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# Development of a Front-End Stage for Future XFEL Detectors

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New X-Ray pixel detectors are required to satisfy the challenging requirements from X-ray Free Electron Laser (XFEL) sources, such as high frame rates, wide dynamic range, and low noise for single-photon sensitivity.
The European XFEL is capable of emitting ultrashort X-ray flashes 27,000 times per second, delivering brilliance that is a billion times greater than conventional X-ray sources.
The new generation of detectors for the Eu-XFEL should feature both a high dynamic range, enabling discrimination of up to $10^4$ photons, and single-photon resolution at low energies such as 1keV.
A new front-end (FE) solution has been studied to satisfy XFEL requirements. The proposed FE includes a Charge Sensitive Amplifier (CSA) with active gain switching, a transconductor, and a trapezoidal filter.
Single-photon capability at low energies can be achieved by employing a filter, based on the Flip-Capacitor filter concept, to minimize the electronic noise.
Moreover, to fulfill the high input photon dynamic range requirement, an active gain switching (AGC) approach is adopted.
The CSA features three feedback capacitances to implement three different gain settings. Based on the input charge, the three gains correspond to different operating ranges. In the first range, the system can detect from 1 to 50 photons with single-photon resolution, in the second range detects up to 800 photons, and in the third range, it detects up to $10^4$ photons at 1keV.
The AGC circuit sets dynamically the proper gain to prevent output saturation, leading to noise minimization, and can be implemented in two ways.
In the standard approach, each time the CSA output exceeds a fixed threshold, typically set close to the power supply, a feedback capacitance is added in parallel.
A more interesting approach, particularly in the field of X-ray detection, is the "predictive" gain switching technique, which dynamically determines the proper gain based on the time instant "t"at which the input signal crosses a predefined threshold.
The time instant "t"depends on the input charge Qin; the higher Qin, the faster the CSA response, and the smaller the time instant "t". If the signal exceeds the threshold at a time instant "t"greater than both "t1" and "t2", which define two timing windows, the CSA operates in its standard configuration with the lowest feedback capacitance. If "t"is between "t1"and "t2", the middle gain is selected. Finally, if "t"is lower than both "t1"and "t2", the CSA switches to the lowest gain setting.
The predictive AGC circuit features several advantages: it involves only one gain transition among multiple gains, the threshold value can be independently set, and so does not need to be close to the power supply, and the gain decision is taken within a time much shorter than the integration time.
The adopted filter features a current as input, so to couple with the CSA, a voltage-to-current converter is required. The conversion must be as linear as possible, which is quite challenging due to the wide dynamic range of the CSA output signal. To prevent the filter output from being saturated, an equivalent resistance of 310 kΩ should be achieved.
Moreover, a DC programming loop is implemented between the filter and the transconductor to cancel the residual output current caused by offset and mismatch.
The implemented filter is based on the Flip-Capacitor Filter (FCF) idea and features a trapezoidal weighting function with a flat top duration of 50 ns. It performs a double integration using a single amplifier.
The filter is included only in the first operating range to be able to achieve the single photon resolution at 1keV.
An estimation of the equivalent noise charge (ENC) has been carried out through Cadence simulations considering the filter for the first operating range.
Multiple transient noise simulations were performed to estimate the rms output voltage at the filter output. The simulated rms voltage noise values are 1.85 mV, 2.1 mV, and 2.8mV for integration times of 50 ns, 100 ns, and 150 ns, respectively. Corresponding ENC values are 35 e−, 40 e−, and 52 e−, assuming a total detector input capacitance, Cin, of 300 fF.
The ENC values, for higher input charge (second and third range), have been estimated by reporting at the input the output rms voltage noise of the CSA signal, as the FCF is not used when the AGC is active, and are

155 e– for the second range and 1044 e– for the third range.
The proposed FE has been optimized for soft X-rays, achieving single-photon resolution at 1 keV, while maintaining a high input photon dynamic range (up to $10^4$ photons) by implementing the predictive gain switching technique. A first prototype has been designed in 65 nm CMOS technology. Preliminary measurements on the first prototype will be reported at the conference.

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