A Versatile Bi-Directional Link System

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12th Workshop on Electronics for
LHC and Future Experiments
25-29 September 2006, Valencia SPAIN

Outline

- Links in HEP
  - Is a different approach viable?
- A Versatile Bi-Directional Link System
  - The concept
  - The GBT ASIC
  - Link configurations
  - Bandwidth
  - Handling SEUs
- The GBT as a "Communications Controller"
- Prototypes
- Summary

Links in HEP

- Data transmission roles in HEP:
  - Data Acquisition (DAQ)
  - Timing, Trigger (TT)
  - Experiment Control (EC)
- LHC Era:
  - A different architecture for each function
  - A dedicated physical support for each architecture
  - Experiments shared some common developments:
    - TTC system
    - GOL
  - But a lot of effort went in developing several similar systems for each of the four LHC experiments!

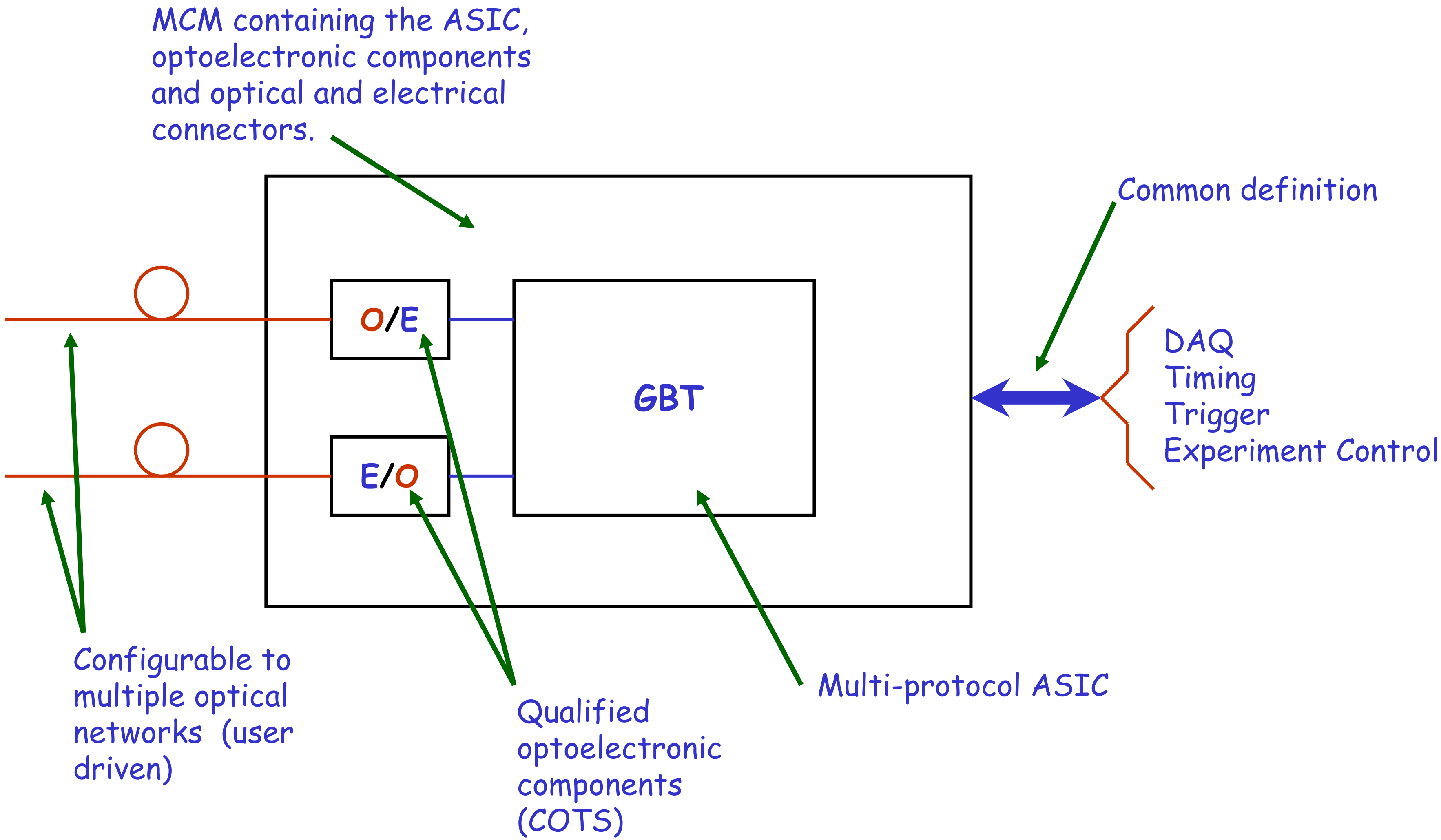
Future HEP Links

- Can we develop a one-size fit-all solution?
  - Same support hardware?
  - Same link architecture?
- An "universal" link requires:
  - The experiments to agree on a common interface!
  - A well defined set of specifications (requirements):
    - DAQ
    - TT
    - EC
    - ASIC
    - OPTOELECTRONICS
- The system has to be Versatile:
  - It has to accommodate several topologies
  - But the physical support can be "shared"
    - Same electronics (ASIC)
    - A limited set of optoelectronics 'flavours'
    - Same MCM

