Clock and Data Recovery Methods for the Readout Control Unit 2 in ALICE TPC

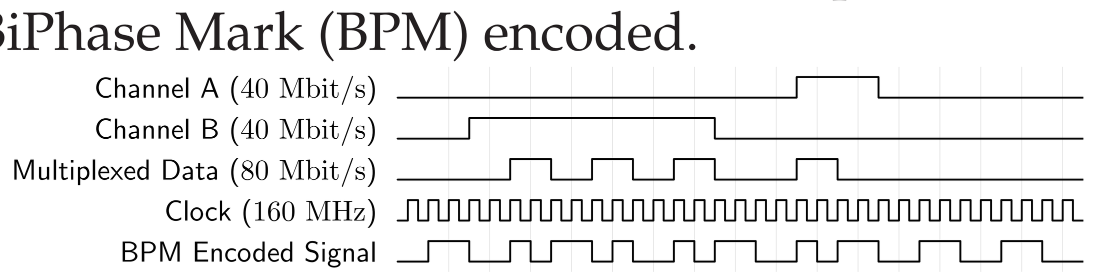
Christian Torgersen[1], J. Alme[2], L. Bratrud[6], E. David[5], T. Kiss[5], C. Lippmann[4], D. Röhrich[1], K. Røed[3], K. Ullaland[1], A. Velure[1]
for the ALICE TPC collaboration
[1]University of Bergen, Norway, [2]Bergen University College, Norway, [3]University of Oslo, Norway, [4]GSI, Germany, [5]Cerntech, Hungary, [6]Vestfold University College, Norway

Abstract

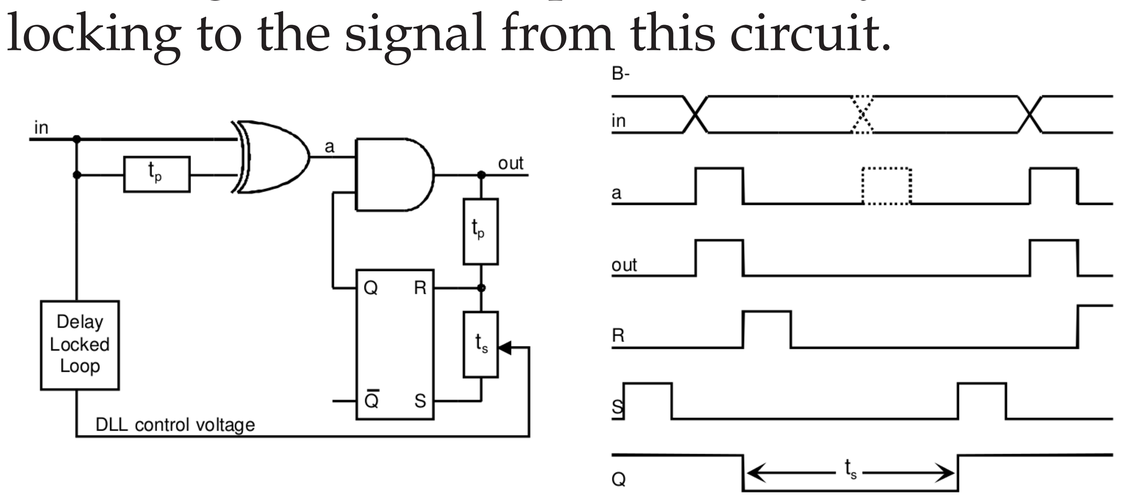
The present ALICE TPC readout electronics consists of 4356 Front End Cards that are read out and controlled by a total of 216 Readout Control Units (RCUs). The RCU communicates with all sub-systems, amongst other the Trigger, Timing and Control (TTC) system, which provides each RCU with the 40.08 MHz LHC clock, used as a system and sampling clock in TPC readout electronics. The LHC clock and trigger data are sent over the TTC fiber using 80 Mb/s Time Division Multiplexed BiPhase Mark encoded signals. It is important to have a radiation tolerant solution to recover the clock with low jitter and with a predefined phase-offset to the LHC input clock. Presently, this is handled by the TTC receiver (TTCrx) ASIC sitting on the RCU.

