ProtoDune SP Run 1 – Timing & Trigger distribution system

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DUNE Timing FDR

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University of BRISTOL

DUNE

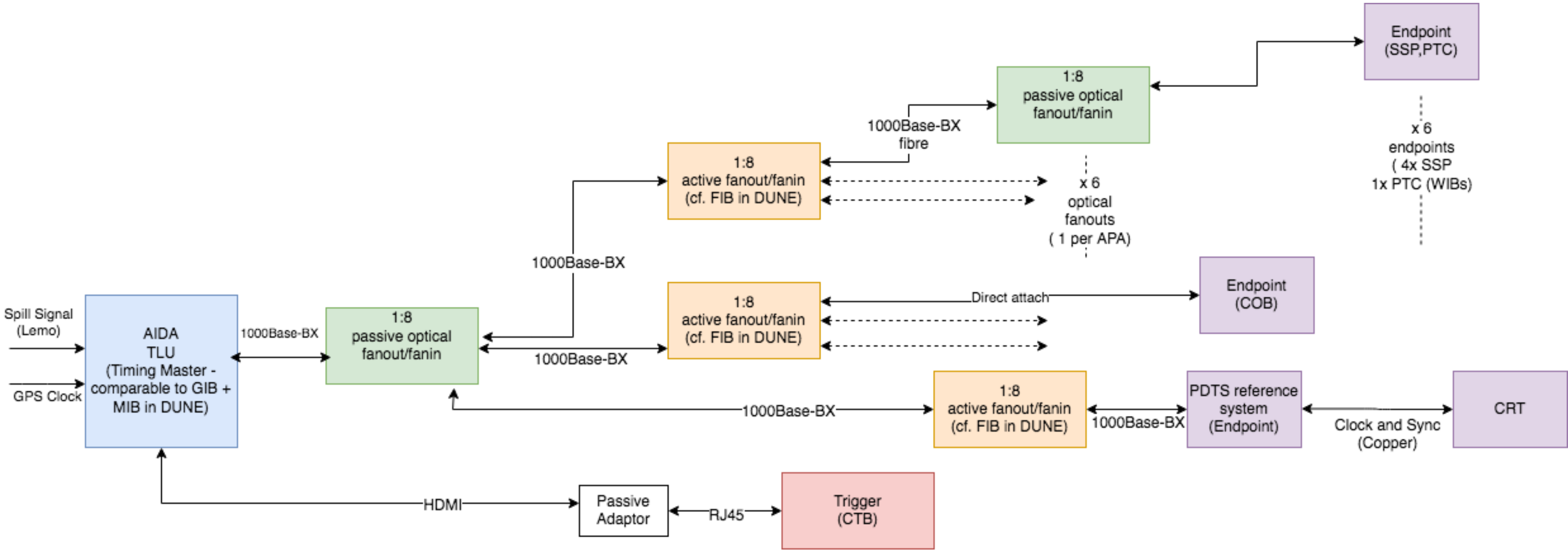
Overview of talk

- Timing & trigger system overview
- Demonstrated functionality
    - GPS/Accelerator interface
    - Active Fanout
    - Timing FMC
    - Protocol
    - Firmware
    - Software
    - Distribution
    - Partially demonstrated functionality
    - Lessons learned
- Relevant EDR Document
    - https://edms.cern.ch/document/2397891/1