Versatile Bi-Directional Link System

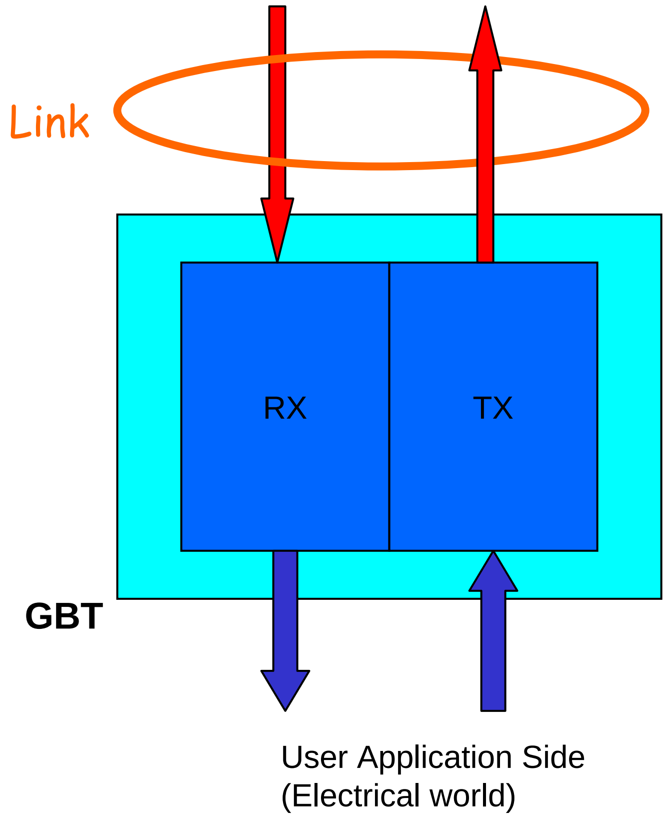
- The objective is to build a system based on a single ASIC which can provide a complete link solution for:
  - Timing
  - Trigger
  - Experiment Control
  - Data Transmission
- What's the target:
  - Implement versatile link topologies
  - Higher bandwidth
    - Data, Timing, Trigger and Experiment Control
  - Bi-directional links
    - Data, Timing, Trigger and Experiment Control
  - Robust handling of irradiation effects
    - Total dose
    - SEU
  - Common development
    - Better use of human/economical resources

Transceiver Module



GBT

- Such a Versatile system requires:
  - Multi-protocol transceiver:
    - 1-to-1
    - 1-to-N
    - N-to-1
- Operation modes:
  - Trigger:
    - TTC functions
  - Link
    - General purpose
    - Simplex/Duplex
- Data transmission modes:
  - Continuous
    - Data is continuously transmitted
  - Packet
    - Data is transmitted in bursts of packets

