Overview and design status of the Fast Beam Interlock System at ESS

EUROPEAN SPALLATION SOURCE

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Abstract

The ESS, consisting of a pulsed proton linear accelerator, a rotating spallation target designed for an average beam power of up to 5 MW, and a suite of neutron instruments, requires a large variety of instrumentation, both for controlling as well as protecting the different hardware systems and the beam. The ESS beam power is unprecedented and an uncontrolled release could lead to serious damage of equipment installed along the tunnel and target station within only a few microseconds. Major failures of certain equipment will result in long repair times, because it is delicate and difficult to access and sometimes located in high radiation areas. To optimize the operational efficiency of the facility, accidents should be avoided and interruptions should be rare and limited to a short time. Hence, a sophisticated machine protection system is required. In order to stop efficiently the proton beam production in case of failures, a Fast Beam Interlock (FBI) system with a targeted reaction time of less than 5 microseconds and very high dependability is being designed. The design approach for this FPGA-based interlock system will be presented as well as the status on prototyping.

FBI System Based on Copper Links

Based on the CERN Beam Interlock system concept but adapted to ESS requirements (fastest reaction time and smaller footprint):

- DC Signal over RS485 + diagnostic over data channel
- Star + Tree architecture
- High density Interface modules (up to 8 FBI_DIF per 1U box)
- < 2 us Reaction time (from Input device to actuator)
- MIL DTL Micro D connectors (small, reliable, high bandwidth)
- Used in Redundant configuration
- < 1 dangerous failure in 1000 years
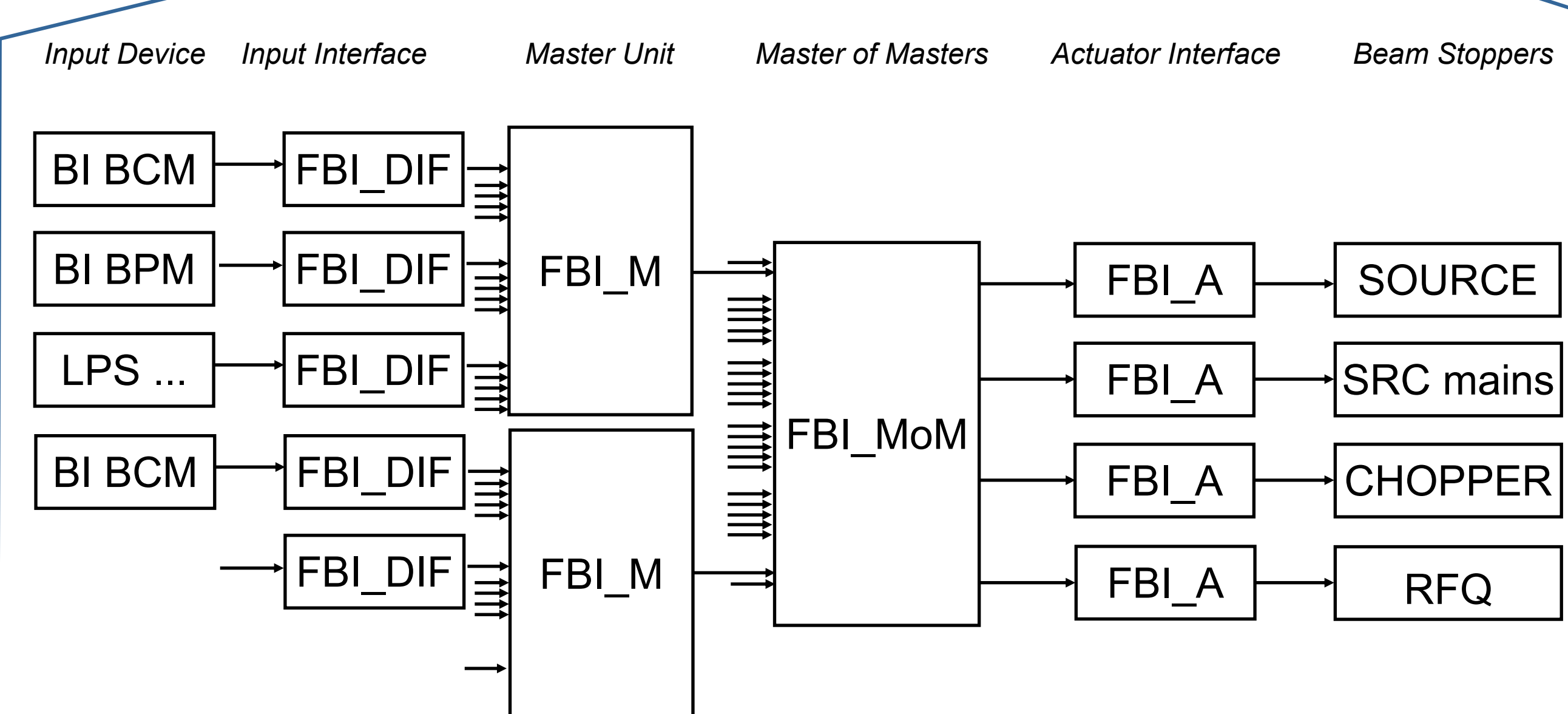- Tailor made for the ESS klystron gallery

