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Design and Assessment of a Robust Voltage Amplifier with 2.5 GHz GBW and >100 kGy Total Dose Tolerance

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In this work a voltage amplifier with a gain-bandwidth (GBW) product of 2.5Ghz utilizing adaptive biasing has been designed, using a standard CMOS technology. The amplifier was tested under gamma-radiation and temperature and features a gain degradation of 4,5 % up to a total dose of 100kGy and 5.6 % within a temperature range of -40 till 130℃. Finally the importance of including the standard deviation of the radiation induced threshold voltage in the simulation and design phase has been shown based on preliminary separate transistor measurements.

Summary

Fiber-optic links offer unique benefits in harsh environments due to their high temperature properties (>200℃) and intrinsic tolerance against electromagnetic interference (EMI). They may provide an attractive solution for applications such as LIDAR (LIgth Detection and Ranging) which is foreseen in the design of the accelerator driven MYRRHA reactor or for the communication between the reactor core and the control room for ITER.

The first block in an optical receiver is the TransImpedance Amplifier (TIA). The TIA converts the incoming photodiode current to a voltage with minimal degradation to the signal-to-noise ratio. The goal of this work is to develop a TIA in standard CMOS with improved tolerance for γ-radiation and temperature (-40…130℃) for use in harsh environments. Simulations show that a critical building block in the TIA is the open-loop gain, determined by voltage amplifiers. Several specifications of these amplifier stages change due to effects of both increasing temperatures and ionizing radiation, hereby degrading the GBW of the TIA. This is due to shifts in the transistor parameters like the threshold voltage, mobility and leakage currents. In order to mitigate these effects, this work uses circuit techniques based on adaptive biasing. Through this open-loop control technique, the voltage gain of the amplifier is intrinsically stabilized, which means the gain is kept constant in spite of shifts in transistor parameters induced by γ-radiation and increased temperature.

Measurements after irradiation show that the gain of the circuit is stable within 4.5 % when irradiated up to 100kGy. Simulations have allowed us to verify that the main degradation is caused by the standard deviation of the threshold voltage shift in the transistors . It is observed that a large VGS-VTH is needed when a good tolerance for high radiation doses is desired.
In order to verify the threshold voltage shift mismatch under radiation, an array of transistors was designed and assessed. These results show the influence of radiation on the threshold voltage mismatch which is sufficient to explain the observed degradation of the amplifier's voltage gain.

The circuit was also tested to verify its temperature tolerance. It shows a mere 5.6 % voltage gain variation in a temperature range of -40 till 130 ℃. This contrasts strongly with the 77% variation of a voltage amplifier using regular biasing techniques. The drain-source resistance of the output transistors drops significantly due to the increasing current needed to stabilize the transconductance of the input transistors. When a constant gain over a larger temperature range is desired the lengths of the output transistors will have to be increased, reducing the bandwidth of the amplifier.

In this work a voltage amplifier ASIC for use in the TIA of an optical receiver has been designed and tested over a temperature range of -40 to 130 ℃ and under γ-radiation up to 100kGy. The circuit uses open-loop gain control and removes the need for sophisticated feedback techniques. Thanks to this open-loop circuit technique, the feedback resistor of the TIA is left as a variable to control gain and bandwidth.

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