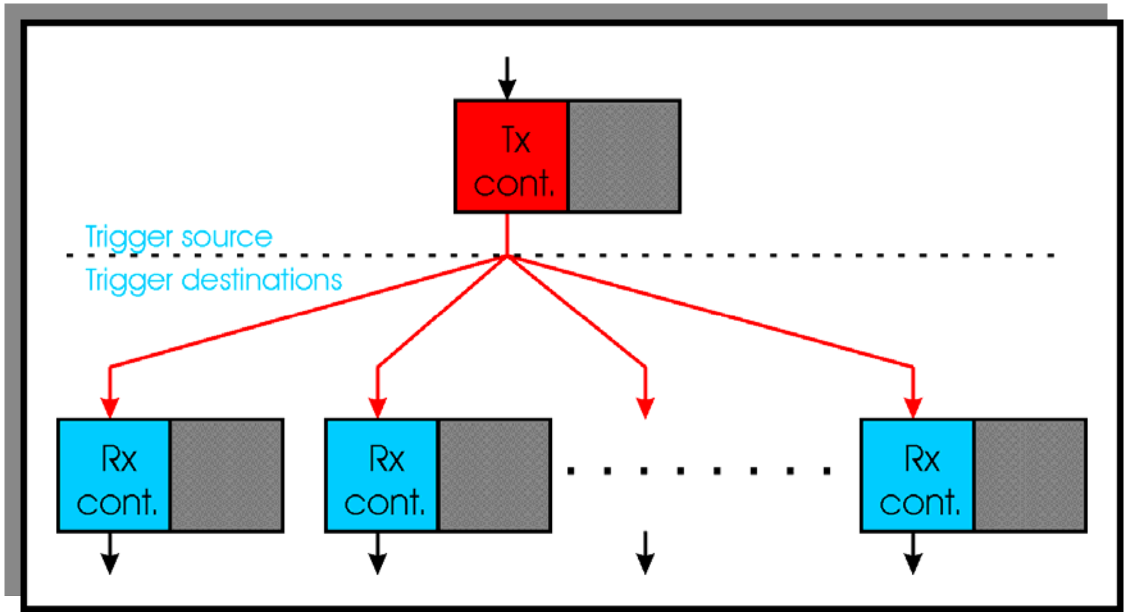


GBT Operation Modes

- Continuous mode (think about a traditional optical link):
  - Each link is 100 % occupied by a single transmitter.
  - The transmitter/receiver pairs are fully synchronous
  - This is the case for:
    - A trigger source sending data to several trigger destinations
    - Synchronous point-to-point data link
- Packet mode (think about a backplane bus):
  - Common Transmission medium is shared:
    - A transmitter can only send data upon the request of a master transmitter
  - Several devices can share the same medium and thus communicate with the same destination without collisions
  - This is the case for:
    - Trigger return link (bus)
    - Asynchronous point-to-point data link

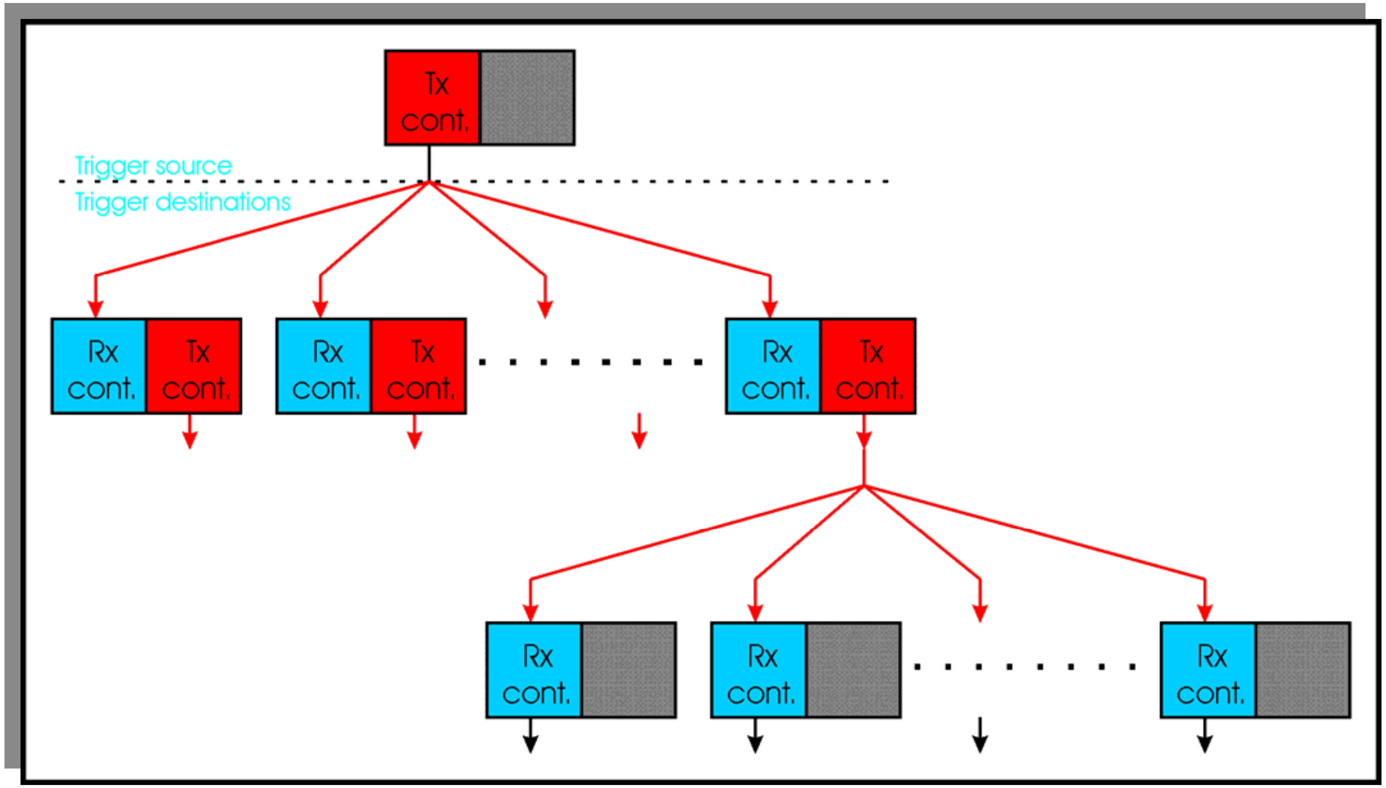
Link Configuration 1: Broadcast Network

- Down-path: Passive Optical Tree
  - Current TTC system architecture
  - One source to N destinations
  - For large N, an high optical power source is required
  - Operation mode: continuous



