

# Fast Beam Interlock System

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# Acronyms



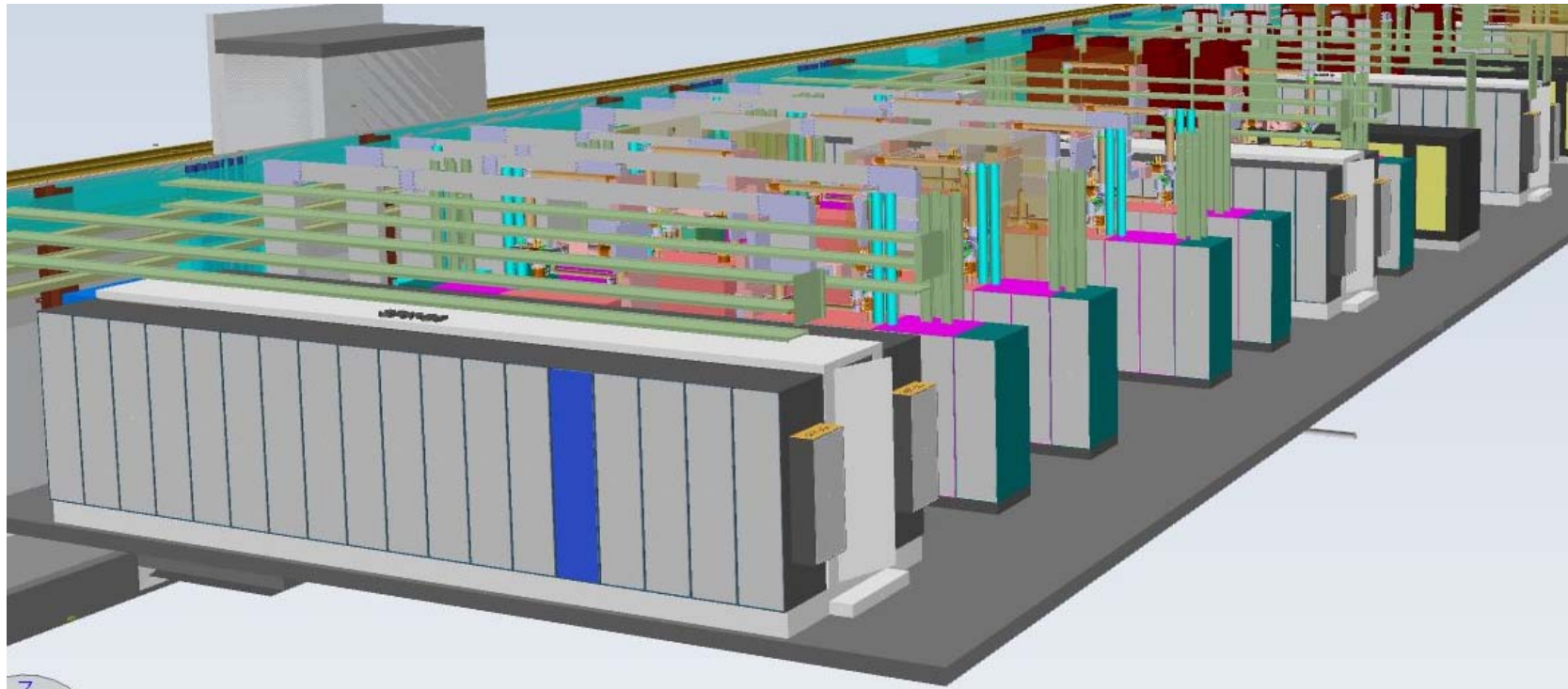
- FBI : Fast Beam Interlock
- FBI\_D : FBI Driver
- FBI\_DIF : FBI Device Interface
- FBI\_M : FBI Master
- FBI\_MoM : FBI Master of Masters
  
- IDev: Input Devices: Devices connected to the FBI as permit sources
  - LPS: Local Protection Systems
  - BI: Beam Instrumentation
  
- PSU: Power Supply Unit
- S/N: Serial Number

- ENVIRONMENT
- FBIS MAIN REQUIREMENTS
- FBIS COPPER LINKS
  - FBIS ARCHITECTURE
  - FBIS DRIVER
  - FBIS DEVICE INTERFACE
  - FBIS MASTER AND MASTER OF MASTERS
  - FBI ACTUATOR
- IMPROVING THE COPPER SYSTEM
- FBIS OPTICAL LINKS
  - FBI ARCHITECTURE
  - FBI DIF
  - FBI M
  - FBI MoM
  - FBI ACTUATOR
- IMPROVING OPTICAL LINK
- CONCLUSIONS
  
- ANNEX1: INITIAL RESULTS OF THE FIRST ENGINEERING MODEL OF THE FBIS COPPER

- Located in the Klystron Gallery (Radiation Free)
- Klystron Gallery is organized by alternating **Rack Enclosures** and rows of **klystrons amplifiers**.
- Each **Enclosure** is composed by two 2 rows of racks
- Each row contains 18 racks
  
- There are 24 racks enclosures spread around the 500m long gallery.
- **The rack blocks are dust proof and waterproof**

- Outside the racks blocks:
  - Klystron power: > 40KW
  - Illumination
  - Wireless communications
- Inside the Rack Blocks:
  - Other RF Systems
  - Pulsed power supplies with high voltage and high current
  - etc

# ENVIRONMENT – KLYSTRON GALLERY



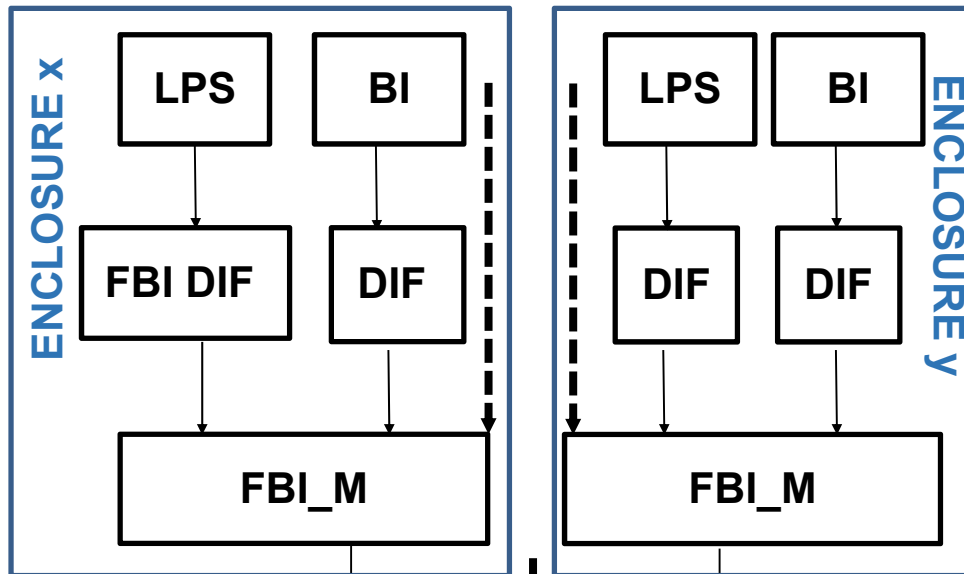
- COLLECT SYSTEM READINESS SIGNALS OR “BEAM\_PERMIT” FROM DIFFERENT MACHINE PROTECTION RELEVANT DEVICES.
- DECIDE DEPENDING ON THE MACHINE STATE
- STOP THE PROTON BEAM IF NEEDED.

- High compatibility with all input devices (PLC and FPGA systems)
- Fast reaction time (<3 $\mu$ s for the first 30m)
- Fast reaction time (<9 $\mu$ s for the following 570m)
- Flexible
- Safe (1.5E-7/h dangerous failure rate per hour)
  - Equivalent to PIL3
- Highly available
- Ready for installation end of 2017



- Based on CERN Beam Interlock for LHC and Linac4
  - Definition of one common Interface to standardize the connection with the BIS.
  - Use multiple masters (Concentrate and decide)
  - Actuator interface to adapt the signal from the Interlock to the desired actuator.
  - BEAM PERMIT is a DC Signal (Linac4)
- Optimized for ESS Needs
  - Tree / Star architecture to fit klystron gallery.
  - Smaller Footprint, thinner cables smaller connectors (MicroD).
  - Different standard (uTCA or Pizza Box)
  - Updated Bill Of Materials
  - Faster response time.
  - Replaced BEAM\_PRESENCE signal by PERMIT\_TEST

