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A radiation-hardened and low flicker noise ASIC preamplifier designed in CMOS technology for the ultra-sensitive ESA JUICE search coil magnetometer

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Important space scientific missions such as ESA CLUSTER (2000), NASA THEMIS (2007), NASA MMS (2014), ESA/JAXA BepiColombo (2016) and ESA JUICE (2024) have and will incorporate an ultra-sensitive three-axis Search Coil Magnetometer (SCM) to measure the magnetic field vector. Over the years, the instrument, which is designed by the LPP/CNRS, has become a reliable and essential device due to the in situ demonstrated performances in terms of high magnetic resolution, robustness, low power consumption and its ease of implementation. The SCM operates in low-frequencies from 0.1 Hz to a few dozen kHz. Therefore, in order to achieve a femtoTesla (fT/sqrt(Hz)) sensitivity (noise floor), the equivalent input noise of the readout electronics must be lower than some nV/sqrt(Hz). Here, we are particularly confronted to the flicker noise (1/f). The electronics'power consumption is to be considered during the design flow since this is a crucial aspect in space applications, among other specifications, for the instrument's lifetime. Furthermore, related effects to cumulative radiation dose, heavy ions and temperature should not impact the readout electronics specifications and therefore the SCM sensitivity.

In this paper, we will introduce the principle of the designed SCM for JUICE (JUpiter ICy moons Explorer) which operates in the frequency range 0.1 Hz –20 kHz. The SCM should provide a 4 fT @5kHz sensitivity (noise floor). The mission's environment requires an operating temperature of -150 ℃ and a total ionizing dose of 300 krads (under shielding).
To meet those constraints, an application-specification-integrated-circuit (ASIC) designed in 0.35µm CMOS technology is proposed. It consists of a low flicker noise preamplifier. The interest in a monolithic integration of the readout electronics is explained. An analytic study of MOSFET transistor noise contribution was done to allow the considerable reduction of the flicker noise (1/f) and to achieve, thanks to an appropriate transistors dimensioning, an input equivalent noise of 4 nV/sqrt(Hz) and a current noise of 20 fA/ sqrt(Hz) at 10Hz. The chip was exposed to a 300 krads of Colbalt-60 total ionizing dose (TID) and tested in nitrogen temperature (77 °K). Measured noise and gain variations of the preamplifier do not affect the SCM sensitivity. The ASIC power consumption is 16 mW, which is interesting if compared to previous adopted electronics based on discreet components. The ASIC radiation-hardiness is insured by enclosed-gate layout transistors and guard-rings around each device.
In the second section of the paper, we will discuss the new ASIC design, which will include, in addition to the low noise preamplifier, a supply voltage regulator and a band-gap voltage reference. The interest of those new functions is to improve the insensitivity of the supply voltage and the biasing in a wide temperature range, which starts at 77°K.

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