Fig. 1: Fast Beam Interlock copper link architecture: 1 device input → I FBI_DIF

Fig 2: FBI System based in RJ45: FBI_DIF (top left), FBI_A (top right), FBI_M (bottom)

IMPROVING THE PROTECTION INTEGRITY LEVEL

In order to fulfill the reaction time it is not possible to use heartbeats on the beam permit lines. However using DC signals for transmitting this critical information may hide dangerous system failures. In order to discover such failures three testing sequences will be used:

Fast Test: The system will include a self testing feature that will turn the permit off **on demand**. This test will show the status of all the links and it will allow to detect hidden failures on the FBI system and scheduling future maintenance. The test will be started by the FBI MoM and will propagate towards the input devices for them to remove permit.

Slow Test: This test will be initiated by the timing system and will be propagated to all the devices connected to timing system and Beam Interlock System. This machine cycle should be used by all Inputs of the Fast Beam Interlock to **virtually generate a negative condition** (Open switches, detection of lost beam, differential BCM comparison) and trip the beam interlock system. The schedule of this test is not yet defined, however it should be executed at least once after each technical stop to ensure that the machine settings and electronics are ready for beam.

Actuator Test: This maybe the most critical test of all. This test will be executed together with the Slow Test (before or after), ensuring that each mechanisms being used to protect the machine works properly.