# FBI COPPER SYSTEM ARCHITECTURE



Device Inputs ~300

5 to 20 FBI\_DIF per enclosure  
1 inputs to 1 output

1 per enclosure  
15 inputs, 1 output

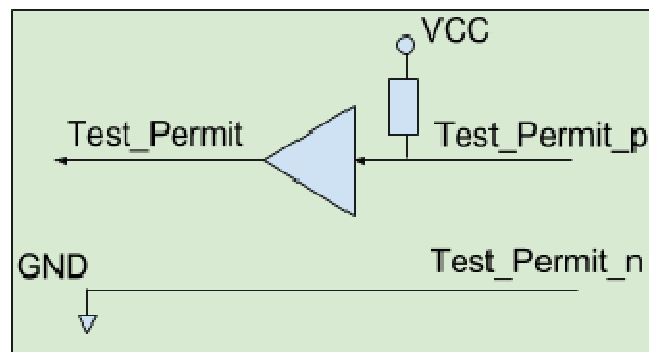
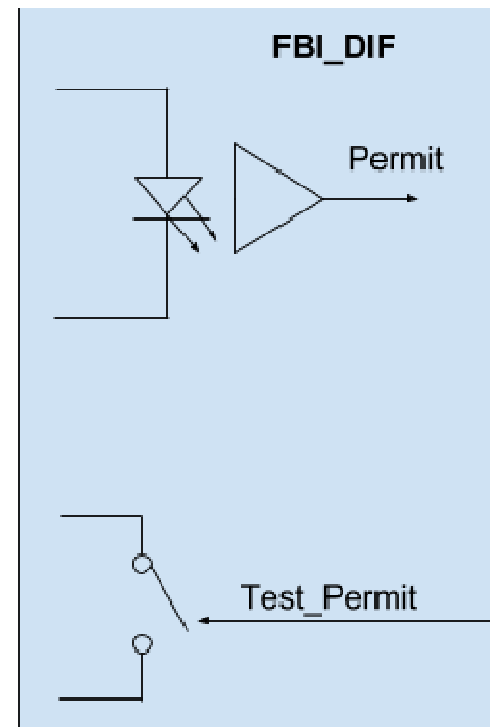
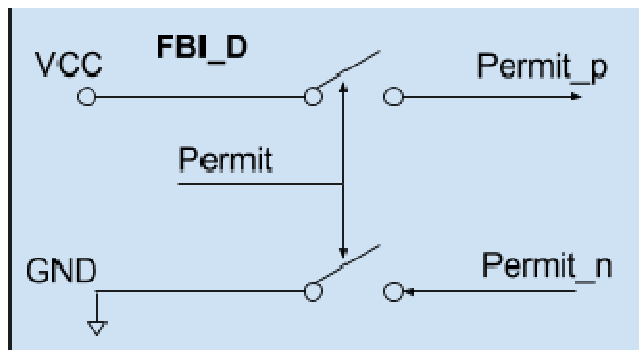
1 Master of Masters  
24 Inputs 8 Outputs

8 Actuator Interfaces  
1 Input + 1 Redundant, 1 output

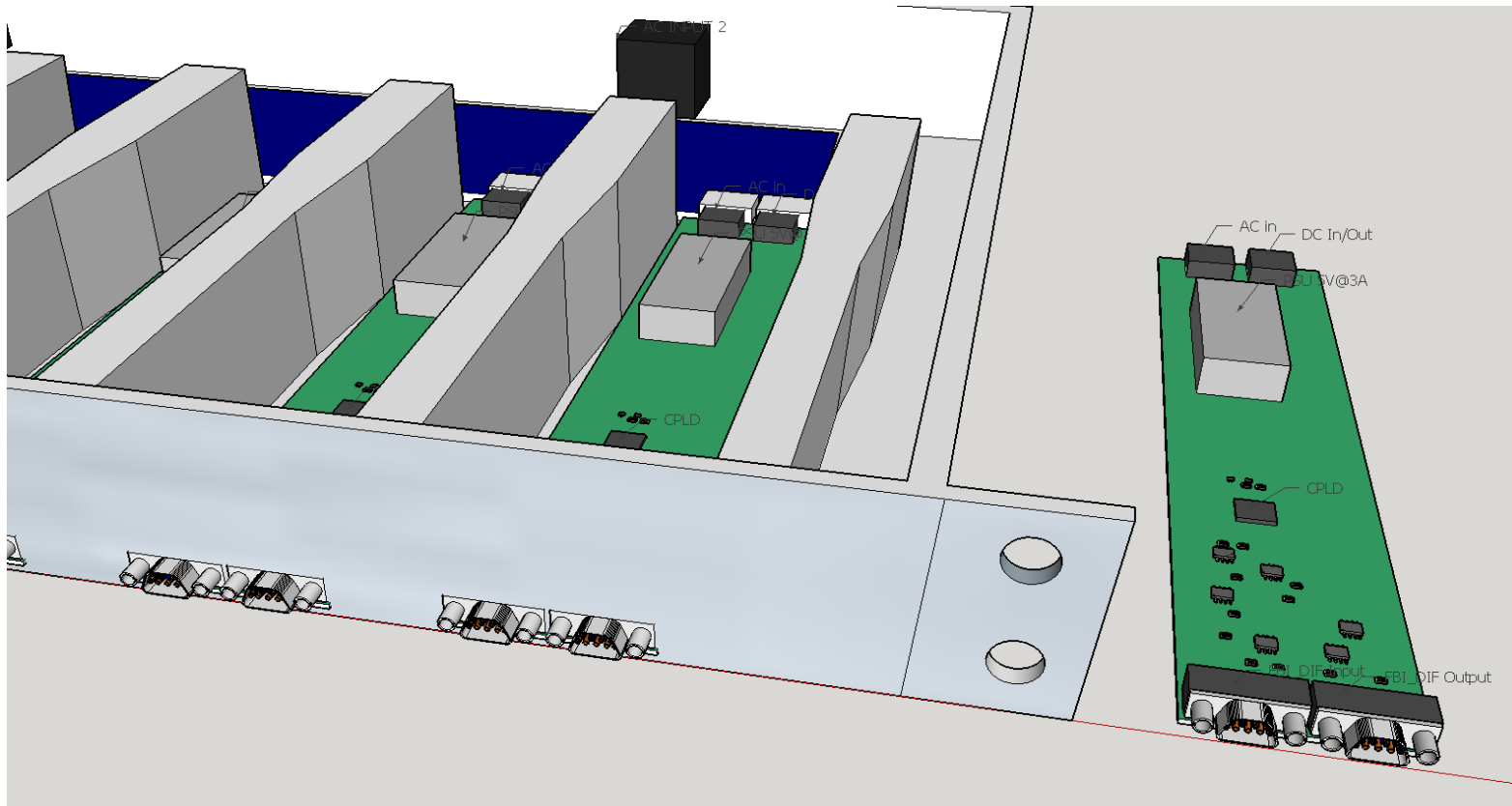
4 Actuators: Source, LEBT Chopper, MEBT Chopper and Timing

- Made to drive the FBI\_DIF
- Implemented within the fast electronics or
  - Developed like a module that can be plug in to the “of the shelf” boards
- Small footprint
- High Sensibility: 1.7V Min to give permit for modern FPGA

# FBI DRIVER



- Translate Beam Permit to a RS485 to have higher immunity and reach.
- Input compatible with PCL and FPGAs
  - Wide Input Voltage range (From 1.8V to 36V)
  - Low current (< 15mA)
- RS485 at the output
- Electrically Isolated from the IDev
- Permit only passes through logic
- Modern components
- Higher Integration
- Self Testing onboard.

