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Radiation hardness compatibility of vacuum gauge electronics for the HL-LHC era

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The HL-LHC upgrade will lead to increased radiation levels in the LHC tunnel. Consequently, hundreds of vacuum gauge conditioning electronics deployed throughout the LHC must be replaced by new radiation tolerant designs. The development of radiation tolerant electronics followed the CERN radiation hardness assurance protocol. Component and system-level radiation tests have been performed at different radiation facilities. Issues encountered with operational amplifiers and mitigation actions are explained. For adequate tracking during production and operation, quality assurance methods were applied. This paper describes the steps taken to ensure radiation hardness compatibility of vacuum gauge electronics for the HL-LHC era.

Summary (500 words)

During the 10 years of HL-LHC operation, a total ionizing dose (TID) of 14 Gy and a high energy hadron (HEH) fluence of $2.4 \times 10^{10} \text{ cm}^{-2}$ are expected in the arc areas, and a TID of 200 Gy and a HEH fluence of $4 \times 10^{11} \text{ cm}^{-2}$ are expected in the dispersion suppressor (DS) areas. Conditioning electronics for vacuum gauges installed in those areas were not compatible with such a radiation environment. Therefore, new radiation tolerant electronics were designed, qualified, produced, and installed first in the DS areas during the second long shutdown. The installation of the remaining electronics for the arc areas will occur during the third long shutdown starting in 2026.

New batches of components from unique date code (DC) and production lots (LOT) were qualified up to 500 Gy with a HEH fluence of $1 \times 10^{12} \text{ cm}^{-2}$ at the Paul-Scherrer-Institute (PSI), under a 200 MeV proton beam with a dose rate of 350 Gy/h. Depending on the component type, various test setups were configured, such as output voltage deviation, single event transients (SET), and single event latch-ups (SEL). Another test setup was dedicated to studying the impact of radiation on the input bias current of specific amplifiers. This test was designed to measure the increase of input bias current with a sensitivity of a few picoamperes.

System-level tests were performed at the CERN High Energy Accelerator Mixed field (CHARM) facility, with a mixed field of secondary particles with wide energy spectra (up to 24 GeV), a HEH fluence of $1 \times 10^{12} \text{ cm}^{-2}$, and a 1MeVn-eq fluence of $3.2 \times 10^{12} \text{ cm}^{-2}$. The CHARM facility offers a more representative radiation environment to the LHC machine. With an average dose rate of 2 Gy/h, a system can be tested up to 500 Gy in less than two weeks. Three systems (Piezo, Pirani, power supply) successfully passed the irradiation test at the CHARM facility, with relative errors of less than 2% at 500 Gy with a HEH fluence of $1.8 \times 10^{12} \text{ cm}^{-2}$ and a 1MeVn-eq fluence of $3.5 \times 10^{12} \text{ cm}^{-2}$.

However, destructive SELs were encountered with some samples of the fourth system (Penning) due to increased Single Event Effect (SEE) sensitivity of an operational amplifier. Even the Penning samples that survived the irradiation test exhibited very noisy measurements due to high photocurrent signals. A new operational amplifier was procured and qualified at PSI and at CHARM, then integrated into the design of the Penning system. Another CHARM system-level test was conducted, and the performance of the electronics was improved, with relative errors of less than 2.5% at 500 Gy with a HEH fluence of $1.9 \times 10^{12} \text{ cm}^{-2}$ and a 1MeVn-eq fluence of $3.1 \times 10^{12} \text{ cm}^{-2}$, while exhibiting reduced sensitivity to photocurrents. An estimation of the annual failure rate of every system was calculated. Lastly, quality assurance methods were applied for each electronic board produced, to track information on radiation-sensitive semiconductor components (DC and LOT) and their installed location in the LHC machine.

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