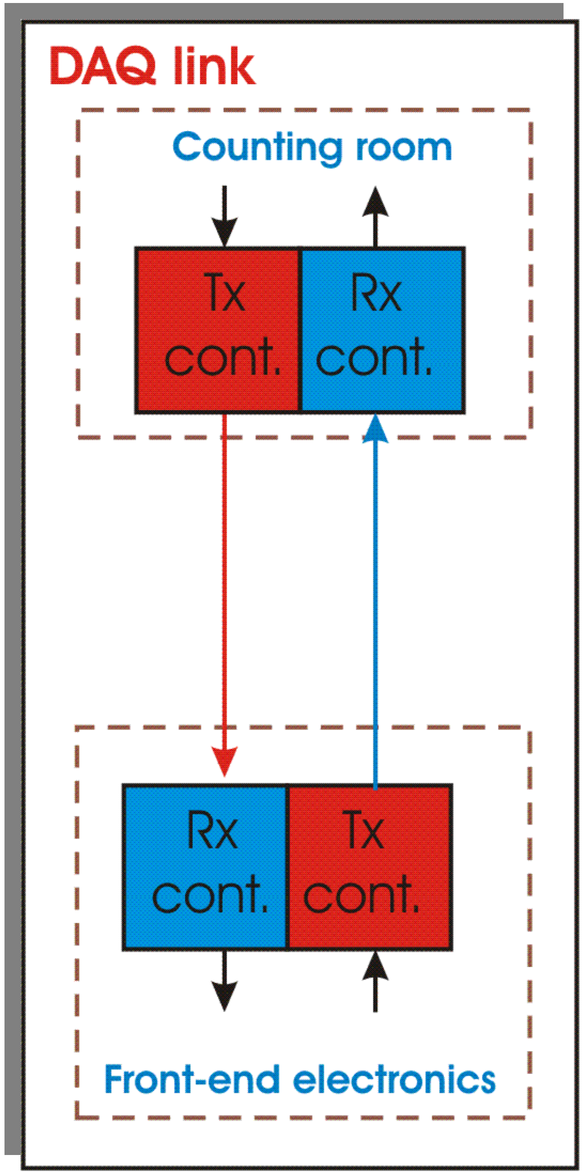
Link Configuration 2: Broadcast Network with O/E/O Repeaters

- Down-path: Passive/Active Tree
  - Passive power splitting with electrical regeneration
  - One source to N destinations
  - Optical or electrical: 1-to-16
    - Moderate optical power at each transmitter
  - Operation mode: continuous
  - Moderate increase in latency: o/e-r-e/o



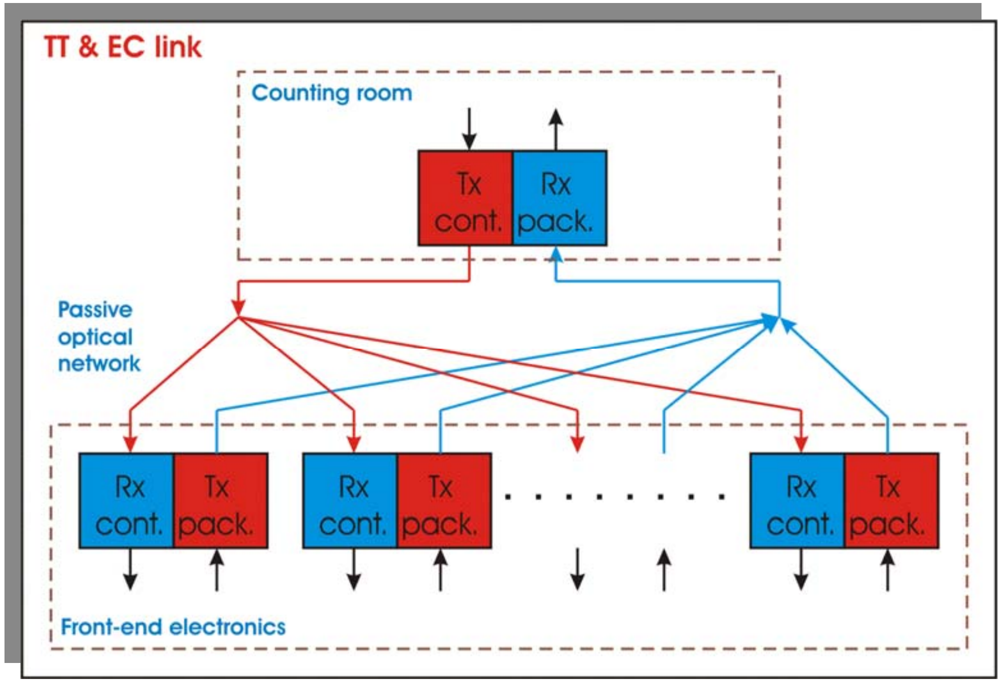
Link Configuration 3: Point-to-Point

- Up/Down-paths: Optical
  - Full bandwidth available for data transmission
  - Simplex/Duplex operation
  - Operation mode: continuous