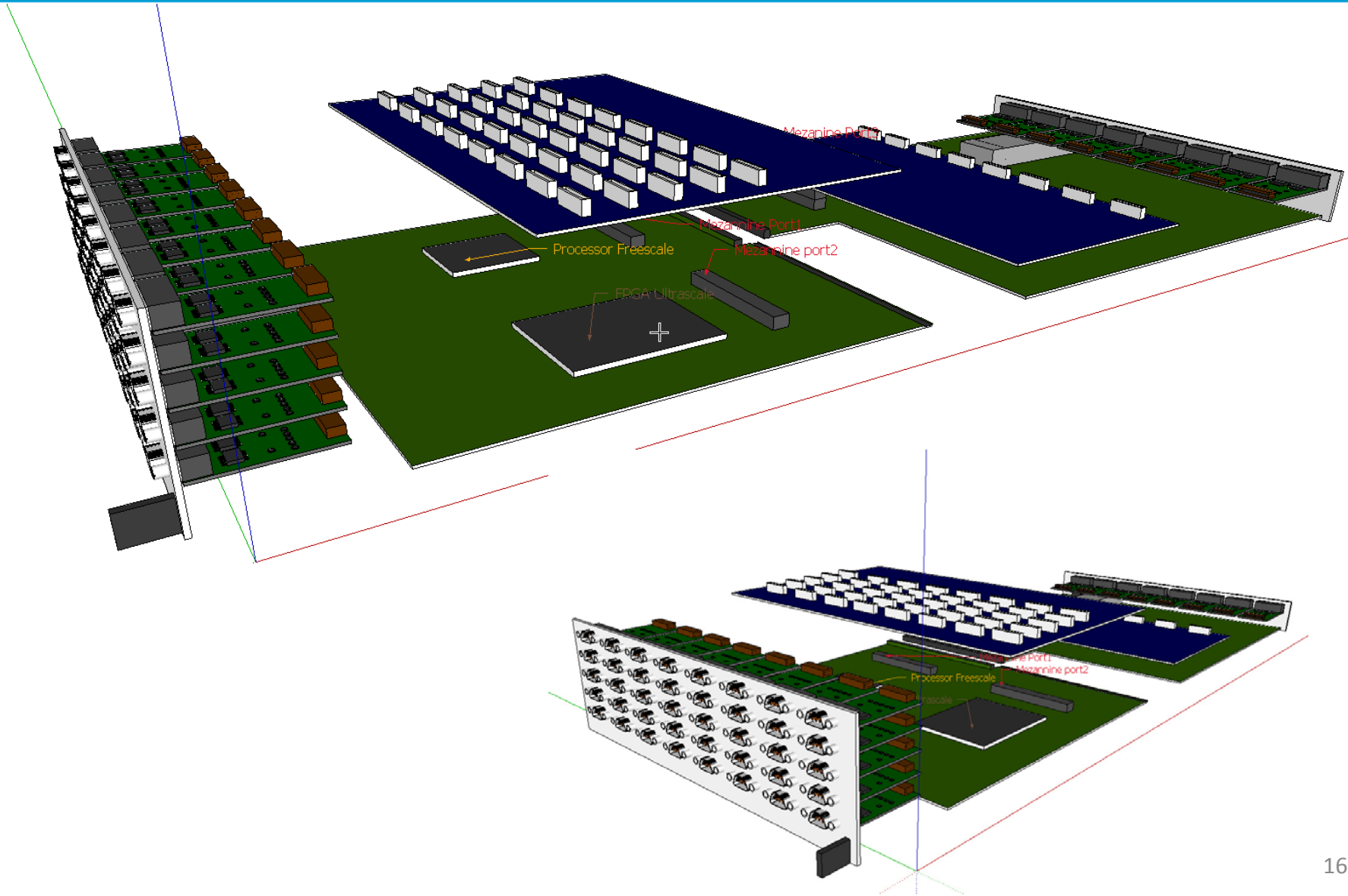


# FBI Master and Mastor of Master



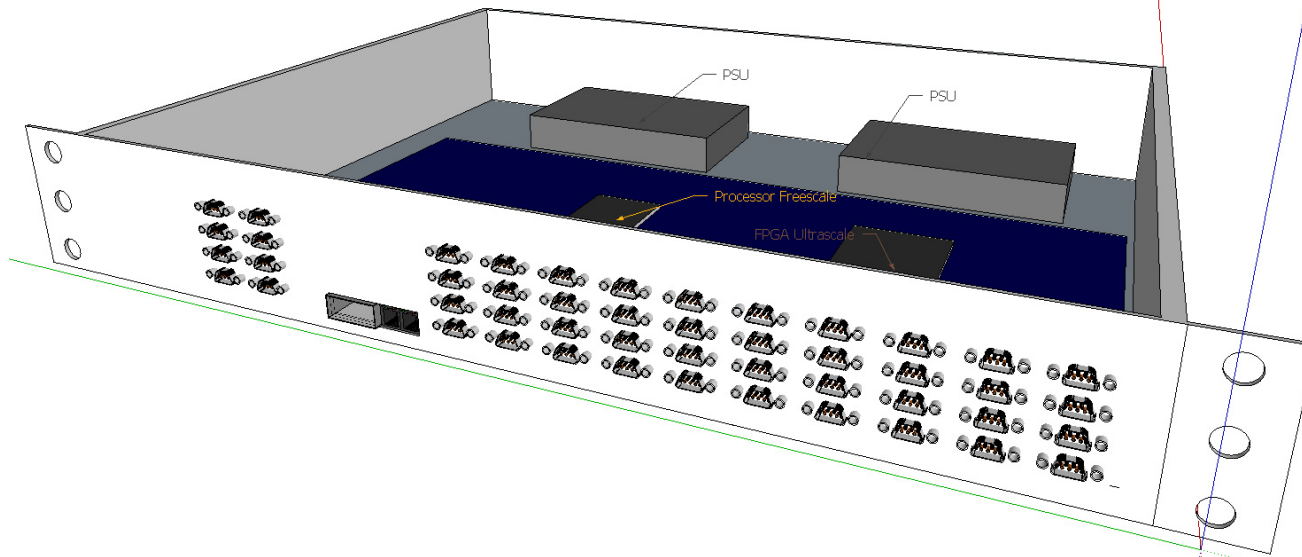
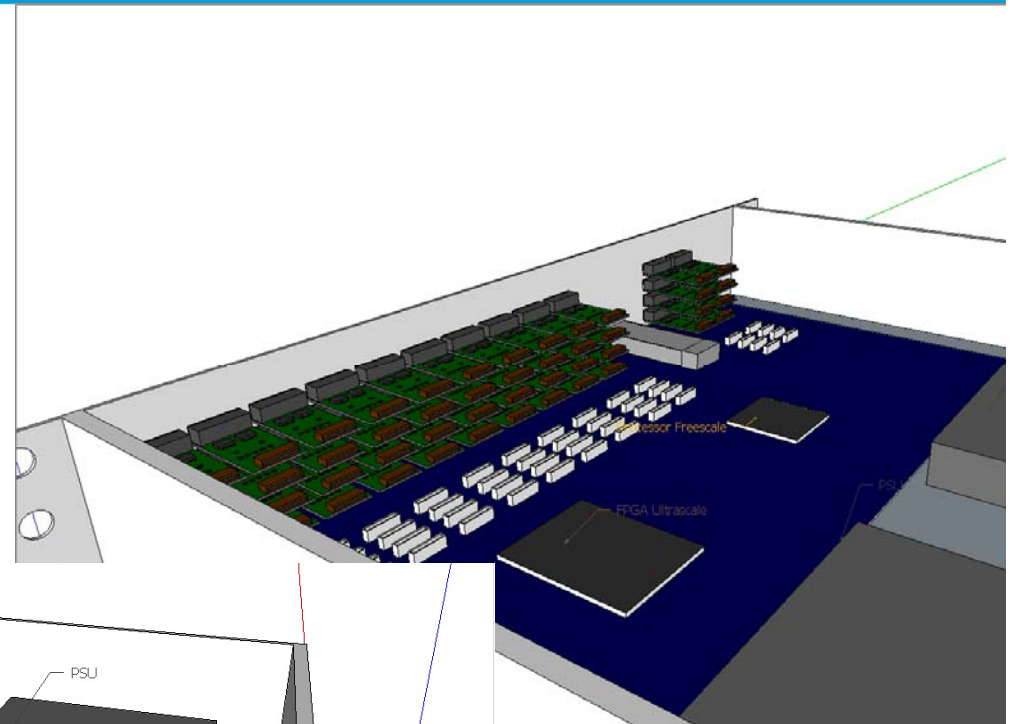
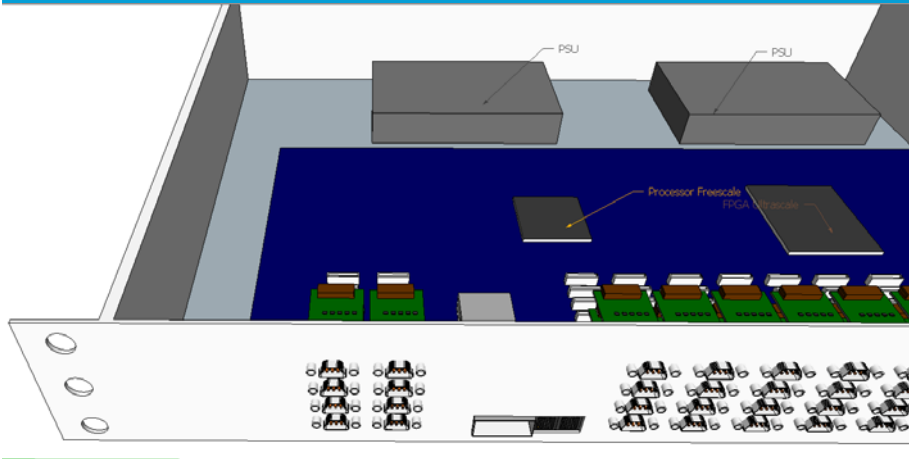
- Based on uTCA or Pizza box
- Permit pass through an FPGA
- Operative system within each box
- Fail safe
- Fast response
- Programmable digital filter @ inputs