FBI System Based on Optical Fibre Links

New Functional Idea

- Architecture is based on ESS gallery layout (24 enclosures/36 racks per enclosure)
- Based on FPGA with integrated serializer + SFP GBit modules for 10 km range + single mode duplex fiber (bidirectional channels between elements)
- FBI_DIF is NOT a modular design. One DIF has 8 MicroD inputs + 1 optical output. (serializing data, saving cables and connections)
- 4 FBI_DIF and 1 master per enclosure
- 1 Master of Masters receiving the 24 connections.
- Optical link detection within SFP (cable and connector problem detection)
- Beam Permit transmitted in data packets with heartbeat and timing information.
- Protection Integrity Level (PIL) or equivalent: To be calculated.
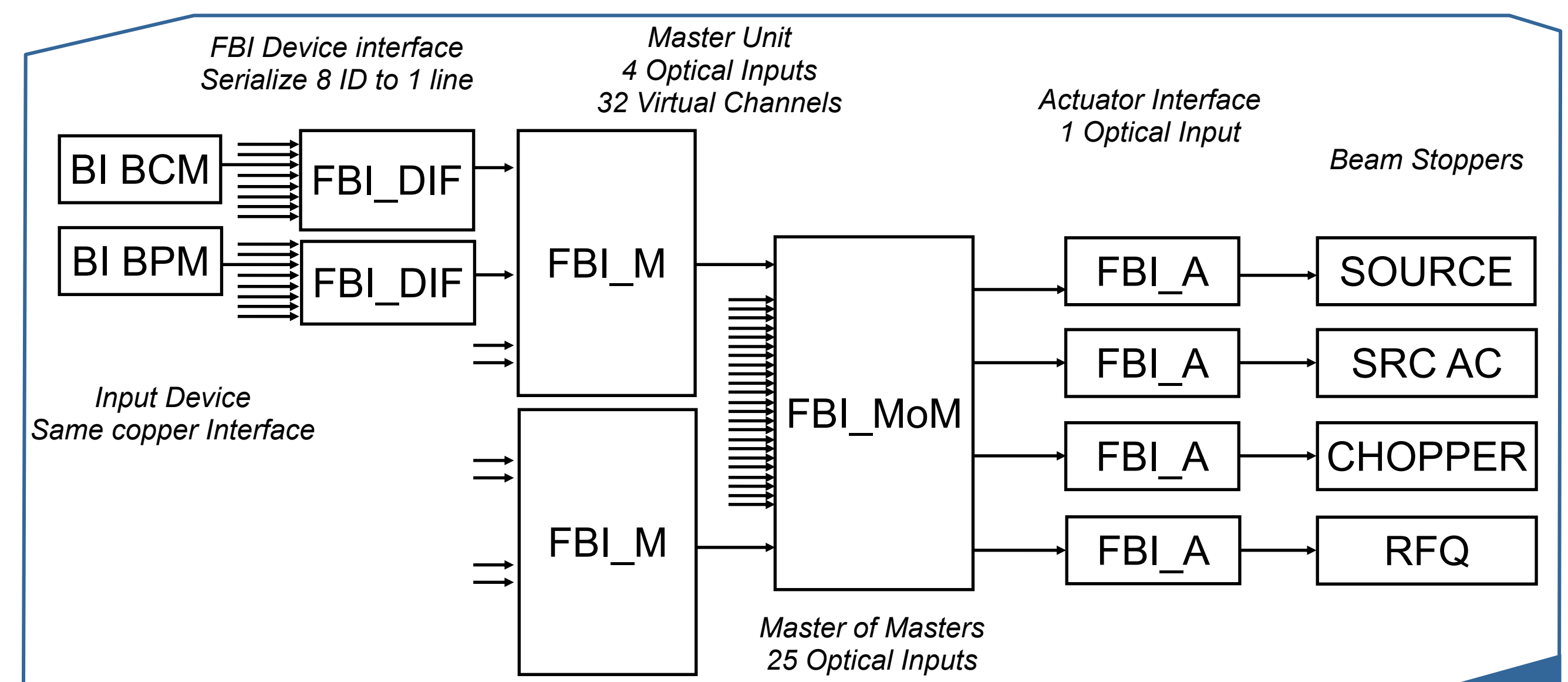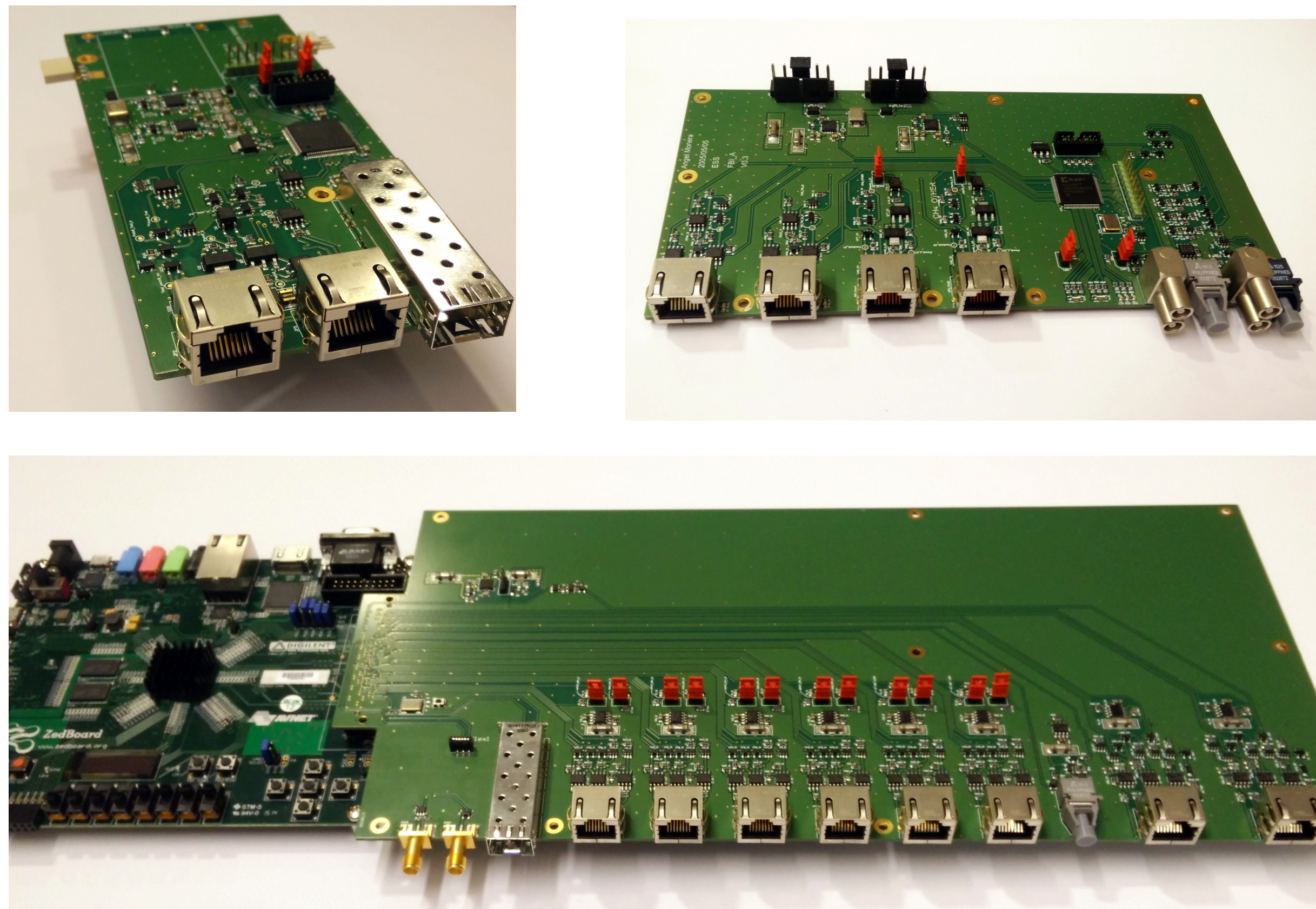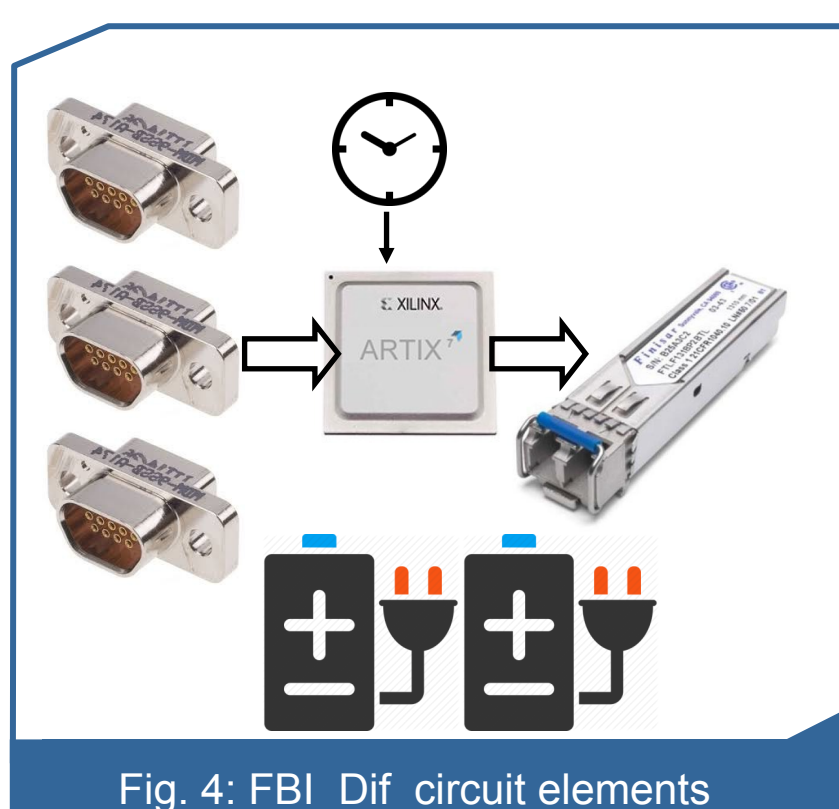- **Propagation time from input device to actuator <1us**

