorber, 5 beam circularization, 6-8 beamsplitter, 9 photodetector for optical power detection.

The Laser Diode Sources

During the former development phase of the industrial, optically pumped Cs clock, the laser diode has been evaluated as the most critical technology. The reach of optimal linewidhts below 1 MHz [6] was historically linked to the use of external cavity diode lasers. Although this technology is well known, it appears to add a significant amount of complexity to a commercial clock.

For Cs clock application and in the frame of the European Euripides LAMA project, III-V Lab has recently developed an active region Al-free DFB laser diode emitting at Cs D1 line 894nm [6]. The implementation is based on previous results at Cs D2 line 852nm. The laser is a Separate Confinement Heterostructure (SCH). The cavity single transverse mode behavior is enabled by a narrow width ridge waveguide. On the other side, the single longitudinal mode operation is ensured by a second-order Bragg grating. The lasers show single mode behavior at Cs D1 line. The linewidth lies in the range of 0.7 to 1MHz. Ongoing developments aim at DFB Cs D1 line at ambient chip temperature.

In parallel, the eagleyard Photonics is currently running the manufacturing of a lot of DFB lasers at 894nm [7]. The thermal/electro-optical tuning coefficients and output power are expected to be nearly identical for the two sources. In summary, today even two European suppliers provide suitable TO3 packaged DFB laser sources as a commercial product. Addressing the Cs D2 transition at 852nm, comparable clock performance was observed for both laser diode sources [3].

SPACE EVALUATION OF OPTOELECTRONIC COMPONENTS

Being conceived for a lifetime of 12 years in medium earth orbit, all components of the clock have to be space-qualified. The current project phase aims at reducing the associated risk. The latter is essentially driven by the space-qualification of the optoelectronic components: the laser diode and the photodiode. The latter is required to detect the physical clock signal contained in only 10nW fluorescence intensity. In a pre-evaluation phase in 2016, the most critical properties and degradation modes of the laser and photodiode were identified based on supplier heritage and expertise of THALES, CNES and ESA. To reduce the remaining qualification risks, a respective space-evaluation program was defined and will be implemented starting 2016.

A. LASER DIODE

The design baseline is a TO3 packaged DFB laser diode as an off-the-shelf component with modifications. Liftetime and component construction have been identified as most critical issues. They will be evaluated in detail in the current project phase. In contrast and based on return on experience from former laser diode qualifications, radiation induced damage (100krad over 12years) was evaluated to be a minor risk. The same holds for the hermeticity of the TO3 packaging which benefits from longstanding industrial heritage. The Thales supplier evaluation concerning industrial quality management and technical feasibility in 2016 was positive for the two supplier eagleyard Photonics and III-V Lab.

B. PHOTODIODE

Former CNES evaluations demonstrated that the off-the-shelf detector initially used for the OSCC development cannot be space qualified mostly due to hermeticity issues of the packaging.
In early 2016 TED conceived with First Sensor a customized detector for a space evaluation. It is based on an off-the-shelf large-area photodetector and a customized TO-packaging. The former is similar to a quadrant detector currently qualified for the use in a space sun-sensor application. Compared to the S1337, it is expected to even slightly increase the detected clock signal level (clock stability) due to a larger active area.

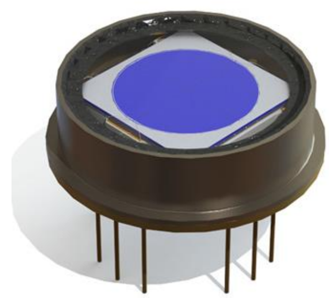

Fig. 3. View of a similar packaging of the large area photodetector (active area 11mm diameter).

The photodetector sensitivity and dark noise level are of key importance for clock performance. Concerning space application, a loss of photosensitivity and an increase of dark noise is expected due to (radiation induced) displacement damage. The two aspects will be verified in the space-evaluation program 2016-2017. The irradiated samples can also be used to model the expected (thermal) annihilation of loss of photosensitivity. Indeed, the total mission dose is typically applied over a very short time, ignoring the continuous annihilation effects all along the mission. A dedicated test will also address the possible impact of substrate type (n-type or p-type) to radiation sensitivity.

The customized TO packaging will benefit from supplier heritage on a similar packaging for EUCLID mission. The Thales supplier evaluation of First Sensor concerning industrial quality management and technical feasibility in 2016 was positive.

CONCLUSIONS

The design of the OSCC engineering model is reported. A dedicated optics sub-system was developed. It is of minimized complexity and does not contain an optical isolator. As a first step towards space qualification, possible degradation modes of the laser diode and the photodiodes were evaluated. To reduce the remaining qualification risks, a dedicated space evaluation program was developed and will be implemented starting 2016.

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