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The back-end electronics card of the JUNO experiment

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On behalf of the JUNO collaboration

The Jiangmen Underground Neutrino Observatory (JUNO) is a next generation multi-purpose anti-neutrino detector currently under construction in Jiangmen, in China, with the main goal to determine the neutrino mass hierarchy, as well as several neutrino mass and mixing parameters with a precision at the sub-percent level. The reactor electron anti-neutrinos of two power plants at a baseline of 53 km will be detected in the central part of the detector, which consists of 20 k-tons of liquid scintillator contained in a 35 m diameter acrylic sphere. The central detector is instrumented by more than 18000 20-inch photo-multiplier tubes (PMTs), and about 25000 3-inch small PMTs. Two veto systems are added to reduce the backgrounds. Data taking is expected to start at the end of 2021. The JUNO electronics system is separated into mainly two parts: the front-end electronics system performing analog signal processing (the underwater electronics), and after 100 meters Ethernet cables,the back-end electronics system, sitting outside water, consisting of the Back-End Cards (BEC), the DAQ and the trigger. For the front-end electronics, global control units (GCU) digitize the incoming analog signals, then store the data in a large local memory waiting for trigger decision, and send out event data corresponding to a certain trigger acknowledgement as well as trigger requests to the outside-water system. The BECs are used as concentrators to collect and compensate the incoming trigger request signals. The FPGA mezzanine cards handle all trigger request signals, and send their sum to the trigger system over an optical fiber. In order to test all the communication channels of the BECs in an efficient and fast way, a common baseboard with interfaces to different mezzanine boards is designed. The poster presents the JUNO electronics system, with an emphasis of the back-end electronics system and on the BECs : their design and the tests already performed.

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1. Introduction

The Jiangmen Underground Neutrino Observatory (JUNO)[1] is a neutrino medium baseline experiment in construction in China, with the goal to determine the neutrino mass hierarchy and perform precise measurements of several neutrino mass and mixing parameters . The experiment uses a large liquid scintillator detector [2] aiming at measuring anti-neutrinos issued from nuclear reactors at a distance of 53 km. The JUNO site is shown in Figure 1.

Figure 1: JUNO site.

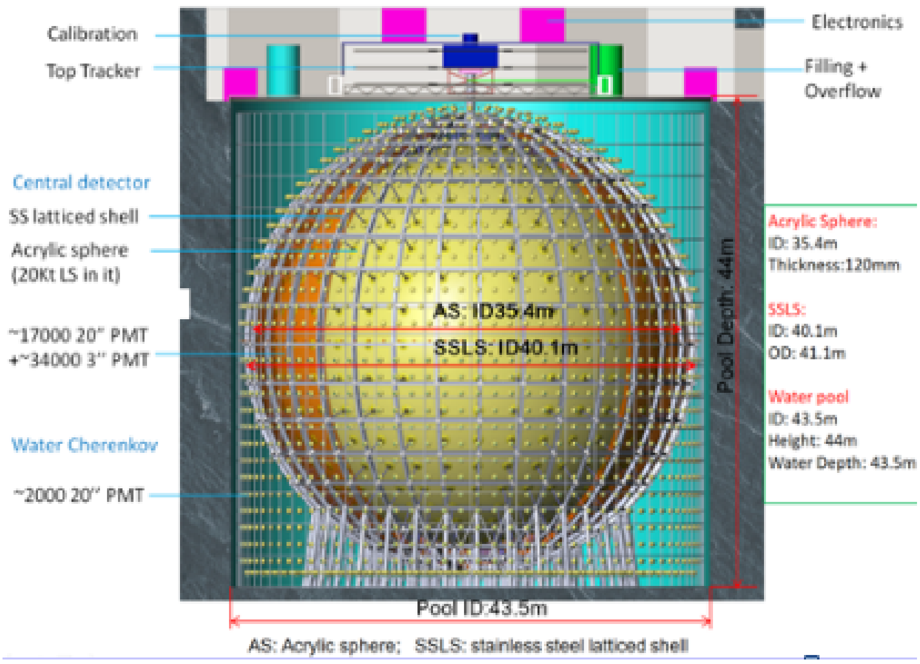

Figure 2: Schematic view of the detector.