# FBI\_MASTER in uTCA



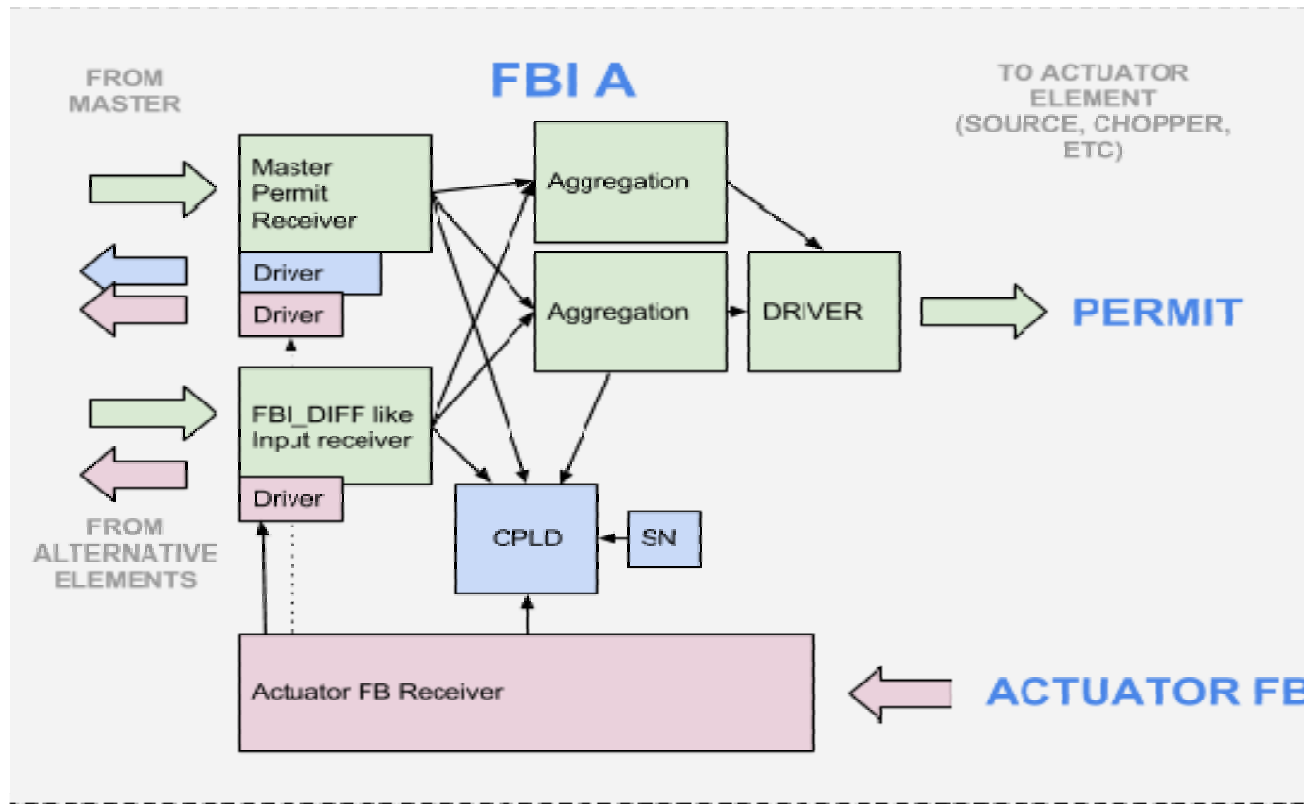


# FBI MASTER Pizza box



- Tailor made for Each Actuator
- Ensures redundant control even if there is one input
- Allows many devices to control the actuator
- Failsafe
- No blind failures
- Permit only passes through logic
- CPLD monitors the permit and Inform the master
- Redundant Power Supply.
- 19 inch pizza box format

# FBI ACTUATOR



- THE GOOD
  - Small footprint
  - Simple electronics
  - Cheap circuits
  - Very reliable connectors
- THE UGLY
  - Connectors are hard to install “on the field”
- THE BAD
  - Expensive connectors
  - Found weak points in the connection between the IDev and FBI\_DIF

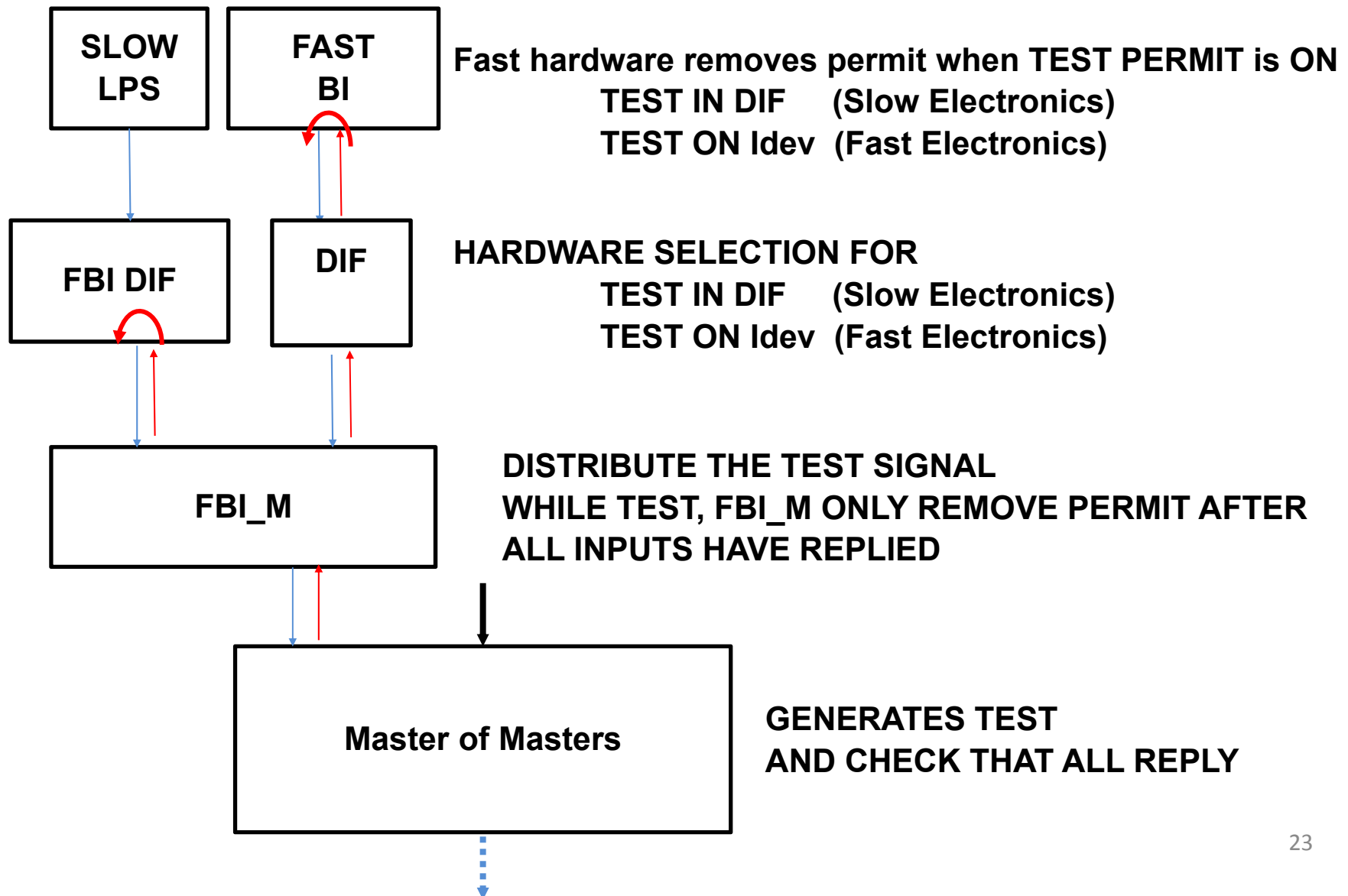
# IMPROVING THE COPPER SYSTEM



- Redundancy maybe added in case of needed additional level or protection to reach the desired protection level.
- Self testing sequence built into and outside the FBIs to remove the Blind failures and increase the protection level of the system.
  - FAST TEST
    - REALIZED BETWEEN PULSES
  - SLOW TEST
    - REALIZED AFTER TECHNICAL STOPS
  - ACTUATOR TEST
    - REALIZED AFTER SLOW TEST

- Realized between pulses
- Check the integrity of the connections from IDev to MoM
- Generated by the FBI\_MoM
- Requires ~20us to execute
- Propagated through FBI\_M to FBI\_DIF
  - Answered by FBI\_DIF if SLOW connected at the input
  - Propagated to the Input Device if FPGA
- While **Permit\_Test** is on, Input device should remove the **Beam\_Permit** signal

# FAST TEST



- Executed after Technical stop
- Check the integrity of the whole system, not only the links and the FBIs but also the Protection functions described by Machine Protection
- Realized with no beam
- Generated by Timing System
- ALL input devices should simulate a trigger in their protection functions and remove the beam\_permit