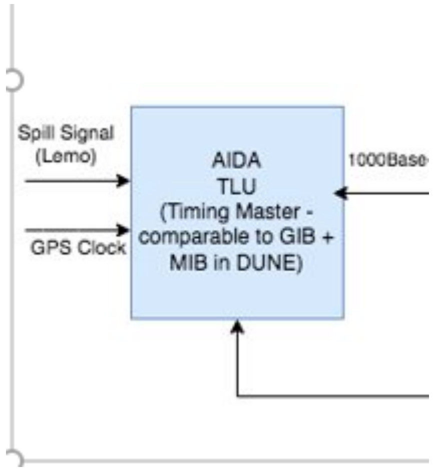
Overview of timing and trigger system

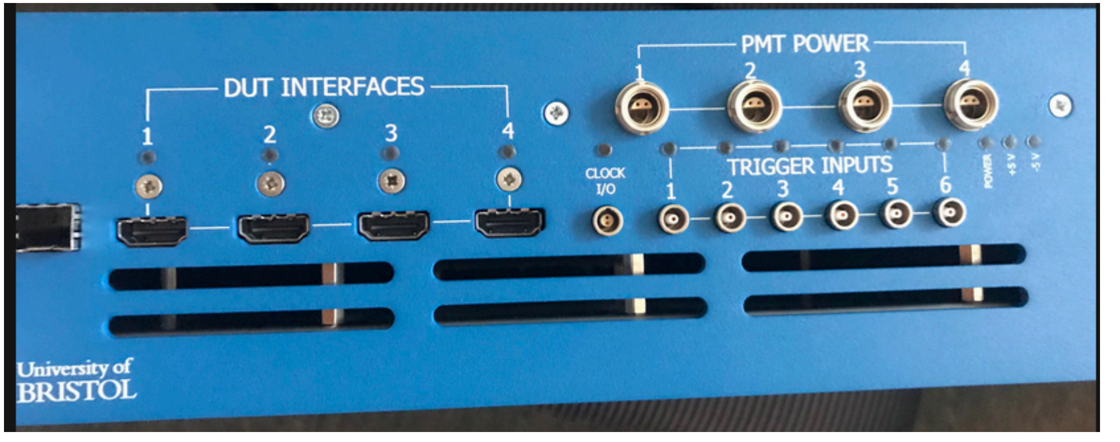
- The protoDUNE timing system was installed, commissioned and operated starting in 2017 until the present.
- The primary task of this system was to provide timing information and trigger distribution to the readout electronics of the single-phase ProtoDune experiment.
- The system was designed and built using a combination of custom hardware with off-the-shelf parts.
- A laboratory set-up at Bristol was used to prototype and test all parts of the setup before installation at CERN

Overview of timing and trigger system



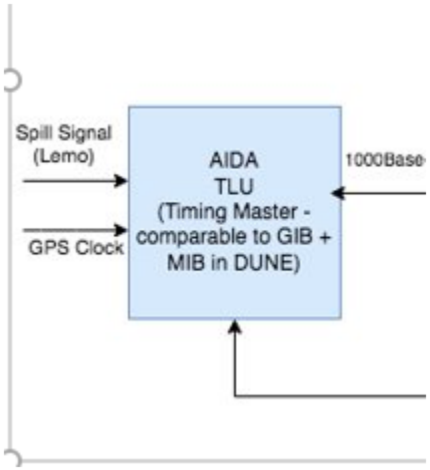
Demonstrated functionality : GPS/Acc interface

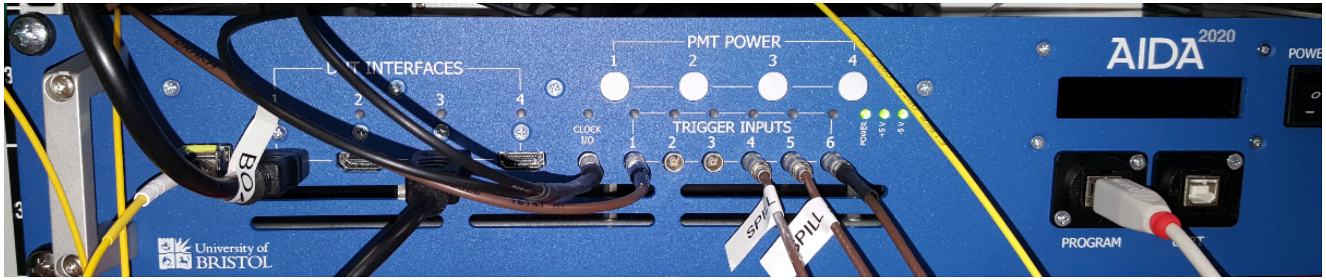




- AIDA Trigger Logic Unit (TLU) designed for flexible timing and trigger distribution for HEP
- Unit contains FPGA board, PCB, and power module.
- Unit was used as the Master timing system for ProtoDUNE SP Run 1
  - Received 10 MHz clock from GPS receiver (via WR interface)
    - Generated synchronisation clock and distributed
  - Accepted external trigger signals and distributed
  - Received SPS signals