Clock and Data Recovery

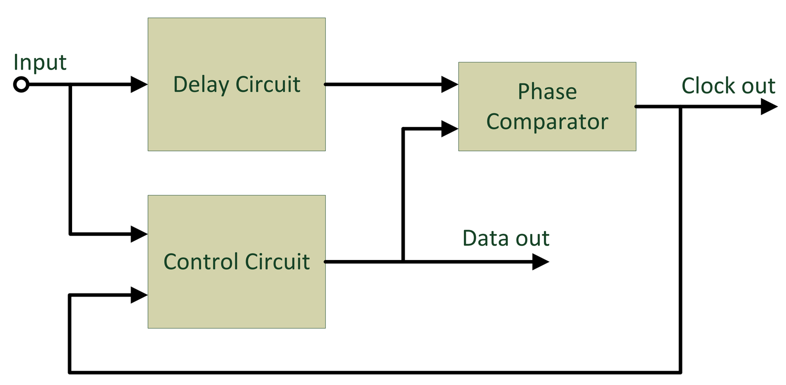
The TTC signal consists of two channels, A and B, which are Time Division Multiplexed and BiPhase Mark (BPM) encoded.



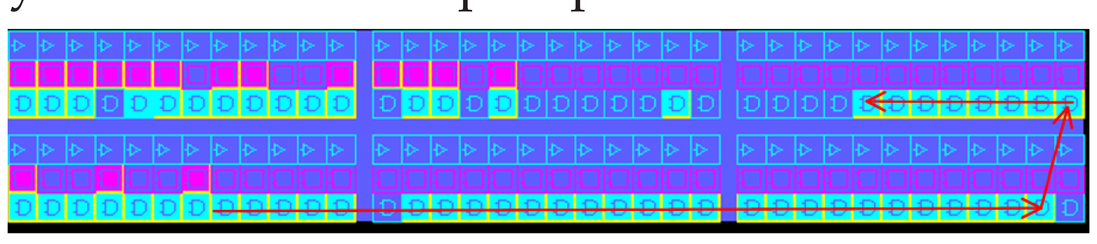
The current clock and data recovery method is using a optical receiver and the TTCrx ASIC [4]. The TTCrx implements a Delay Locked Loop (DLL) and a Phase Frequency Locked Loop (PFLL) in order to recover clock and data. Phase detection is performed by the use of a phase detection circuit seen on the figure below to the left. The delay, t_s is controlled by the DLL, and clock regeneration is performed by the PFLL locking to the signal from this circuit.



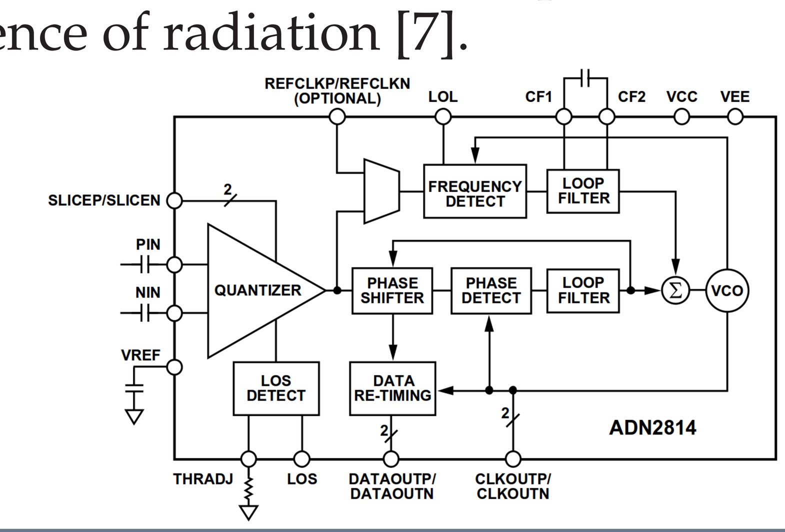
As a replacement for the TTCrx, a custom linear CDR circuit has been implemented in the fabric of the SmartFusion2 FPGA [5].



The circuit creates a linear delay line based on propagation delay through a series of inverters, laid out with an optimized layout in order to minimize delay differences between rising and falling signals. Phase detection is performed by an XOR, and the control circuit is implemented by the use of a D- flip-flop.

