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Design and Implementation of a Compact Analog Constant Fraction Discriminator for High-Resolution Timing in Gamma-Ray Spectroscopy

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This work presents Twin_Peaks_CFD1, a custom analog front-end card designed for the read-out of PMTs coupled to lanthanum bromide scintillators. It integrates 16 discrete analog constant fraction discriminators (CFDs) on a compact 12x10 cm board, providing precise timing information for nuclear lifetime measurements. The design emphasizes cost-effectiveness, utilizing off-the-shelf discrete components, as well as compactness, achieved through innovative use of miniature coaxial connectors and cables as delay elements. The minimalist analog shaper/discriminator design is devised without operational amplifiers, making use of only a handful of RF transistors and LVDS receivers in place of comparators.

Summary (500 words)

This work introduces the design and implementation of a custom analog front-end card, named "Twin_Peaks_CFD1," tailored specifically to the needs of the fast timing array (FATIMA) of the DESPEC experiment at GSI, Darmstadt. FATIMA comprises 36 cerium-doped lanthanum bromide scintillators, coupled to traditional photomultiplier tubes, aimed at measuring lifetimes of exotic nuclear states by detecting gamma rays. The necessity for excellent time-of-arrival information, coupled with clear spectroscopic distinction between gamma energies, led to the development of Twin_Peaks_CFD1, which hosts 16 discrete analog constant fraction discriminators (CFDs) on a compact 12x10 cm board.

The board interfaces seamlessly with the TAMEX4 Time-to-Digital Converter (TDC) board, a widely used FPGA-based TDC at GSI, offering precise edge measurements with a resolution of 15 ps rms.

A notable feature of the Twin_Peaks_CFD1 design is its reliance on off-the-shelf electronics components and low-cost FPGAs, emphasizing cost-effectiveness and accessibility.
Twin_Peaks_CFD1's compactness is achieved through the use of 16x 50 cm long, 1.3mm thick coaxial cables as analog delay elements, integrated via miniature coax connectors (U.FL) typically found in WiFi antenna assemblies. When neatly curled up and fixed with cable ties, the cables don't extend beyond the board edges, while the total thickness of the assembly remains below the height of the stacked double LEMO connectors at the front edge.

A CFD's primary task is eliminating the time-walk effect, i.e. the amplitude dependent distortion of the leading edge measurement. To accomplish this function in analog circuitry, CFD designs usually require high-speed operational amplifiers. A specialty of this design, however, is the complete lack of op-amps - to save power, costs and board space. Instead it employs only a handful of low-cost RF transistors in combination with differential LVDS receivers in place of analog comparators.
Without sacrificing performance, the heart of the circuit, the constant fraction shaper, was reduced to its most minimalist form, now comprising only a single transistor and a delay line, apart from passive components.

CFD performance tests with a PMT-like test pulse yield a leading edge precision of 60 ps (stdev) while the amplitude was varied up to factor 10 (20mV-200mV). Gamma-gamma coincidences with the CFD plus actual detectors yield a precision of better than 190 ps (stdev).

Due to its compactness and cost-effectiveness, Twin_Peaks_CFD1 exhibits limited flexibility in accommodating different signal shapes within a running experiment. However, this limitation can be mitigated by exchanging delay lines and adjusting on-board resistive dividers to suit the specific requirements (delay, fraction) of different detectors.

In conclusion, Twin_Peaks_CFD1 represents an innovative solution tailored for the unique demands of the FATIMA array within the DESPEC experiment, as well as similar set-ups. Its compact design, cost-effectiveness, and integration with existing infrastructure make it a valuable tool, offering precise timing measurements essential for advanced nuclear physics research.

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