Demonstrated functionality : GPS/Acc interface





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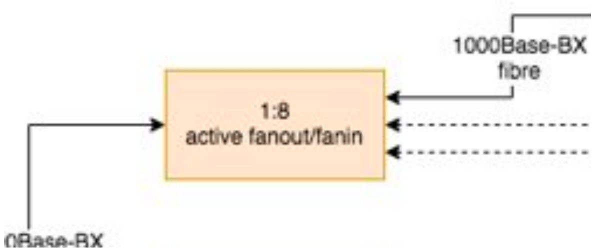
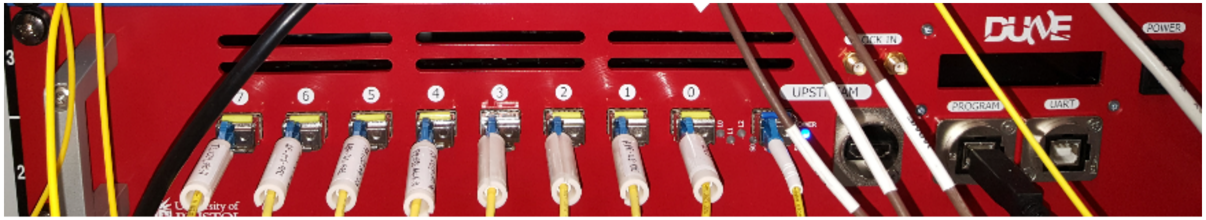
Demonstrated functionality: Active Fanout





- Active Fan out boxes – designed for protoDUNE
- Received timing and trigger signals from TLU and provided 8 outputs on optical fibre
- Can also operate in stand alone mode

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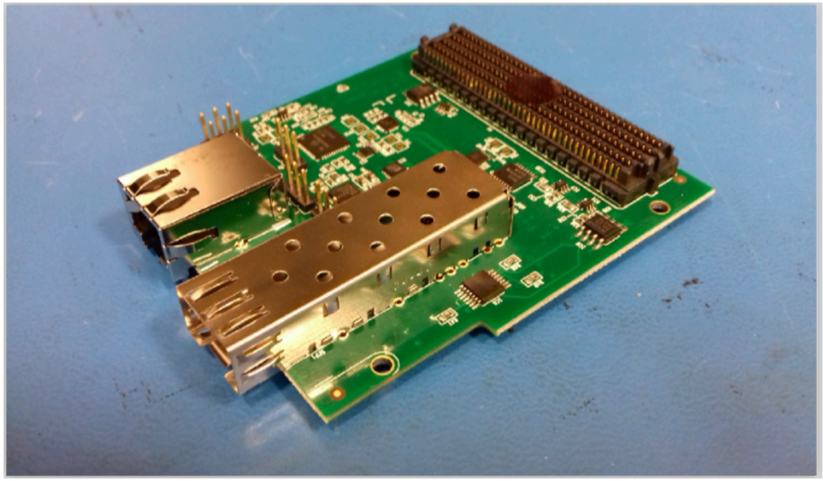
Demonstrated functionality: Timing FMC