The neutrino detector consists of a large volume of liquid scintillator with a 20 k-ton fiducial mass, deployed in a laboratory 700 meters underground. The JUNO readout electronics system will have to cope with signals of 18000 photo-multiplier tubes (PMTs) of the central detector, as well as 2000 PMTs installed in the surrounding water pool to detect the Cherenkov light from muons. To avoid signal loss due to long distance transmission, most parts of the electronics system will be located in the water, close to the detector body. A schematic view of the JUNO detector is presented in Figure 2.

2. JUNO electronics system

The JUNO electronics system can be separated into mainly two parts:

1. the front-end electronics system performing analog signal processing (the underwater electronics), and after about 100 m cables,

2. the back-end electronics system, sitting outside water, consisting of the DAQ and the trigger.

Besides, power supply needs also to be delivered to underwater electronics from outside water. Figure 3 shows the scheme used for the JUNO electronics. Three PMTs are connected to a Global Control Unit (GCU) through coaxial cable. We protect the coaxial cable from water using a metallic bellow surrounding the coaxial cable. The GCU power supply is represented by black cable. The links for the data exchange between underwater electronics and back-end electronics are performed through Ethernet cables (blue lines in Figure 3). The Ethernet cable was the chosen solution due to its reliability, its low price and high robustness. For the connection between the GCU and the back-end card (BEC) all the pairs of the cable are used. Table 1 shows the BEC-GCU link. The 2 pairs out of 4 inside the Ethernet cable are used to transfer data from BEC to GCU (trigger and clock running at 125 Mbps and 62.5 MHz). The other 2 pairs are used to send data from the GCU to the BEC.
The second Ethernet cable is linking the GCU and the data acquisition system (1 Gbps Ethernet packet with event data and slow control command).

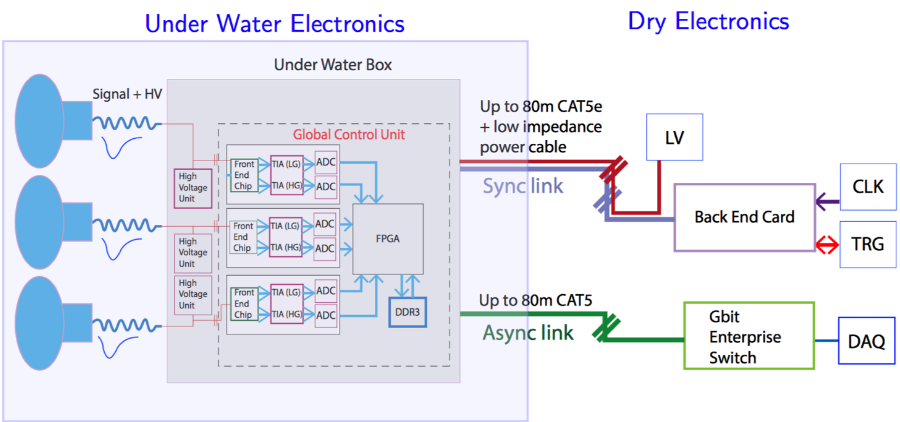

Figure 3: Scheme of the electronic read-out of JUNO.

Name	Signal frequency	origin	to	destination
Pair 1-2:	62.5 MHz clock	BEC	$\rightarrow$	GCU
Pair 4-5:	125 Mbps data	BEC	$\rightarrow$	GCU
Pair 3-6:	125 Mbps data	GCU	$\rightarrow$	BEC
Pair 7-8:	62.5 Mbps data	GCU	$\rightarrow$	BEC

Table 1: Table of the pair assignation in the Ethernet cable connecting the GCU and the BEC.

