DUNE ColdADC ASIC Preliminary Testing Results

Authors go here

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DUNE Electronics Consortium

Abstract

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Contents

1 Introduction [Grace/Lin]

Note to authors: executive summary of the testing plan and status. Include specs table.

The DUNE ColdADC is a digitizer ASIC intended for operation in the Deep Underground Neutrino Experiment (DUNE) Far Detectors. It will operated immersed in Liquid Argon (LAr) and will need to operate reliably, without any servicing or component replacement, for over 30 years at a temperature of approximately 88 K.

The ColdADC was implemented in 65 nm CMOS by a team comprised of engineers from Fermilab (FNAL), Brookhaven National Laboratory (BNL), and Lawrence Berkeley National Laboratory (LBNL). The prototype was submitted for fabrication in late 2018 and received in early 2019. Evaluation is ongoing.

The first prototype meets essential requirements (except suitability for long-term reliable operation at 88 K). The key performance specification, noise, is as expected. The prototype is currently being integrated into a new revision of the DUNE Far Detector Front-End Mother Board (FEMB). Preliminary results are good, and the DUNE Far Detector FEMB is displaying better noise performance than the SBND FEMB, which uses a Commercial Off-the-Shelf (COTS) ADC. This enables the use of a lower gain setting in LArASIC.

The key specifications of the ColdADC compared to the measured results are presented in Table 1.

Specification	Value	Result	Note
Operation Temperature	RT and 88 K	Success	
Sampling Rate	2 MHz	2 MHz	
Noise	200 μV-rms	202 μV-rms	At 88 K
Differential Nonlinearity (DNL)	0.5 LSB (at 12-bit level)	$0.18/-0.5$ LSB	At 2 MHz and 88 K, worst case across channels
Integral Nonlinearity (INL)	1 LSB (at 12-bit level)	$1.56/-1.8$ LSB	At 2 MHz and 88 K, worst case across channels
Effective-Number-of-Bits (ENOB)	11.0 bits		At 2 MHz and 88 K
No Missing Codes Across Dynamic Range	N/A	Success	
Crosstalk	No Specification	$< 1\%$	
Power Dissipation	No Specification	420 mW	290 K

Table 1: Summary of Results

2 Test Setup

2.1 Cryogenic Test System (CTS) [Lin]

2.2 BNL Test System [Gao]

Describe BNL test setup including the test boards.

2.3 Fermilab Cryo Cooler Test System [Christian]

Describe Fermilab test setup including the test boards.

2.4 LBNL Test Board [Lin]

3 Functional Testing [Christian]

Note to author: Discuss functional testing including reading/writing registers with I2C and UART, verifying the data I/O, including LVDS current control, and verifying clock generation.

4 Performance Results

Note to authors: discuss in this section the high level performance results. The main message here is to convey to the readers that the ASIC functions well overall. The details of the known issues will be discussed in the next section.

4.1 Noise

4.1.1 ColdADC Only

4.1.2 LArASIC + ColdADC [Gao]

4.2 Static Linearity (INL,DNL)

4.3 Dynamic Linearity (ENOB, SNDR)

4.4 Channel Crosstalk [Gao]

4.5 Power Consumption [Gao]

5 Issues Identified and Mitigations

Note to authors: describe studies that have been done to identify the issues and possible mitigations.

5.1 Auto Calibration [Grace]

5.2 Level Shifter [Grace]

5.3 ADC Core Linearity [Prakash]

5.4 SHA/MUX Linearity [Prakash]

5.5 SDC Linearity [Dabrowski]

5.6 IR Drop * [Christian/Miryala]

5.7 SHA/MUX Crosstalk [Grace/Prakash/Lin]

5.8 BGR Op-amp [Dabrowski]

5.9 Overflow Wraparound [Grace]

6 Production Testing [Furic/Gao]

6.1 Test Setup

6.2 Results

7 Summary

References

[1] "LBNF/DUNE Conceptual Design Report", https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/LBNF-DUNE%20CD-1-Refresh%20Directors%20Review/SitePages/Conceptual%20Design%20Report.aspx

[2] First scientific application of the membrane cryostat technology, D.Montanari et al, *AIP Proceedings 1573, 1664 (2014)* http://scitation.aip.org/content/aip/proceeding/aipcp/10.1063/1.4860907

[3] "The GENIE Neutrino Monte Carlo Generator", C. Andreopoulos, et al., Nucl. Instrum. Meth. A614, 87 (2010).