Link Configuration 4: Bidirectional One-to-N / N-to-One

- Down/up-links: Passive Optical Trees
  - Passive optical tree in both directions
  - Down-link: 1-to-16
  - Fan-In-Out: 16-to-1
    - For moderate power optical source
  - Operation mode:
    - Down-link: continuous
    - Up-link: packet
    - Up-link under control of the master transmitter



Data Rate and User Bandwidth

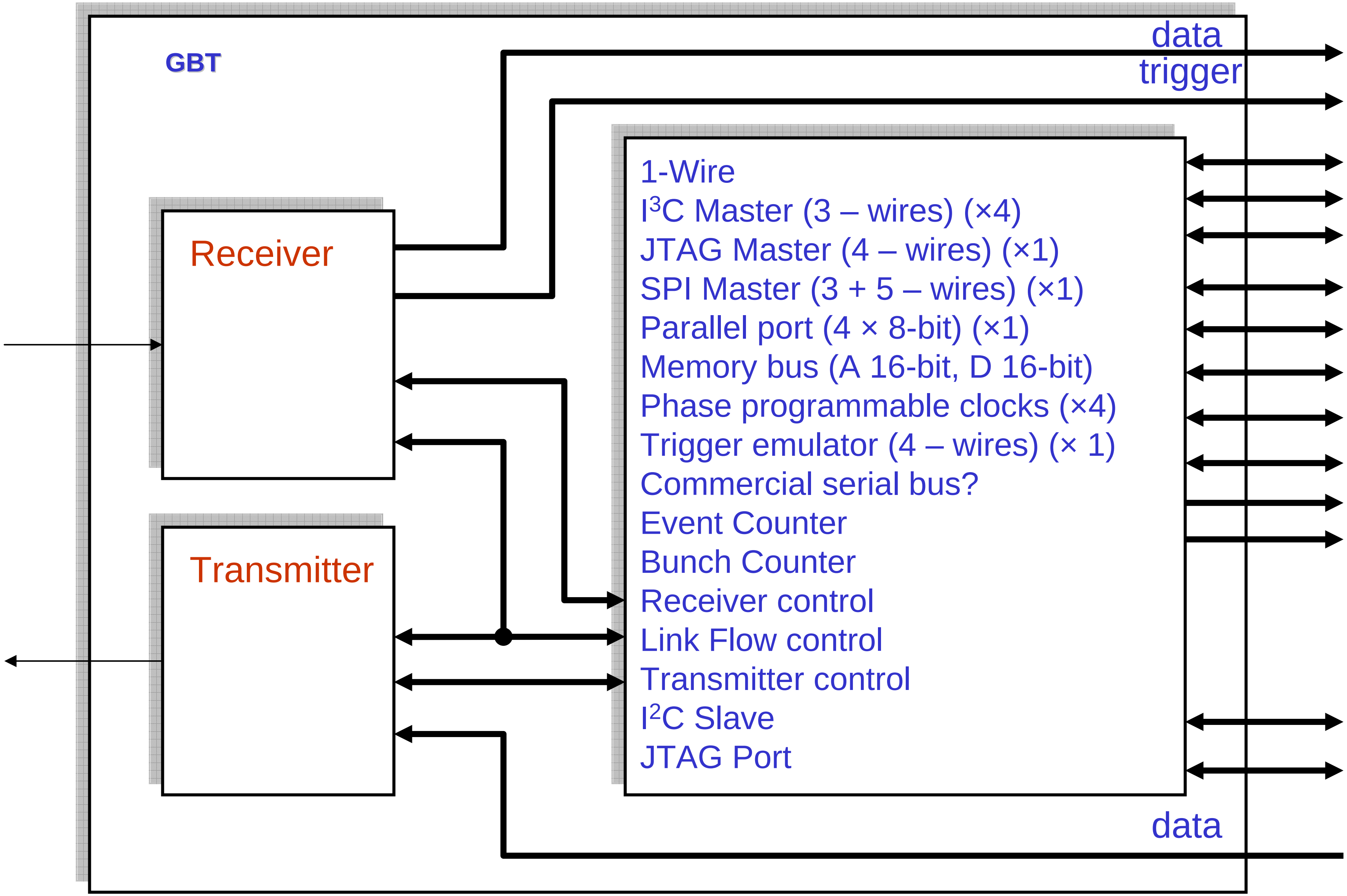
- Data rate and word size will depend on the SLHC frequency
  - Still not decided!
  - Numbers below assume f_{SLHC} = M ◈ f_{LHC} (not necessarily true)
- Transmission data rates must be multiples of the (S)LHC bunch crossing frequency:
  - Trigger system remains synchronous with the accelerator cycles
  - Fixed latency communication channels
  - 130 nm CMOS technology:
    - Raw 3.2 Gbit/s OK, (~5 Gbit/s maybe feasible)
    - Transmission of 88-bits encoded at 40 MHz (the LHC rate)
    - Effective data bandwidth of 2.56 Gbit/s (for 3.2 Gbit/s raw)
  - 90 nm CMOS technology:
    - Raw 6.4 Gbit/s OK, (~10 Gbit/s maybe feasible)
    - Transmission of 128-bits properly encoded at 40 MHz (the LHC rate)
    - … or transmission of 64-bits encoded at 80 MHz (the SLHC+ rate)
    - Effective data bandwidth of 5.12 Gbit/s (for 6.4 Gbit/s raw)