The main challenge of the whole electronics system is the very strict criteria on reliability: a target of maximum of 1% failure over 6 years for the PMTs full readout chain, as well as the large data transfer of 125 Mbps that needs to be delivered over 100m Ethernet cables.

3. Back-end electronics

Figure 4 shows the FPGA mezzanine card called Trigger/Timing interface mezzanine (TTIM) (blue box) and the BEC. The TTIM is an FMC mezzanine card. It connects the BEC to the trigger system. The BEC is composed of 6 equalizer cards (green box) and one baseboard (red box). The baseboard makes the link bewteen the TTIM and the equalizer cards. The baseboard provides also the power supply to the TTIM and the equalizer cards [3]. We have chosen this design for different reasons:

- We chose small PCB card to have more mechanical robustness and a more even power supply.
- The equalizer cards are plugged to the baseboard. So we have more flexibility to replace a defect one without changing all the BEC.
  Each equalizer card receives 8 Ethernet cables trough RJ45 connectors. The channel coming from the GCU go trough equalizer to compensate the signal alteration due to the long cable. One BEC receives 48 Ethernet cables from 48 underwater boxes, corresponding to the signals of 144 PMTs. We use in total about 140 BEC for the large PMTs system.

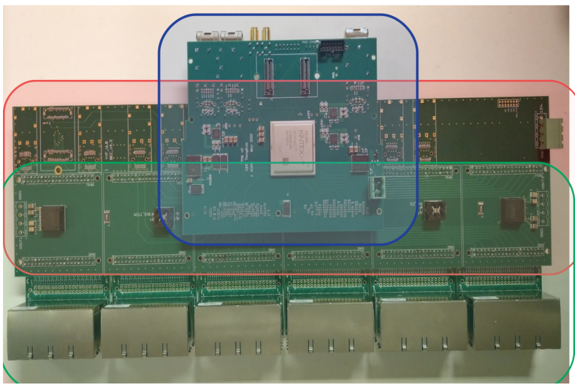

Figure 4: Picture of the BEC version 4. The TTIM is in blue, the base board in red and the 6 equalizer cards are in green.

4. Test of the BEC

The current test for the BEC is a self test. We connnects two Ethernet connectors of the BEC trough a 100 m Ethernet cable. We use the TTIM FPGA as PRBS generator and send the signal trough the cable. We then use the PRBS checker inside implemented inside the same FPGA to check the recevied data.
We also use eye diagram to see the quality of the transmission line. Figure 5 shows the eye diagrams for a signal with a transmitting rate of 250 Mbps. The higher transmitting rate ensure a big margin on the reliability for the real application. We make the eye diagrams and the bathtub curves for the two receiving ports of each RJ45 connector. The Figure 5 shows two open eyes and the a large bathtub. From this we can conclude that the transmission is very clean. We have tested each cable at each position on the back end card.

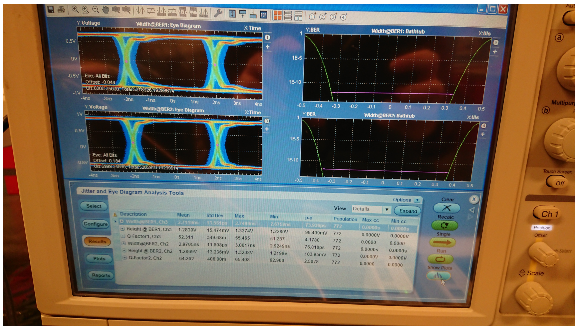

Figure 5: Eye diagrams and bathtub curves for the two receiving channels of one RJ45 connector.

5. Conclusion/ Future plan

The stand alone tests (BEC and TTIM) show that the system works properly. It remains to do long term tests and combine tests with the GCU and the full electronics chain.

References

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