Certification of the amplifier-shaper-discriminator ASICs produced for the ATLAS MDT chambers at the HL-LHC

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***Abstract*—The front-end electronics of the ATLAS muon drift-tube chambers will be upgraded in the experiment's phase-II upgrade to comply with the new trigger and read-out scheme at the HL-LHC. A new amplifier shaper discriminator chip was developed in 130 nm Global Foundries technology for this upgrade. A preproduction of 7500 chips was launched in 2019 and tested in 2020. The presentation will summarize the functionality of the new ASD chip, the test set-up and testing procedure as well as the test results which show a production yield of 93%. Based on the successful test of the preproduction chip the series production of 80,000 chips was carried out in fall 2020. The tests of a sample of 1000 production chips show the same yield as the preproduction chips.**

ALL subdetectors of the ATLAS experiment will undergo a major upgrade for the operation at CERN's High-Luminosity LHC (HL-LHC). Part of the upgrade of the ATLAS muon spectrometer [1] is the replacement of the front-end electronics of the Muon Drift-Tube (MDT) chambers.

An MDT chamber is read out in groups of 24 tubes (3×8 or 4×6 depending on the number of tube layers per multilayer). Hedgehog cards with coupling capacitors are used to collect the signals from the 24 tubes and route them to the active part which consists of three octal Amplifier Shaper Discriminator (ASD) chips and a 24-channel Time-to-Digital Converter (TDC) chip mounted on a mezzanine card. The digitized signals from up to 18 mezzanine cards are collected by a multiplexer, the so-called "Chamber Service Module" (CSM) which sends the data via an optical fibre to the downstream read-out system.

The present TDCs are incompatible with the planned first-level trigger rate of the ATLAS experiment of 1 MHz at the HL-LHC and have to be replaced by new TDCs. As the TDCs are on common mezzanine cards with the ASD chips, also new ASD chips had to designed and produced for the upgrade ATLAS muon spectrometer.

The present ASD chip was designed in Agilent 500 nm technology which has become obsolete. For the upgrade of the ATLAS muon spectrometer a new ASD chip was designed in Global Foundries 130 nm CMOS technology [2]. The design of the new chip follows the design of the present chip, but incorporates a fix of a specific design error of the present chip in the output logic. A block diagram of the new ASD chip is presented in Figure 1. The chip has a differential charge sensitive preamplifier, bipolar shaping with ion tail cancellation and a Wilkinson ASD for time-walk corrections to the discriminated signals. Each channel is connected to a discriminator providing LVDS output signals. A discriminator threshold common to all the channels can be programmed and generated inside the chip.

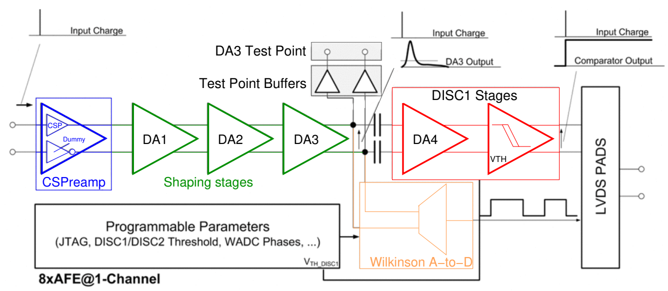

Fig. 1. Block diagram of the new ASD chip. [2]

A preproduction of 7500 chips was launched in 2019 and tested in 2020. The tests were carried out manually using a test board provide by the ATLAS muon group of the Ludwig-Maximilians University (LMU) of Munich. Figure 2 shows a photograph of the tester. The tester allows the test of one chip at a time. It contains charge injection circuits individual for each of the eight channels of the ASD chip and circuits for the analysis of the output signals. It uses a USB interface for the communication between a personal computer and the on-board microcontroller.

The chip tests proceed along the following steps:

- Reject chips which cannot be powered up or cannot be put into operation;
- Reject chips which draw abnormal currents;
- Reject chips with channels that have wrong output LVDS levels;
- Reject chips with dead channels;
- Reject chips with two large thresholds spreads;
- Reject chips with abnormal ADC counts for an input charge of -20 fC.

For the last three tests in the list above pulses with predefined charges are injected to the eight channels of the chip one after the other. Figure 3 illustrates how the threshold of a channel is determined. Pulses with -20 fC charge is injected into a channel and the efficiency to detect the injected signal is measured as a function of the value of the discriminator threshold. As a results one get a typical efficiency turn-on curve where the efficiency is 0 for large threshold values and