Appendix

Example for citing references. References [1–3] should be entered in bibliography.tex file under your section.

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Example for citing references. References~\cite{dunecdr,montanari_35ton,genie}.
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Here is an example of how to insert Fig. 1. Figures should be saved in ./figures directory.

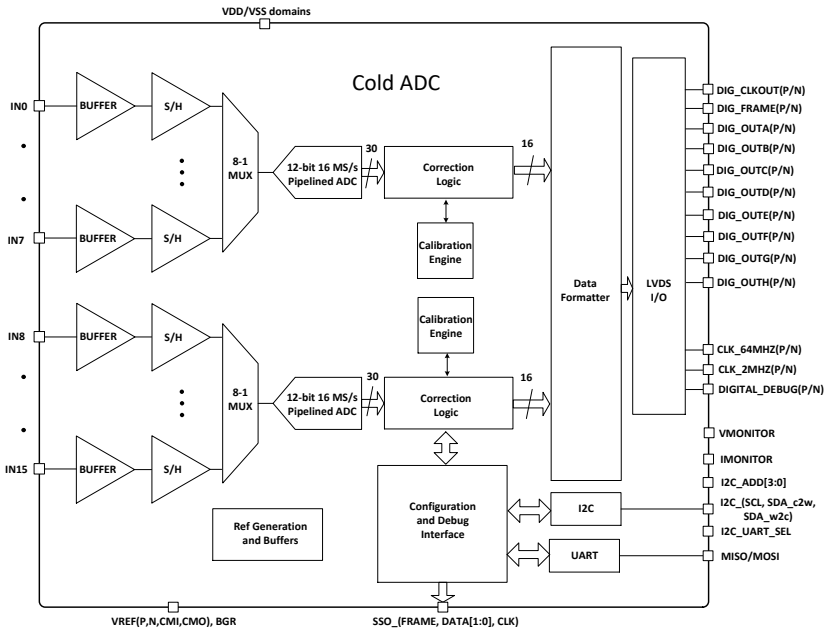

Figure 1: ColdADC Block Diagram.

```
\begin{figure}[htb]
\centering
\begin{center}
\includegraphics[width=0.7\textwidth]{figures/coldadc_blockdiagram.pdf}
\end{center}
\caption{ColdADC Block Diagram.}
\label{fig:adc_blockdiagram}
\end{figure}
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Here is an example of how to create Table 2.

Component	dimensions [m]
APA (active)	$2.29(wide) \times 5.9(high)$
APA (external)	$2.32(wide) \times 6.2(high)$
TPC (active)	$7.0(long) \times 7.2(wide) \times 5.9(high)$
TPC (external)	$7.3(long) \times 7.4(wide) \times 6.2(high)$
cryostat (internal)	$8.9(long) \times 7.8(wide) \times 8.1(high)$

Table 2: Dimensions of DUNE-PT.

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\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{ Component } & dimensions [m]  \\ \hline \hline
APA  (active) &  $2.29 (wide) \times 5.9 (high)$ \\ \hline
APA  (external) &  $2.32 (wide) \times 6.2 (high)$ \\ \hline
TPC (active)       & $7.0 (long) \times 7.2 (wide) \times 5.9 (high)$  \\ \hline
TPC (external)       & $7.3 (long) \times 7.4 (wide) \times 6.2 (high)$  \\ \hline
cryostat (internal) &  $8.9 (long) \times 7.8 (wide) \times 8.1 (high)$  \\ \hline
\end{tabular}
\caption{Dimensions of DUNE-PT.}
\label{tab:TPC-dim}
\end{table}
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