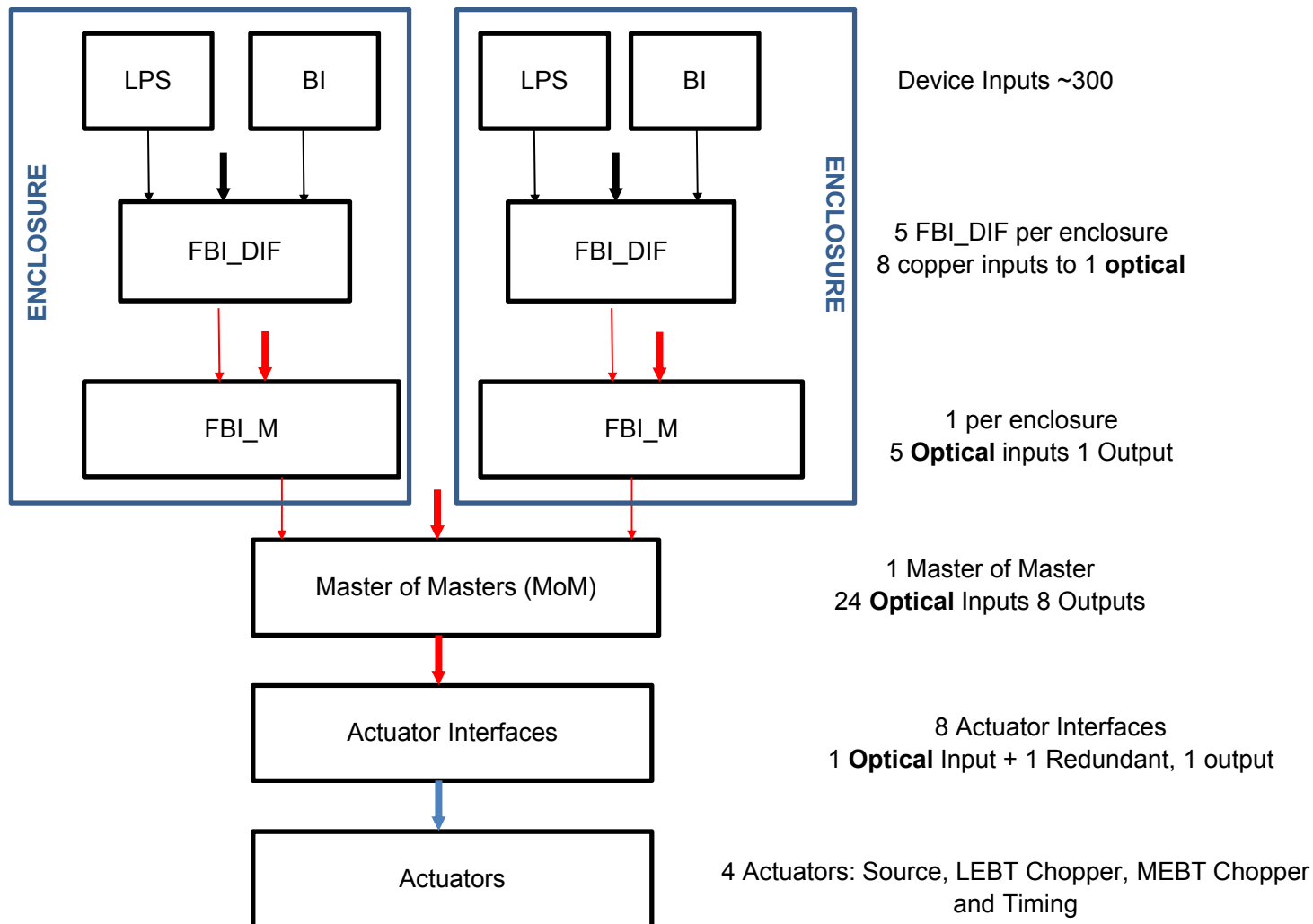


- Generated by the Machine Operators
- Two stage test:
  - WITH LONG BEAM AND LEBT FC **IN**
    - TO TEST THE SOURCE AND LEBET CHOPPER
  - WITH SHORT AND SAFE BEAM AND LEBT FC **OUT**
    - TO TEST THE MEBT CHOPPER AND ANY OTHER BEAM ACTUATOR
- Beam will be generated and the FBI\_MoM will trigger one by one the different beam actuator at half of the pulse time to ensure correct behavior.

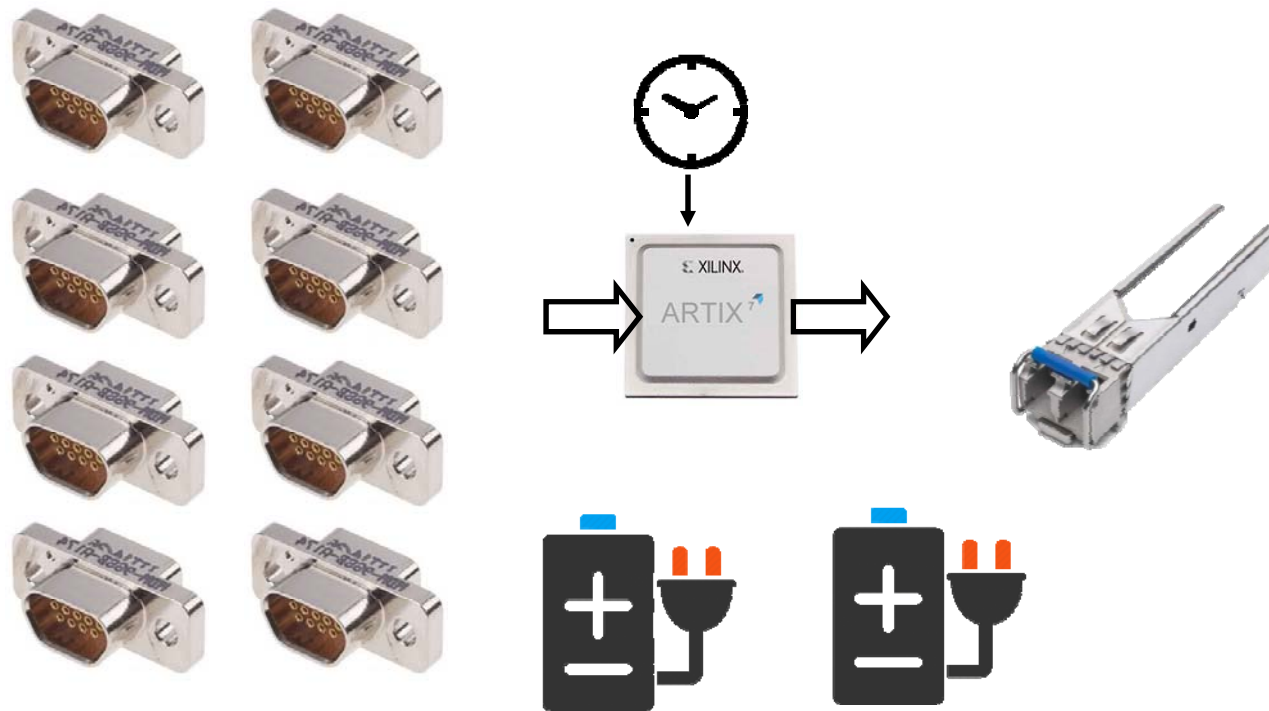
- EVOLUTION of the FBI Copper version
- Links between ID and FBI\_DIF still been copper for compatibility
- Copper links replaced by Gbit OPTICAL LINK:
  - FBI\_DIF to FBI\_M
  - FBI\_M to FBI\_MoM
  - FBI\_MoM to FBI\_A
- Uses FPGA with Internal serializers for all communications

- Follows same distribution as copper
- FBI\_DIF will concentrate signals instead of just adapting levels
- Copper links uses DC signals as before
- Optical links uses Gbit connection with BEAM\_PERMIT packed into DATA
- BEAM\_PERMIT path becomes dynamic, no blind failures if bit is stock