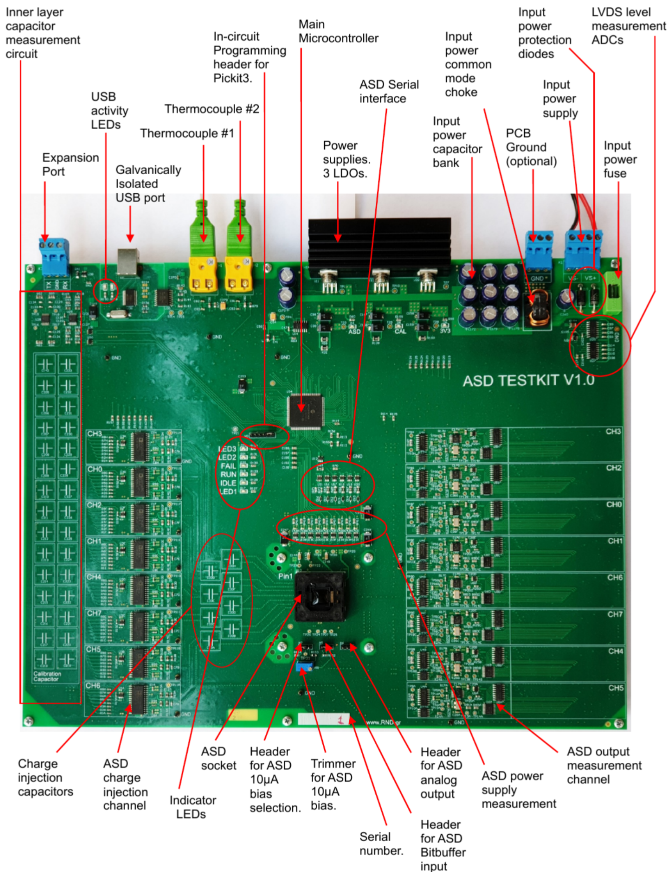

Fig. 2. Photograph of the test board designed by the LMU Munich for the tests of the ASD chips.

1 or low threshold values. The inflexion point of the curve is taken as the threshold value of the channel under investigation.

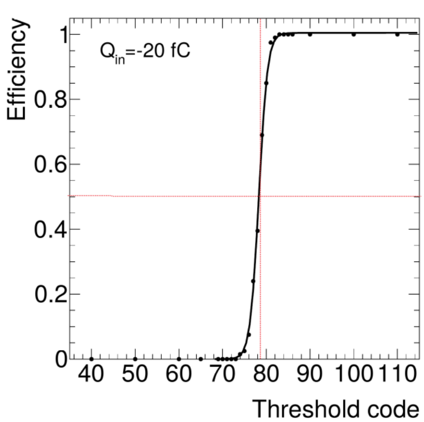

Fig. 3. Efficiency as a function of the discriminator threshold for a fixed input charge of -20 fC. The actual threshold decreases with increasing threshold code.

Figure 4 shows the distribution of the measured RMS spreads of the actual thresholds of the eight channels of an ADC chip. Almost all the chips have a very small threshold spread below 5 mV. Chips with threshold spread greater than 5 mV are rejected.

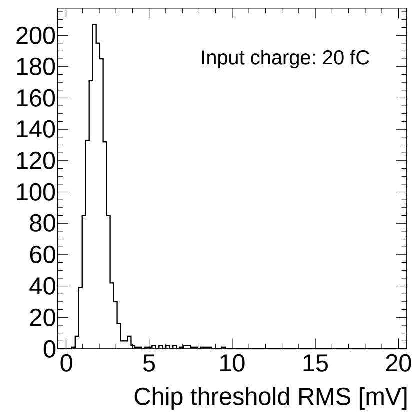

Fig. 4. Distribution of the RMS spreads of the thresholds of the eight channels of an ADC chip.

The distribution of the pulse heights measured by the Wilkinson ADCs of the chips is presented in Figure 5. The distribution is nearly perfectly Gaussian with very few outliers. Chips with ADC values outside the 3σ window around the Gaussian's mean value are rejected.

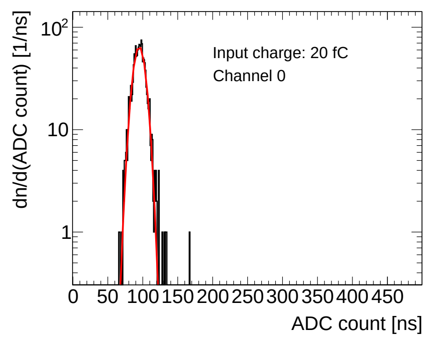

Fig. 5. Distribution of the pulse heights measured by the Wilkinson ADCs of the chips for -20 fC input charge. The measured ADC values are encoded in the width of the LVDS output signals.

More than 91% of the tested chips pass all criteria. 0.07% of the chips cannot be put into operation. 0.22% chips have bad LVDS output levels. 0.07% of the chips have too low total currents. 1.87% of the chips have dead channels. 1.87% show too large threshold spreads and 4.02% give bad ADC values.

The same very high yield as for the preproduction was found for a sample of 1000 production chips. The remaining 79,000 ASD chips will be tested by a company in a automated procedure.

References

[1] The ATLAS Collaboration, *Technical Design Report for the Phase-II Upgrade of the ATLAS Muon Spectrometer*, CERN-LHCC-2017-017, https://cds.cern.ch/record/2285580

[2] S. Abovyan et al., *The new octal amplifier-shaper-discriminator chip for the ATLAS MDT chambers at HL-LHC*, Proceedings to the 14th Pisa Meeting on Advanced Detectors, NIM-A 936.