Line Codes and Error Correction

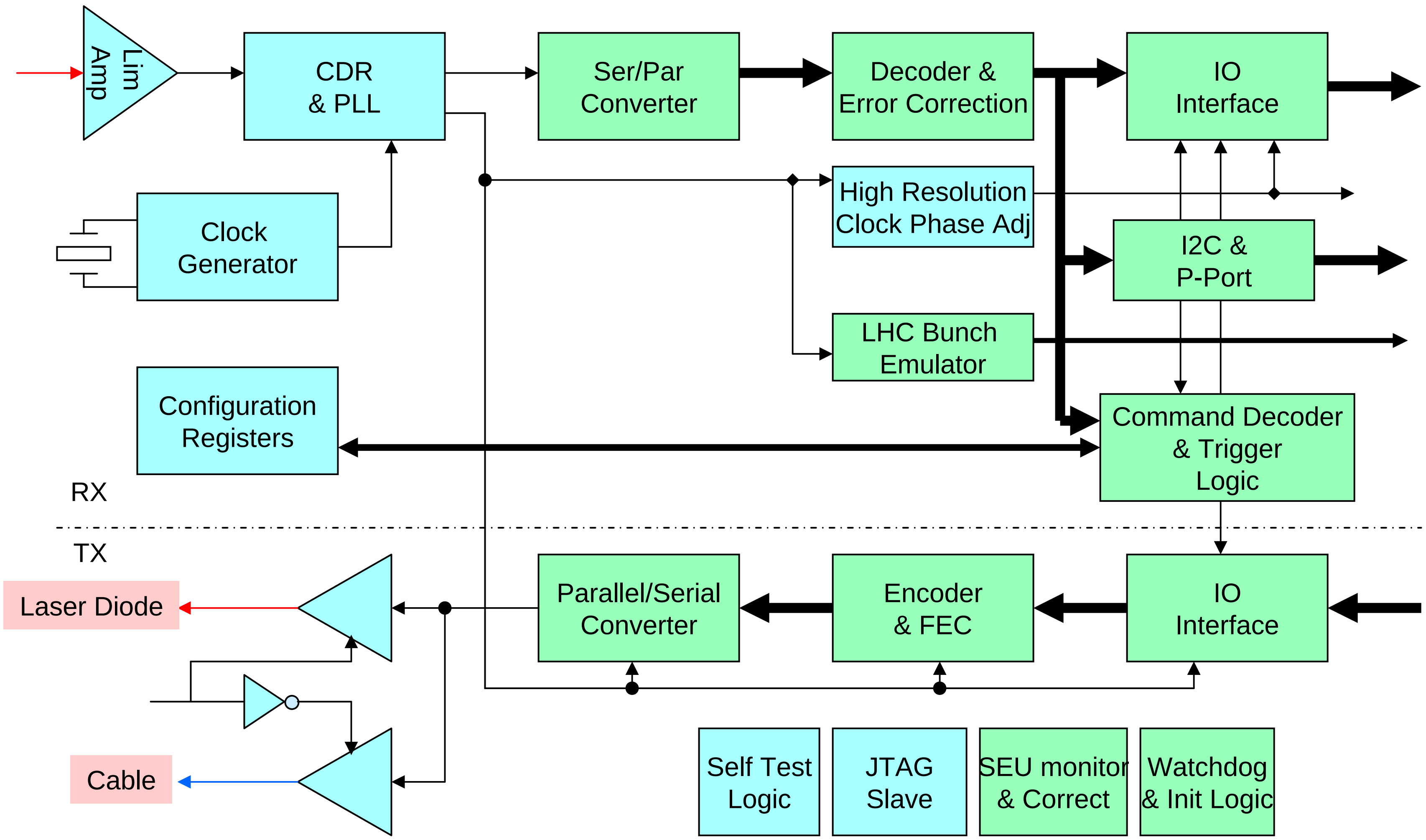
- High SEU rates are expected for SLHC
- SEU errors at the optical receiver (PIN-Preamp) will be detected as corrupted data bits
- Traditional Error Coding followed by Line Coding will not work!
  - The order of operations must be reversed
- To deal with higher SEU rates in SLHC the following scheme is proposed (illustrative example only):
  - 64-bit data is first scrambled for DC balance
  - The scrambled data is Reed-Solomon encoded: 16-Bit FEC field
  - An 8-bit redundant header is added to form a frame
  - This results in an 88-bit frame.
    - Line rate → 40 MHz × 88-bit = 3.52 Mbit/s
  - To minimize the dead-time due to a loss of synchronization the scrambler is designed as self synchronizing:
    - One LHC clock cycle is enough to synchronize the scrambler
  - The efficiency of the line encoding is: 64/88 = 72.7 %