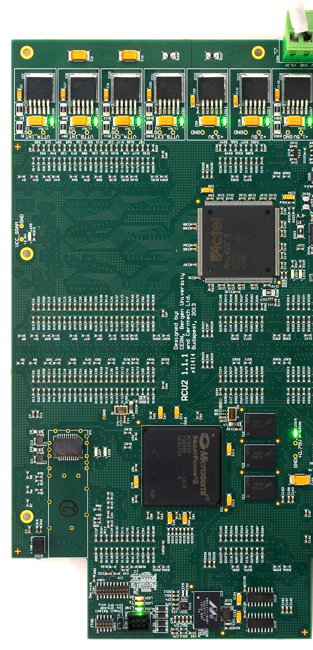


As a supplement to the linear CDR circuit, a commercial CDR chip [6] has been implemented on the RCU2. The solution is proven to function in absence of radiation [7].



Introduction

- The Time Projection Chamber (TPC)[1] is the main tracking detector of the ALICE experiment[2]. The detector is divided into 18 sectors on each side, which are divided into 6 readout partitions. One readout partition consist of 18 - 25 Front End Cards connected to one RCU with a parallel multi-drop bus.
- The LHC is presently in a shutdown period for maintenance and upgrade. The next running period will have higher energies and luminosities, which demands higher data throughput and improved radiation tolerance of the readout electronics. Thus it was decided to make a new RCU; the RCU2 [3].
- In the existing RCU, Clock and Data Recovery (CDR) has been performed by the TTCrx ASIC. At the time of the upgrade to the RCU2, the TTCrx was reported obsolete, forcing a new method for CDR. Two solutions were implemented, and their performance in terms of jitter and radiation tolerance has been tested.



Jitter Measurements

Measurement	Measurement Point	
	RCU2 CDR circuit	TTCrx
Standard deviation	28 ps	24.5 ps
Maximum positive deviation	275 ps	137 ps
Maximum negative deviation	390 ps	107 ps
Peak to peak deviation	665 ps	243 ps
Maximum $\Delta+$	219 ps	95 ps
Maximum $\Delta-$	216 ps	80 ps

- Jitter has been measured both on the TTCrx on the current RCU system and the CDR circuit implemented in the SmartFusion2 of the RCU2.
- Measurements indicate higher amount of deterministic jitter on RCU2 CDR circuit.

Radiation Tolerance

Investigation of radiation tolerance for the two circuits implemented on the RCU2 was performed by indirect measurements, sending the recovered clock signals to two on-chip PLLs of the SmartFusion2. A loss of lock on a single PLL was assumed to result from FPGA PLL failure, and loss of both PLL locks were assumed to reveal clock recovery circuit failure.

- Tests were performed by irradiating the CDR components alone, and thereafter irradiating the optical receiver.
- There were clear indications that the optical receiver could be the source of the high amounts of loss of lock.

Irradiated part	Fluence [/cm²]	MSS PLL loss of lock	Hamming errors	Recovered clock PLL loss of lock
SmartFusion2	1.92×10^{11}	> 20	0	12
Optical receiver	1.0×10^{11}	0	838	586

