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rPOL2V5: a compact radiation-hard resonant switched-capacitor DC-DC converter for the CMS HGCAL

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A high power density resonant switched capacitor DC-DC converter (rPOL2V5) has been developed as a possible alternative to the bPOL2V5, of particular interest to the CMS High-Granularity Calorimeter (HGCAL) due to the relatively compact 12nH air-core inductor that it requires. The converter is based on an ASIC developed in a 130nm CMOS technology. It is powered by a 2.5V input, it can supply a maximum current of 3A to the output voltage range 1-1.5V. This work presents the strategies adopted at ASIC and PCB level to bring the converter to maturity, and the electrical and radiation characterization results.

Summary (500 words)

rPOL2V5 is a radiation-hard resonant switched-capacitor DC-DC converter, which can be adopted in a two-stages power distribution scheme proposed for the High-Luminosity Large Hadron Collider experiments. It is a second-stage converter that steps down the voltage from 2.5V to an adjustable output voltage in the range 1-1.5V, providing up to 3A of output current. The converter's module hosts an ASIC designed in 130 nm CMOS (which includes the power switches and the control circuitry) and discrete components such as capacitors and inductors. The resonant switched capacitor topology allows this converter to feature a smaller inductor (12nH) compared its buck converter counterpart bPOL2V5, whose inductor is approximately 8 times bigger (100nH). Thanks to its compactness, rPOL2V5 can be of interest for environments with challenging space constraints, such as the CMS High-Granularity Calorimeter (HGCAL). The harsh environment of HGCAL is characterized by large magnetic field (up to 4 T) and challenging radiation levels: a total ionizing dose (TID) exceeding 200Mrad and a neutron fluence up to 8 x 10ˆ15 1 MeV neq cm-2. Therefore, the converter is equipped with an air-core inductor to be compliant with the magnetic field, while hardening by design techniques have been adopted for the ASIC design. In particular, enclosed layout transistors have been used to avoid TID-induced leakage currents, while triplication of the most important control circuitry has been adopted to protect the ASIC from potentially destructive events, generated by SEEs up to a Linear Energy Transfer of 40 MeV·cm2 /mg.
The first prototype of rPOL2V5 proved the effectiveness of its novel multi-mode control strategy and the tolerance of the converter to a TID of 220 Mrad. Nevertheless, its characterization highlighted a not always reliable operation of the converter and a sub-optimal efficiency in certain operating conditions. This works focuses on the second prototype of rPOL2V5, which has been designed to improve these aspects and bring the converter to maturity. The ASIC control circuitry has been simplified with respect to the previous prototype: two of the four operation modes have been discarded to avoid issues in the mode-to-mode transitions, while the control circuitry has been improved to guarantee safer and enhanced efficiency operation for Vout larger than 1.2V.
The parasitic inductances of the input and output path are responsible for overvoltages on the power devices that could affect the reliability of the converter. These inductances have been therefore studied and reduced by almost 50% compared to the original module by choosing appropriate ESL capacitors and a proper PCB stackup. The first prototype of rPOL2V5 adopted a flip chip assembly and copper filled microvias in pad. In order to ease the manufacturing constraints and costs of the production, a new module that features exclusively through vias outside of the flip-chip area has been also designed.
Together with the design strategies at ASIC and PCB level mentioned above, this work presents the electrical and radiation characterization results of this new prototype of rPOL2V5.

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