(Further details were given by Giulia Papotti this morning)

The GBT as a TTC and Communications Controller



GBT Block Diagram

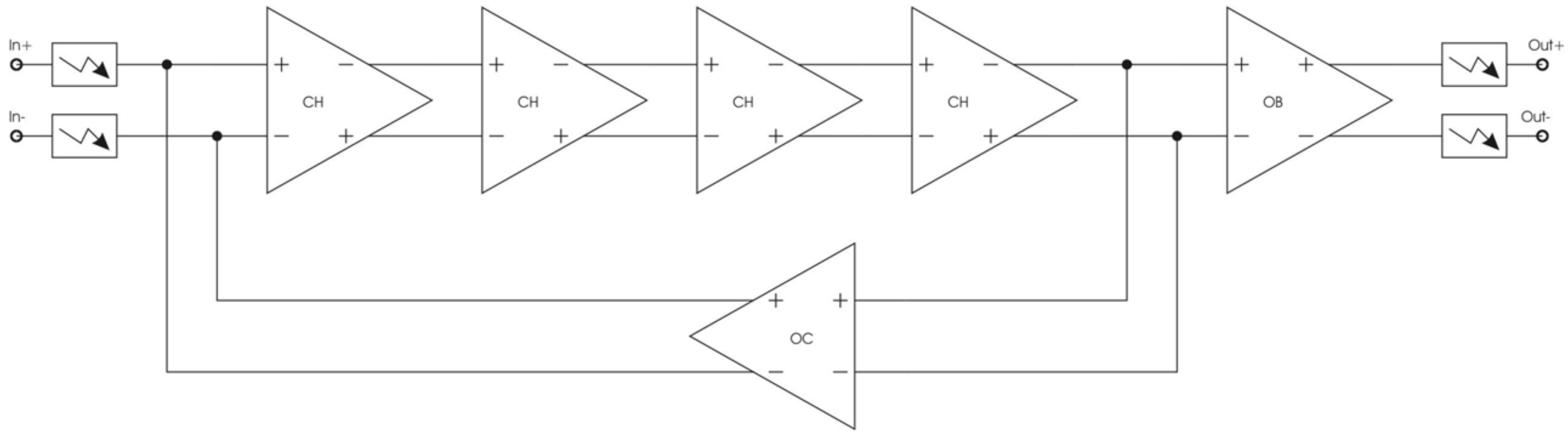


Needs 3*logic + Voting

Prototypes

- Three GBT building blocks were prototyped in 130 nm CMOS:
  - Laser driver (Gianni Mazza, INFN Torino)
  - Encoder / decoder (Giulia Papotti, CERN)
    (Presented this morning)
  - Limiting Amplifier (Paulo Moreira, CERN)