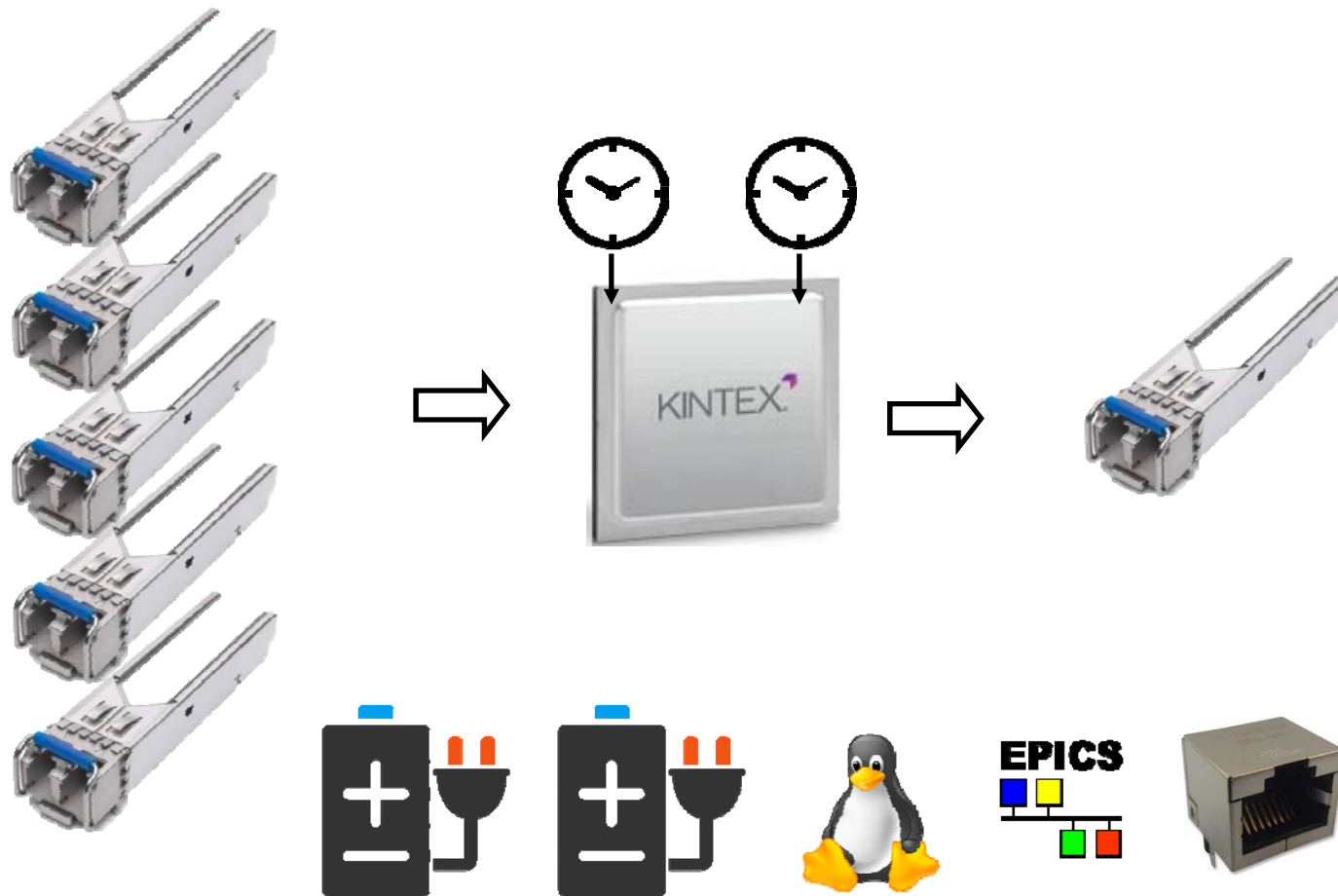
# FBI OPTICAL ARCHITECTURE



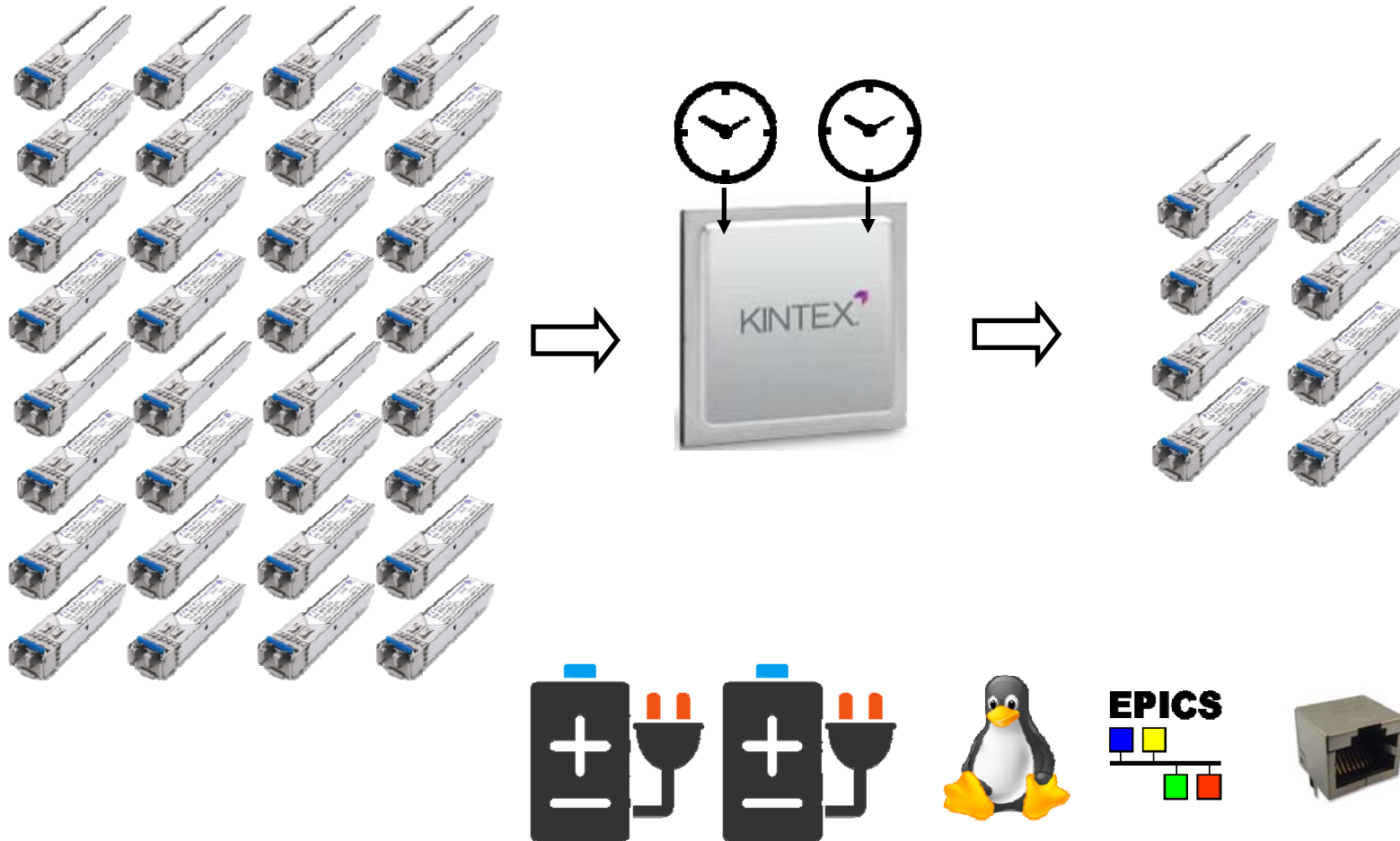
# FBI DIF Optical



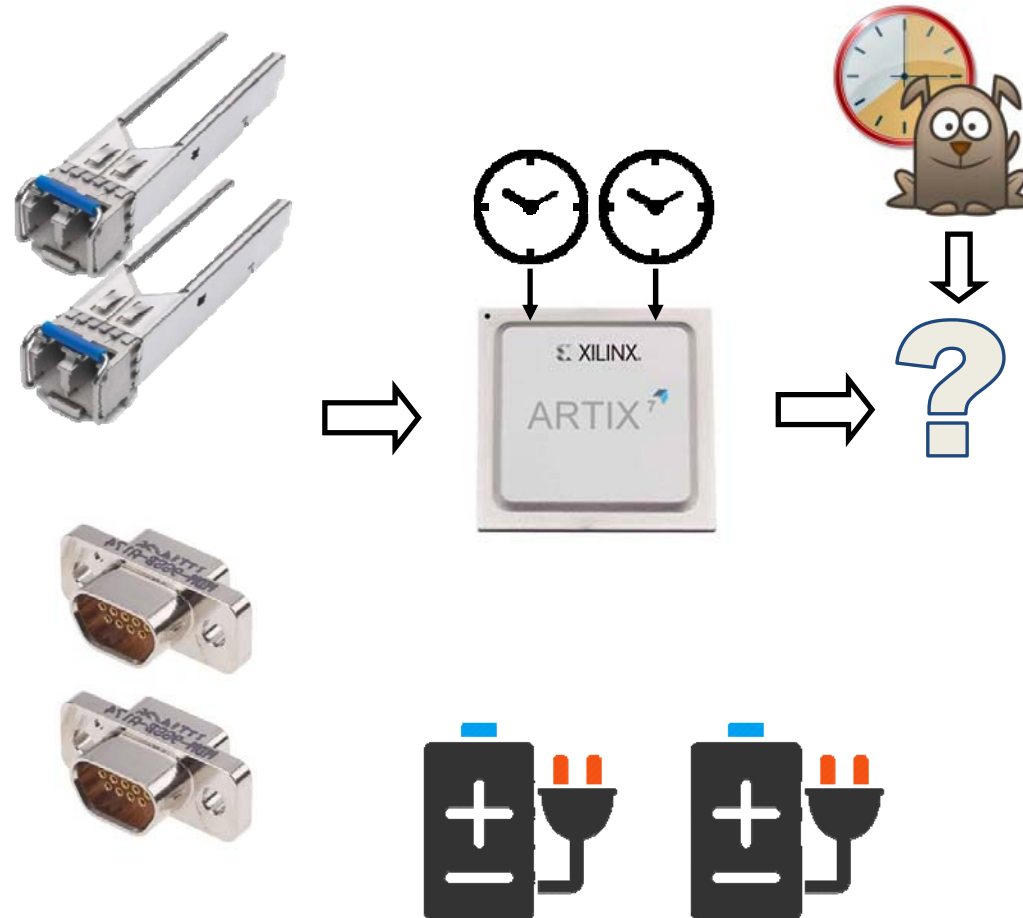
# FBI MASTER OPTICAL



# FBI MASTER of MASTER OPTICAL



# FBI ACTUATOR OPTICAL





- THE GOOD
  - Increased Speed compared to Copper System
  - Dynamic path for BEAM PERMIT
  - Increased noise immunity
- THE UGLY
  - Optical transceiver are as expensive as MICRO D connectors
  - Test still need to be performed between the Input device and FBI\_DIF
  - BEAM PERMIT depends of programmable devices (complex analysis)
- THE BAD
  - Fiber optics have shorter lifespan than copper