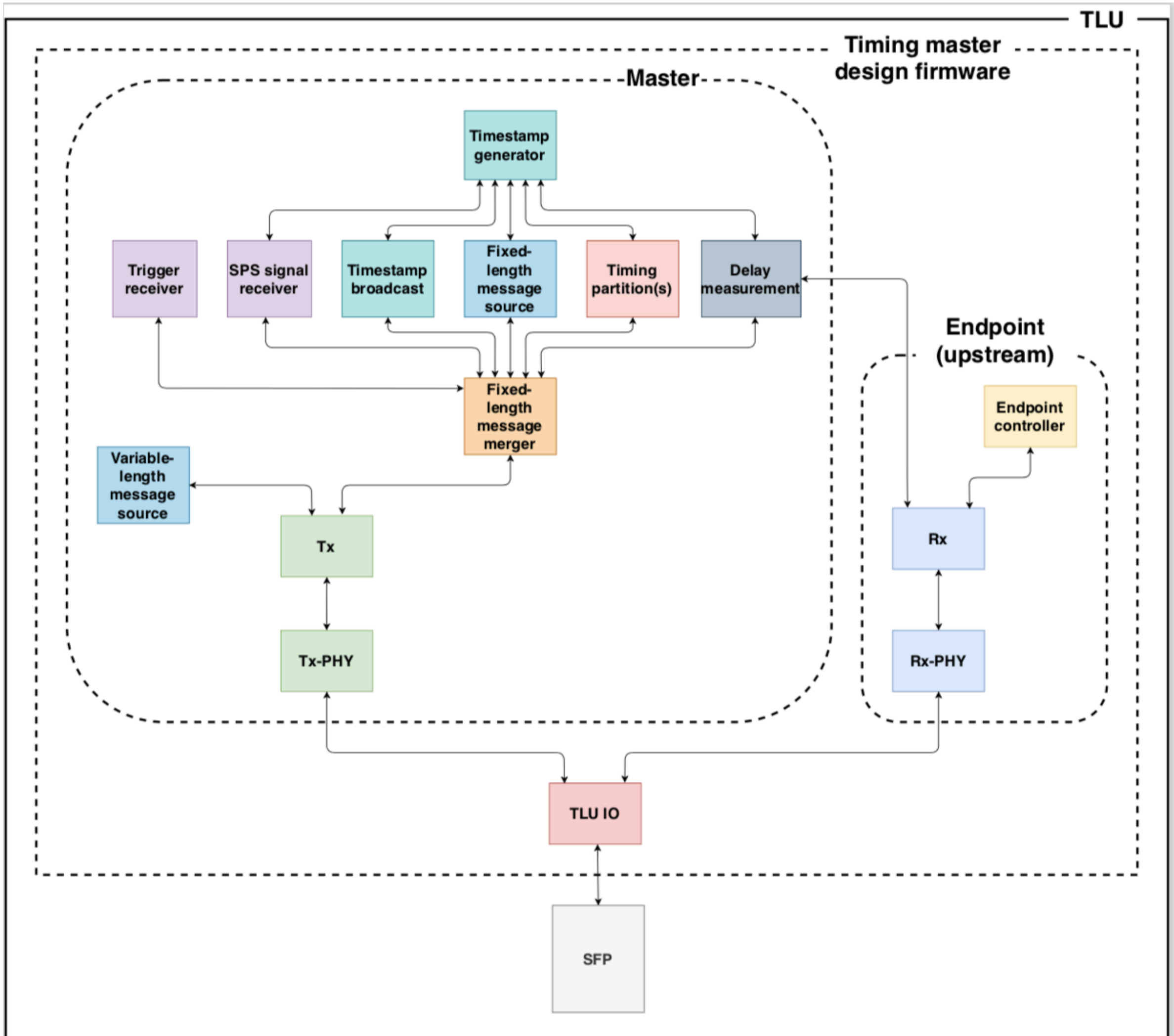


- Extremely useful versatile board
- Can act as a master or an endpoint
- Can be plugged into a standard FMC connector on host board
- Portable and functional, helped commissioning, lab testing, etc
  - Used for CRT interface in PD run 1
  - Used for tests at ICEBERG (FNAL)
- Can be used for DUNE timing test systems (as part of DAQ kits)
  - Also an endpoint hardware reference design

Demonstrated functionality: Protocol

- The following was demonstrated:
  - Basic principle of operation - i.e. distribution of time stamps to readout electronics
  - Clock distribution at 50 MHz, links operating at 250Mbit/s
  - Automated link acquisition, lock and error detection
    - Every packet has a checksum at the end. 8b10b encoding also has to be correct
  - Synchronisation
    - e.g. Setting timestamps in endpoints
  - Bi-directional communication
    - From TLU to Active Fanouts to Endpoints
    - Endpoints modules which could not turn on/off transmitters – so had to adjust.