Fig 3: Fast Beam Interlock optical architecture with signal concentration in FBI_DIF (8 to 1)
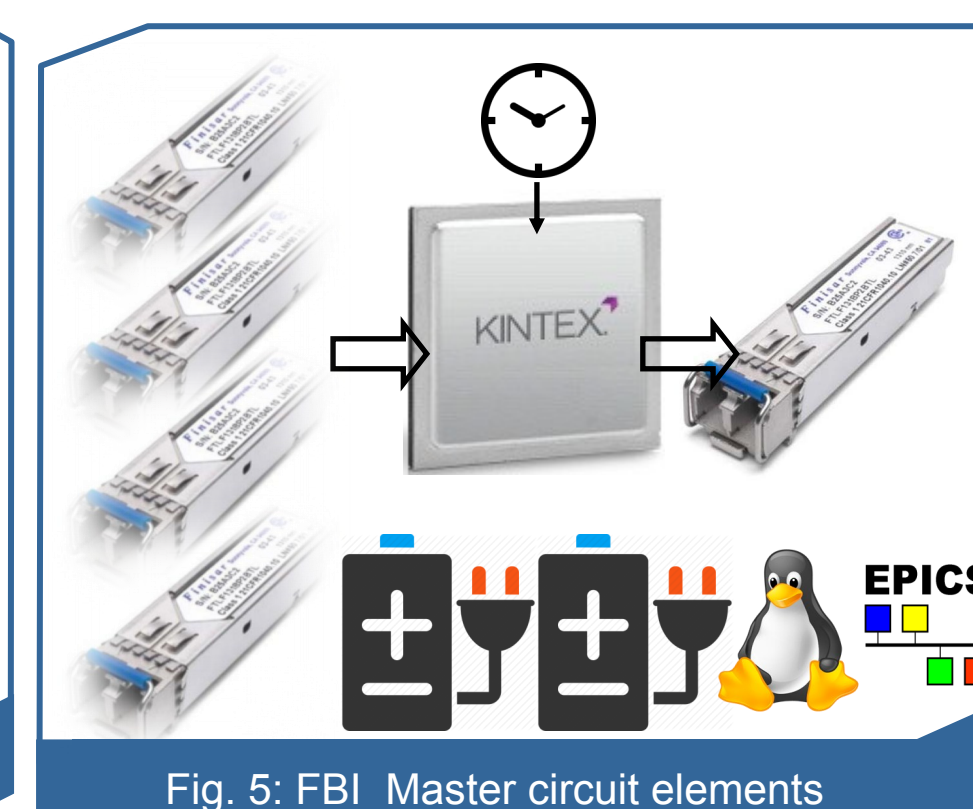