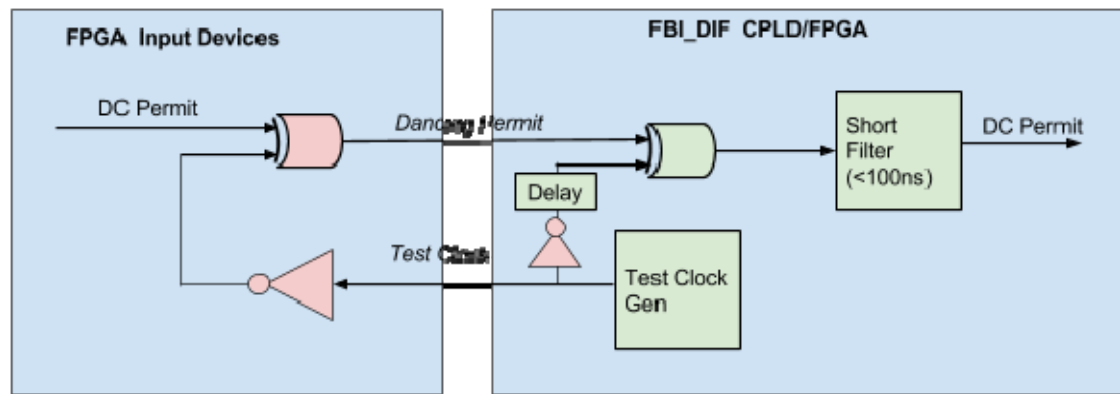
# IMPROVING OPTICAL (ideas)



- Separate Slow and Fast beam Interlock
  - Remove FBI\_DIF and use Optical from IDev till FBI\_Master.
- Fast TEST to warranty full FBIS functionality all time
- Dancing Permit (Next Slide)
- ***Slow and Actuator TEST will still need to be executed after every technical stop***

# IMPROVING OPTICAL - DANCING PERMIT

- Based on the detection of a phase change of a signal generated by the FBI\_DIF
  - No free oscillation
  - Delay can be set automatically
  - Test signal can be any one (even random)



- (BAD)
  - Its more intrusive in the Device Electronics Firmware
  - Requires extra settings for the FBI\_DIF

# CONCLUSIONS

- NO CONCLUSIONS ☹
  - WE STILL TRYING TO CHOOSE WHAT IS BEST

CHARACTERISTIC	COPPER	FIBER
PRICE		X
SPEED	X	X
NOISE IMMUNITY		X
FAST DESIGN	X	
KNOWLEDGE	X	
MAINTENANCE	X	

- WE NEED AN ENGINEERING MODEL OF THE FBIS OPTICAL TO COMPARE

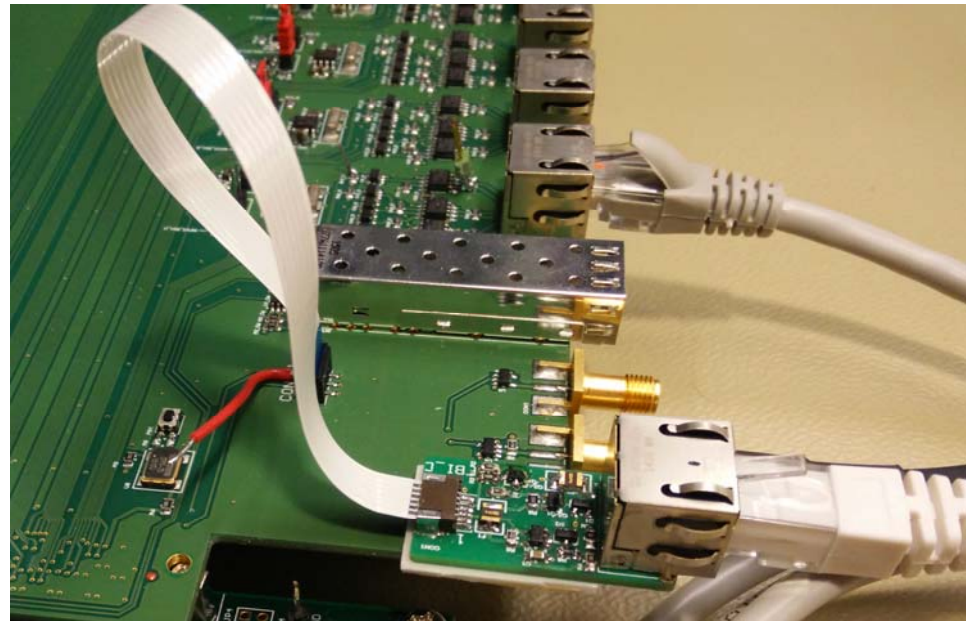
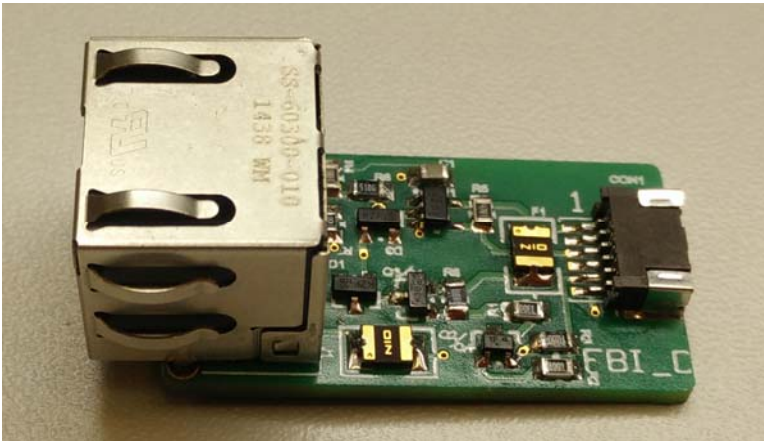
THE END