Demonstrated functionality: Firmware



Demonstrated functionality: Firmware

- Timing master implementation
  - Trigger generation
    - Before CTB, ability to set random and poisson
  - Rate control and run control
    - Ability to limit trigger rate (implement trigger rules)
    - Vetoing of triggers until run control application accepts them
  - Partitioning
    - Ability to use "groups" which would receive specific commands/requests
  - Interface to Central Trigger Board – two separate links to send out timing information and receive trigger information
  - SPS timing signals distribution (spill start, end)

Demonstrated functionality: Firmware

- Endpoint implementation
  - Demonstrated on four different FPGA families
  - Intermediate master implementation – timing mezzanine card which can act as the master – used extensively prior to TLU installation
  - Debugging and test frameworks (local loopback)

Demonstrated functionality: Software

- Basic board control functionality for all hardware
  - Fixed length, variable length commands
  - Including python wrapper to allow stand-alone command line control and monitoring
  - All basic features required for protoDUNE I operation
  - ArtDAQ board reader for master timing control
    - Interfaced to run control for central configuration

Demonstrated functionality: Distribution

- Copper
  - Twinax cable – (direct attach)
  - Twisted pair – HDMI - RJ45 (CTB)
- Multimode fibre (850nm)
  - Bi-directional one-to-one communication with point-to-point duplex links
  - Fanout distribution to eight endpoints
- Single-mode fibre (1310nm/1550nm)
  - Up to 48 endpoints via passive bi-directional fanout
  - (max distance tested 200m)
- Lab tests of link delay stability across temperature and ageing effects
  - Putting fibre and electronics in environmental chamber

Partially Demonstrated functionality

- Fundamentals
  - Coarse timing alignment adjustment (20ns blocks), (delays set to zero during PD run 1)
  - Individually addressed messages
    - Identifiers for each endpoint
  - activation/de-activation of endpoint transmitters
    - Tested in lab
- Software
  - Timing alignment setup and check (although possible with python wrapper)
- Hardware
  - Operation at 62.5 MHz base clock – firmware built without errors, not yet tested
- Firmware
  - fine adjustment of phase not demonstrated

Lessons learned

- Thorough testing in laboratory setting is essential before deployment in experiment!
  - Helped easier debug of several issues
- Timing "kits" sent to endpoint collaborators frequently revealed misunderstandings over usage, firmware etc.
  - More disciplined approach to providing documentation, recipes etc would save time when kits are sent out.
  - Providing timing system as early as possible is crucial to spot bugs – important to receive feedback early from systems
- Functionality requirements evolved as the experiment (and endpoint needs) matured – led to "critical" development happening on very short time scales.
  - Producing detailed requirements in advance allows resources to be used effectively and reduces number of "high strain" periods.
- Planning in advance the structure of how the software will interface to the firmware is extremely important – will help develop coherent control and monitoring.

Summary

- A successful timing and trigger distribution system was developed for protoDune Run I
- Composed of both custom and COTS hardware, dedicated firmware and software
- Functionality demonstrated in several areas, e.g.
  - Timestamp generation, distribution, synchronisation
  - Reception of external signals
  - Distribution on optical, copper
  - Bi-directional links
  - Partitioning
- This provided a solid base from which to develop the Dune Timing System (modular firmware, testing functionality etc) - already reaping the rewards in developing system for protoDUNE II and DUNE.