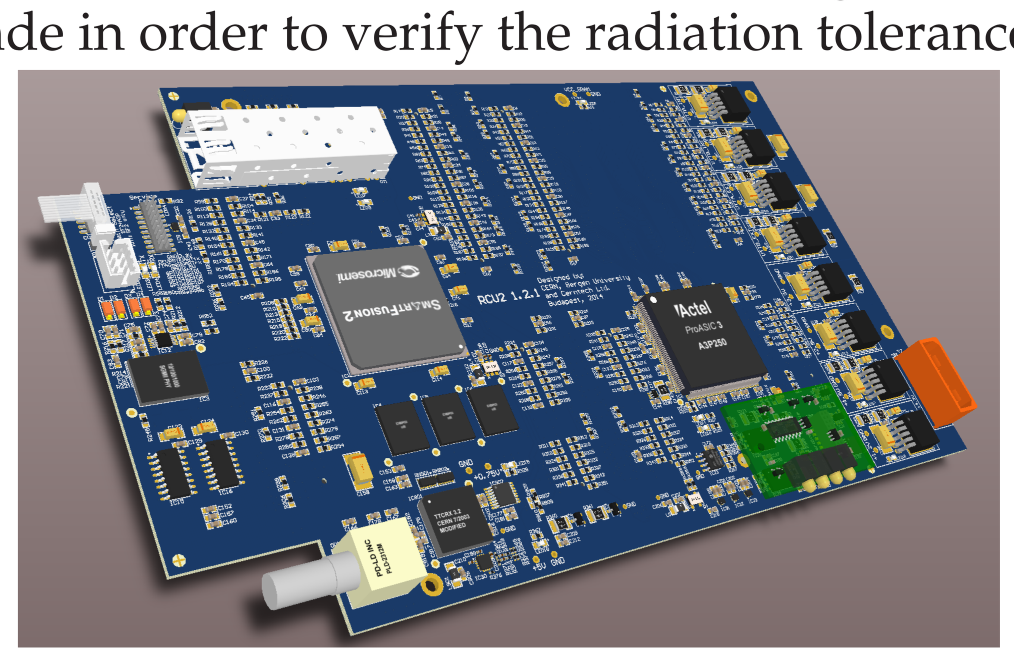
Irradiated part	Cross section	MTBF Run3 [a], 216 RCU2s [hours]
SmartFusion2	2.3×10^{-10}cm²	1.9
Optical receiver	6.09×10^{-9}cm²	0.07

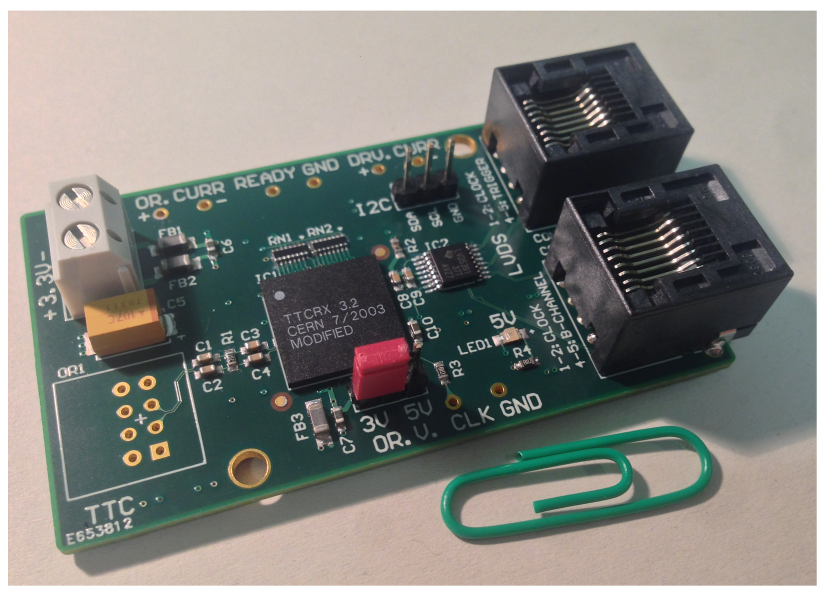
Further irradiation campaigns [8] were organised of in order to investigate the optical receiver behaviour in such environment, and finally the PD/LD PLD2321 was selected.

[a]Only for comparison - run 3 will be after 2019.

Summary and discussion

The jitter performance of the custom CDR solution is not as good as for the TTCrx. However, the jitter performance of the TTCrx far exceeds the specifications given by the physics of the TPC, 300 ps rms [9]. The initial jitter measurements of the custom CDR solution indicates that the jitter performance is within the specification, but further system simulations are needed to verify this.
Irradiation campaigns of both implemented circuits on the RCU2 did reveal that neither of the solutions will behave well in radiation. The performance of the new solutions are worse than for the current RCU, indicating that these solutions cannot be used without structural hardware modifications. However, the radiation tolerance of the custom CDR solution would be sufficient in presence of an ideal input signal, which unfortunately is not the case.
After the irradiation tests, a batch of unused TTCrx chips could be retrieved. As the TTCrx is a field proven solution, the RCU2 was redesigned in order to implement these. In addition, test cards were made in order to verify the radiation tolerance.





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