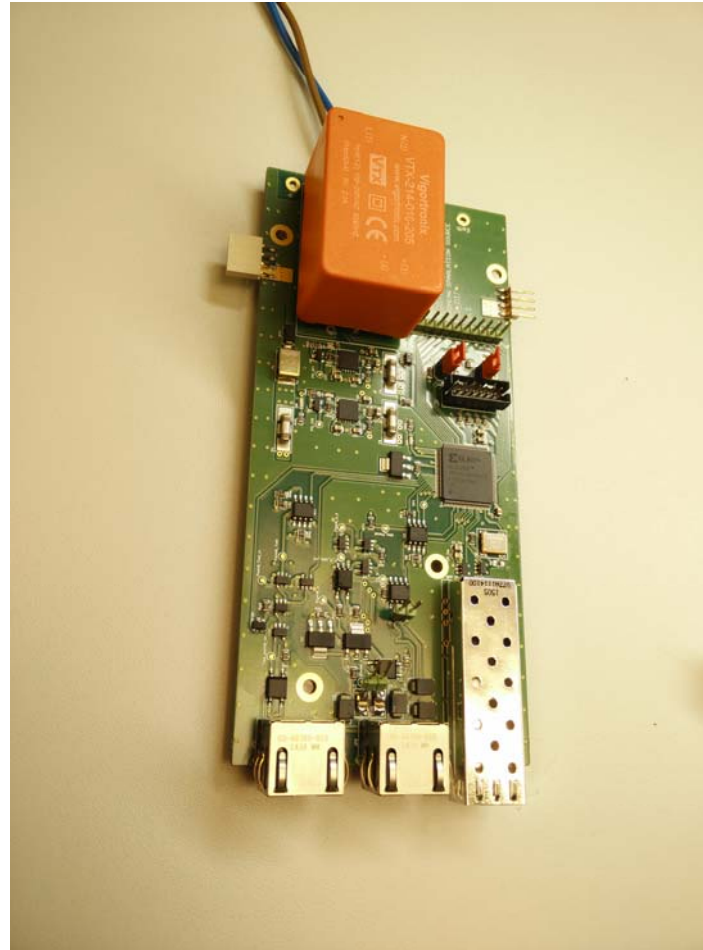
• THANKS

# ENGINEERING MODEL of FBIs COPPER

# FBI DRIVER (on pluggable module)

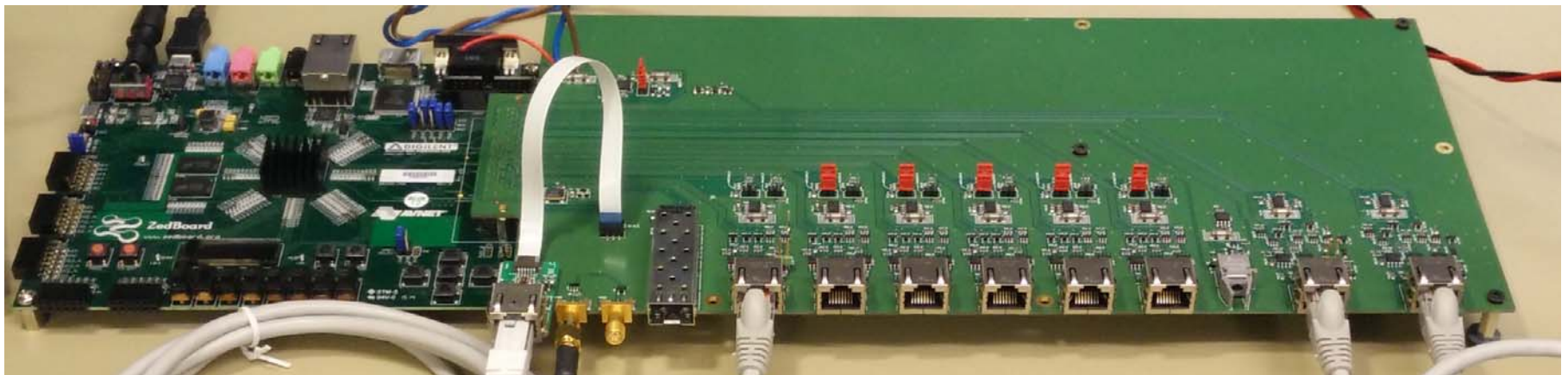


# FBI DEVICE INTERFACE

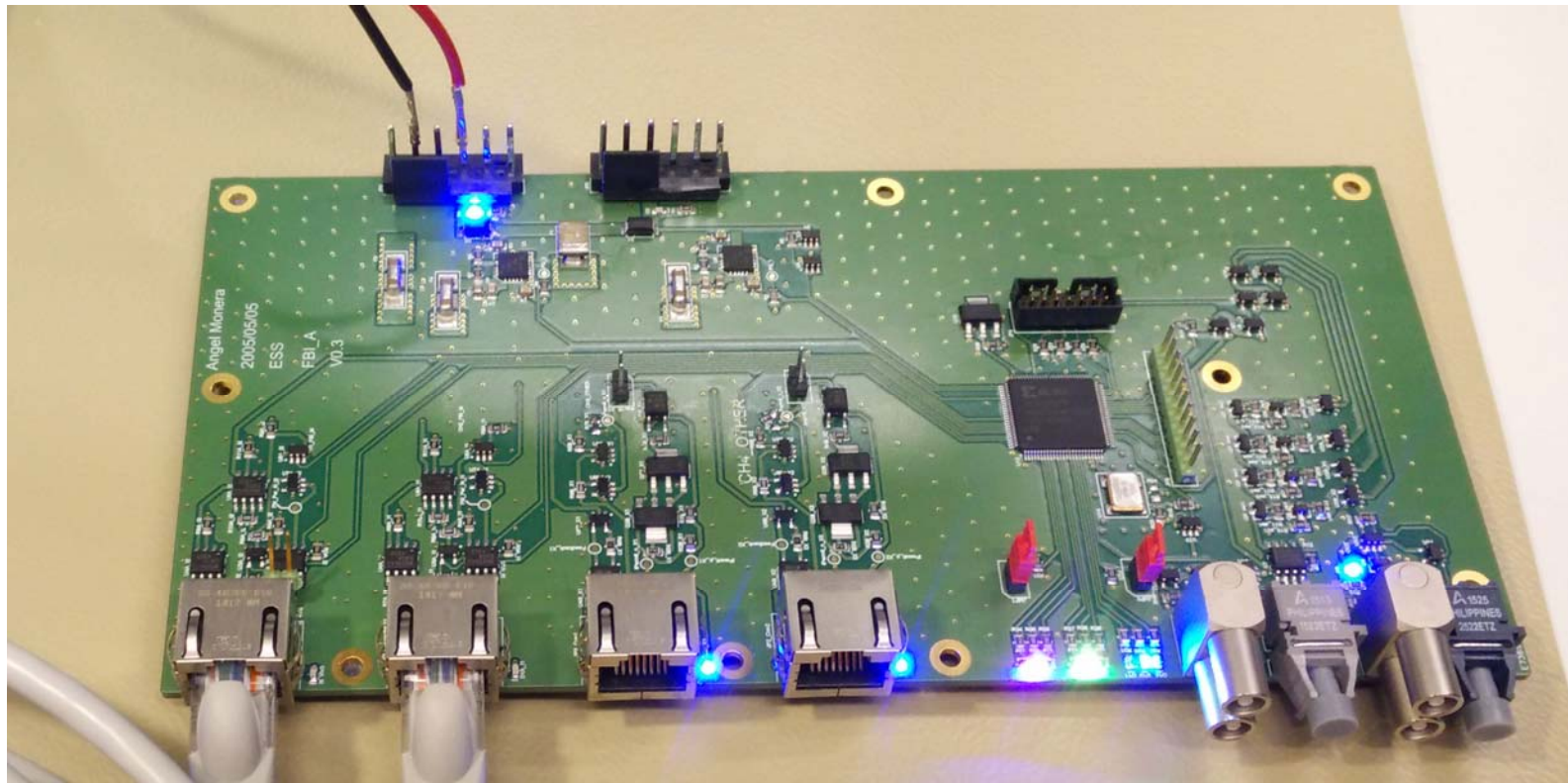




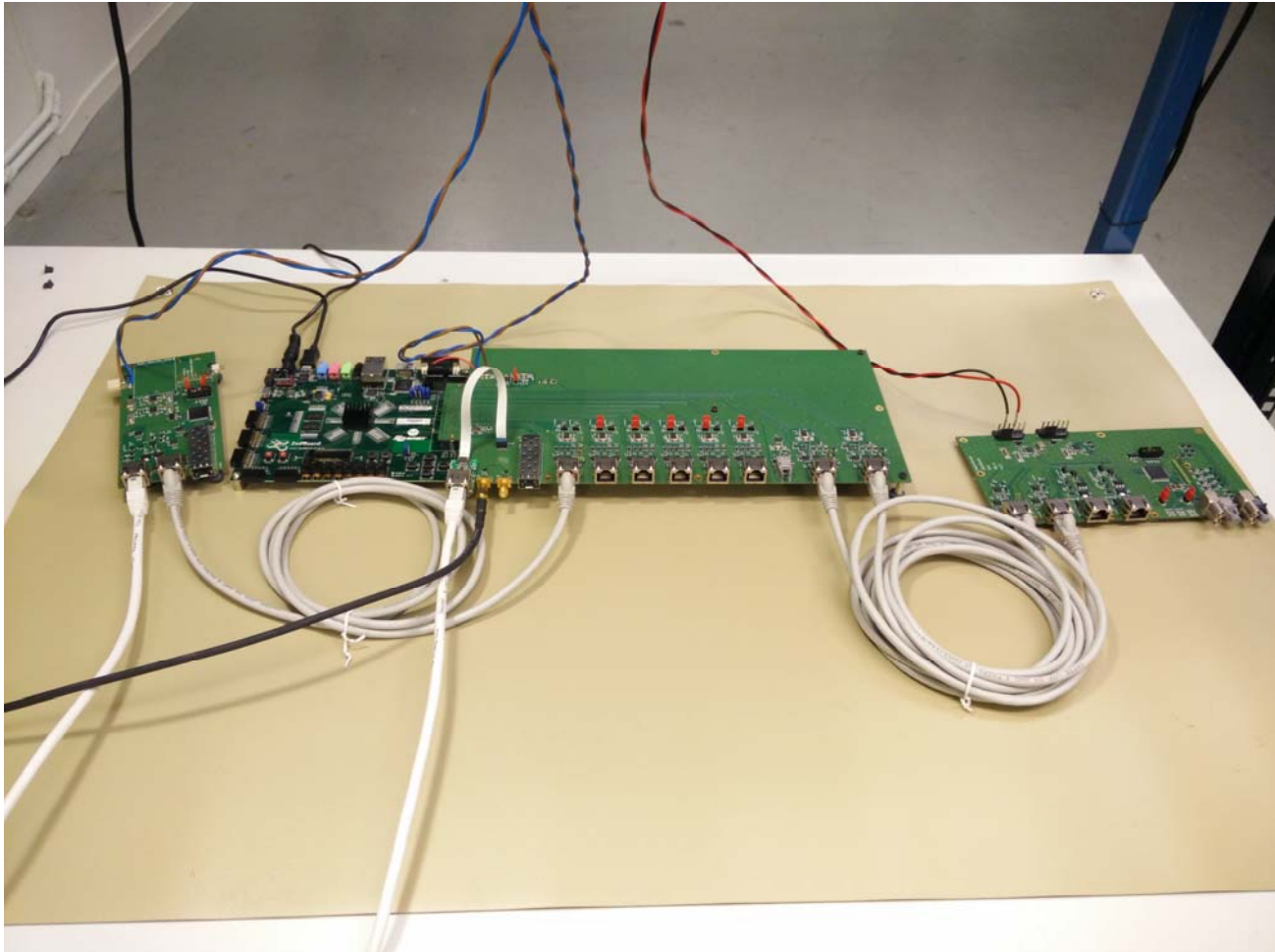
# FBI MASTER



# FBI ACTUATOR



# FBI's SYSTEM



# RESPONSE TIME