Limiting Amplifier

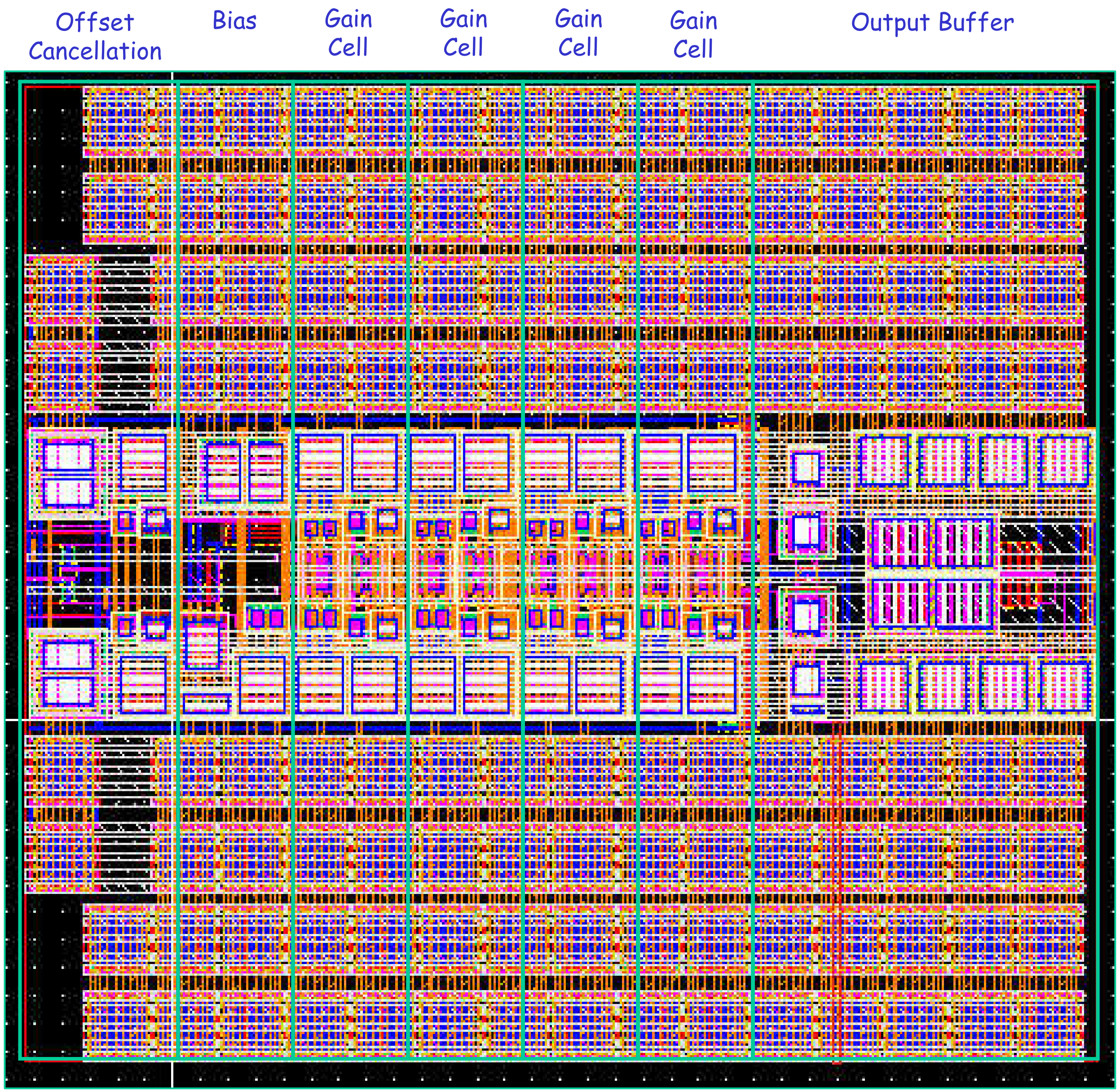


Specifications:

- Data rate: 3.60 Gbit/s
- Gain: > 55 dB
- Bandwidth > 2.52 GHz
- Equivalent input noise: < 1 mV
- Minimum input signal (differential): 10 mV
- Maximum input signal (differential): 600 mV

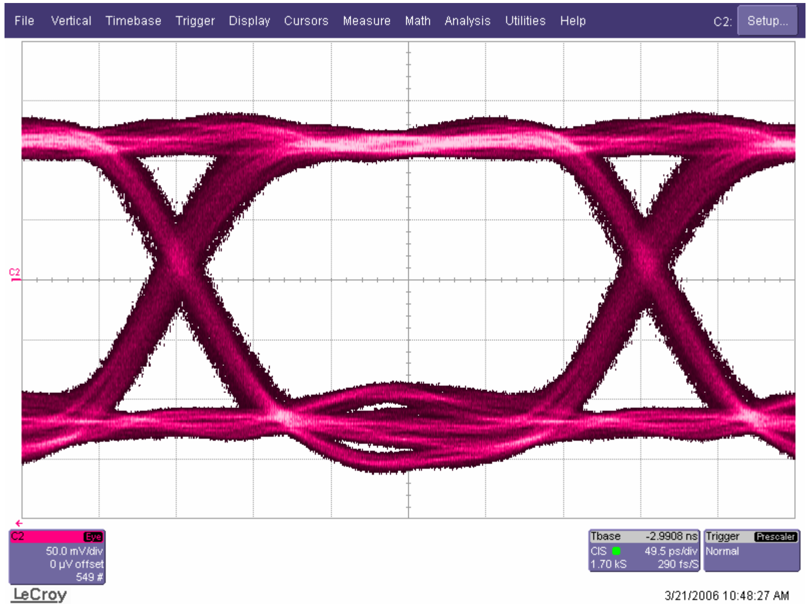
Limiting Amplifier

Size: 194 µm × 194 µm



Limiting Amplifier

3.35 Gbit/s



1 Gbit/s

Summary

- We propose a Versatile Link solution for:
  - Timing Trigger Links;
  - Data Acquisition Links;
  - Experiment Control Links.
- The system allows flexible link topologies:
  - Bi-directional
  - Uni-directional
  - Point-to-Point
  - Point-to-Multipoint
- Specifications and Interfaces are still evolving for which we **need** the feedback of the potential users
- Some universal building blocks have already been prototyped:
  - Laser driver
  - Encoder/decoder: Line code and FEC
  - Limiting amplifier
- The Versatile Bi-Directional Link project has been proposed by the Microelectronics group as a CERN common development.