Fig. 4: FBI_Dif circuit elements
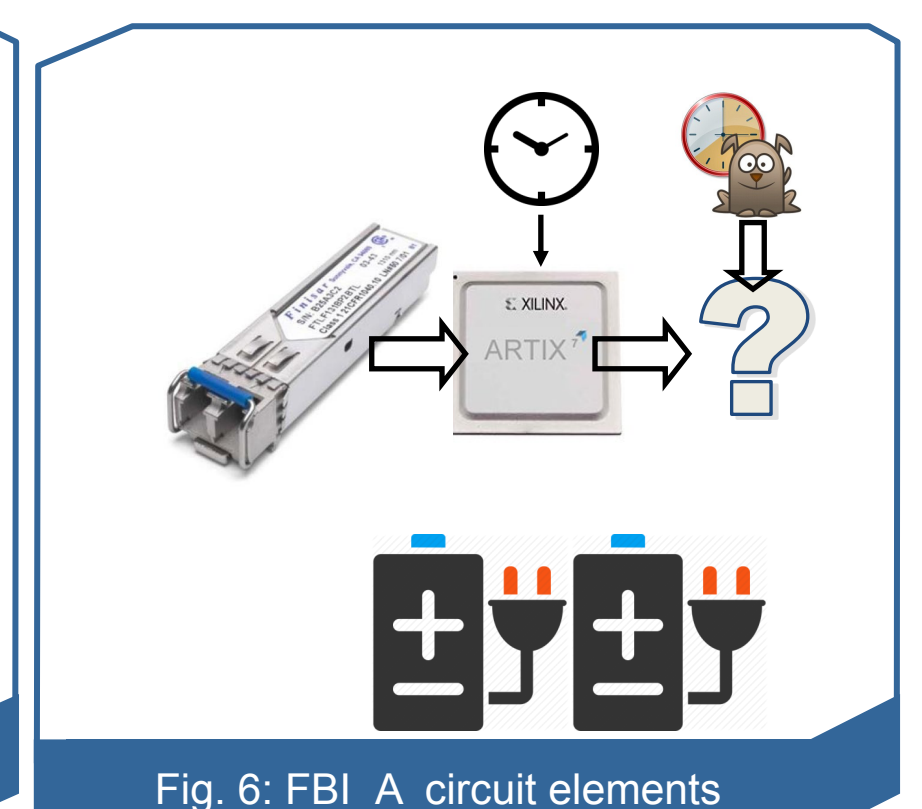
Fig. 5: FBI_Master circuit elements

Fig. 6: FBI_A circuit elements

SYSTEM FEATURES

- Very "simple" hardware with a small number of components.
- Thanks to the high speed data transmission and the data with integrated heartbeat, the system connections are tested all the time having an online real-time diagnostics of the most critical path of the system.
- Timing information and packets numbering would be sent together with permit allowing detection of packet losses or corrupted links.
- Slow Test and Actuator test will be executed keeping an overall high protection integrity level and avoiding blind failures on the input systems.

Conclusions

A first prototype based on the copper connections has been developed already but other design concepts are under investigation. Future iterations will take the ESS architecture more into account, trying to minimize the total installation cost.

An FMEDA analysis can improve the design significantly, such that weak points in the design can be easily detected and corrected in time. Further improvements will be done for the copper based FBI System, reducing the dangerous failure rate and improving the systems reliability.

Outlook

- Second Iteration of FBI System based on copper links with improved dangerous failure rate and reliability (thanks to the FMDA analysis realized over the first prototype).
- First Iteration of the FBI System based on optical fibre and its corresponding FMDA analysis.
- First real test of the FBI system in Catania (Italy) during summer 2016 where a prototype will be installed to protect the LEBT.
- Choosing Copper of Optical based in PIL performance and system reliability.