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512-Channel SiC Beam Monitor Electronics: Single-Particle up to Clinical Beam Rates Using Commercial Components

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A 512-channel beam monitor was developed to measure beam parameters at particle rates from single particles up to clinical rates (several GHz). The system is designed for silicon carbide (SiC) strip sensors for increased radiation tolerance. The sensor readout uses four 128-channel analog charge-integrators with on-chip multiplexers, complemented by ADCs and a SoC module (FPGA + CPUs). Gigabit Ethernet, an SFP+ interface, and electrical and optical links enable communication with auxiliary systems. The system operates from a single power supply and was implemented on a $426 \times 253 \text{ mm}^2$, 12-layer PCB. All components, except for the sensors, are commercially available.

Summary (500 words)

The electronics for a 512-channel beam monitor were developed to characterize particle beams at the MedAustron facility in Wiener Neustadt, Austria. Particle rates at the facility range from a few kHz (used for high-energy physics applications) up to several GHz (used for cancer treatment). The system is designed for integration into the existing accelerator environment.

The use of SiC-based sensors is planned due to their ability to handle high voltages and low dark currents, even after irradiation (unlike Si). This allows DC-coupling of the sensor strips to the front-end. These sensors enable precise detection of particle interactions, even at high fluxes. Still, the system can alternatively be equipped with other detectors, such as conventional silicon sensors.

The system is built on a $426 \times 253 \text{ mm}^2$, 12-layer PCB. The low-voltage part is powered from a single 9–25 V supply, which is converted to the required voltages through DC/DC converters, and, for the analog sections, additional filters with low-noise capacitors and low-dropout regulators. In the front-end part, the layout separates each signal line from the others by a ground line or ground plane wherever possible, to minimize interference. In addition, analog and digital signals are separated using fences wherever feasible.

High-voltages up to 1000 V can be supplied via SMA connectors; they are filtered and can be used for sensor biasing. The front-end part of the system is designed to operate in a vacuum, optionally. Various cooling methods can be used, including air cooling, heat pipes, and water cooling.

The analog signals from the sensors can be attenuated by current dividers. They are then fed into four 128-channel charge-integrating and analog time-multiplexing chips (AD8488, commonly employed for X-ray panel readout) and then into ADCs. The digital signals then pass through voltage-level translator chips into an SoC module (Xilinx Zynq Ultrascale+), which collects data, manages clocks and control signals for the analog front-end, and handles communication with external systems. The output data format is variable-sized packages containing 16 analog front-end samples, timestamps, and checksums for data integrity verification.

For communication with the outside world, the system supports Gigabit Ethernet, a 10 Gbit/s SFP+ interface, and several electrical and optical interfaces, such as trigger inputs for synchronization to the accelerator control system. The system can operate in triggerless, continuous streaming mode as well as in a triggered mode. Besides accurate time-stamping, the latter is useful in reducing network traffic between measurements. The I/O and power supplies for the FPGA module are also integrated into the board. An optional daughterboard provides 14 additional optical I/O ports for future system expansion.

All electronic components on the PCB, except for the sensors, are commercially available. Using COTS (commercial off-the-shelf) components provides a cost-effective solution for particle beam monitoring. Due to the long lead times of the designed SiC strip sensors, the system was tested in the laboratory using signal generators and at the MedAustron facility using silicon strip sensors instead of dedicated SiC sensors. Single-particle detection and beam profiling of clinical beams were successfully demonstrated.

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