A coupled dark state magnetometer developed for space missions

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The development of an optically pumped magnetometer for space missions is a challenging task considering the electrical, mechanical and thermal limitations and restrictions in a harsh environment. The coupled dark state magnetometer (CDSM) is a self calibrating, scalar magnetometer specifically designed for these challenges.

The coherent population trapping effect (CPT), within the hyper fine structure of the ^{87}Rb-D$_1$ line, allows a precise detection of magnetic fields. Several of these CPT resonances, in the form of Λ-systems, are excited and coupled simultaneously. In Figure 1, the two magnetically shifted (orange and green) Λ-systems are coupled to measure the magnetic field and to minimize external influences such as neon buffer gas pressure shift, sensor temperature shift and light shift. The blue Λ-system acts as a frequency reference for the CDSM's self calibration. The laser light's circular polarisation only excites Λ-systems according to the $m_F \pm 1$ selection rule. In Figure 1, the solid lines indicate excitations with σ^+ and the dotted lines excitations with σ^- polarised light.

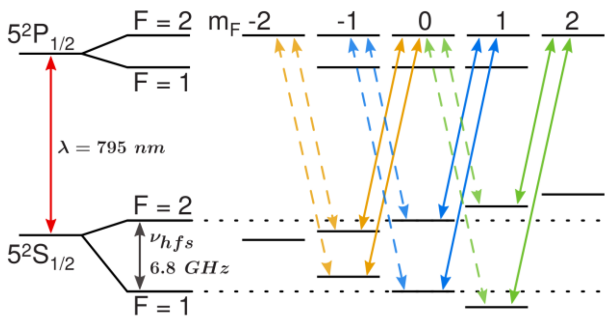

Figure 1: Excitation scheme of multiple Λ-systems within the hyper fine structure of the ^{87}Rb-D$_1$ line. The dotted and solid lines indicate resonances with different m_F quantum numbers.

For an omnidirectional sensitivity, additional CPT resonances (not shown in Figure 1) are exited depending on the angle between the magnetic field and the laser propagation axis.

The CDSM's current space ready flight model design is displayed in Figure 2. Optical fibres connect the ^{87}Rb sensor unit to the vertical cavity surface emitting laser (VCSEL) diode unit and the photodiode, both within the electronics unit. The laser current is FM-modulated with a 3.4 GHz signal to match the ground state hyper fine splitting with the first upper and lower sidebands to establish the Λ-systems. A blue resonance (Figure 1) stabilizes this GHz frequency. A field programmable gate array (FPGA) ensures the autonomous operation in space. Currently an accuracy below 0.2 nT is achieved.

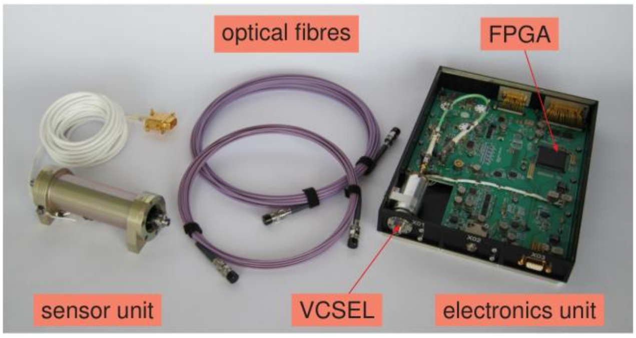

Figure 2: CSES flight model with its main components. From left to right: the vapour sensor unit, the optical fibres and the electronics box.

Since February 2018, the first CDSM version has been operating successfully in a low Earth orbit as part of the China seismo-electromagnetic satellite (CSES) mission. In 2022, the magnetometer will be launched with a newly designed sensor unit on board of the Jupiter icy moons explorer (JUICE) mission.

This new sensor design features a dual transition principle. The light is sent through the spectroscopic glass cell twice to compensate for different atomic transition rates due to the light's circular polarisation. Now both, the dotted and solid resonances are equally excited. This allows to optimise the accuracy and further reduces the external influences.

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Pollinger et al 2018 Meas. Sci. Technol. https://doi.org/10.1088/1361-6501/aacde4

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