



Department of Physics and Technology

Master Thesis

**Interface Design for the
Gigabit Transceiver Common Readout Unit**

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Overview

Introduction

- LHC Upgrade

- Gigabit Transceiver System

- Primary Objectives

PCB Design

- Design Discussion

- Transmission Lines

- Design Parameters

GBT Control Software

- Hardware

- Software

Testing and Verification

- External Loop-back Test

- Testing Software and

- Hardware

Conclusion



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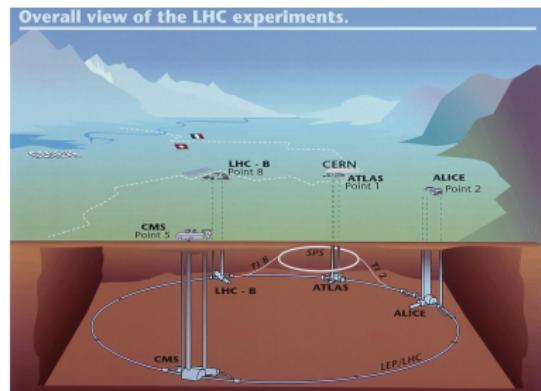
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LHC Upgrade

- Large Hadron Collider (LHC)
 - Particle accelerator
 - 27 km circular tunnel
 - 13 TeV
- High-Luminosity LHC
 - 10x beam luminosity
 - Increase in radiation and amount of data
 - → Gigabit Transceiver



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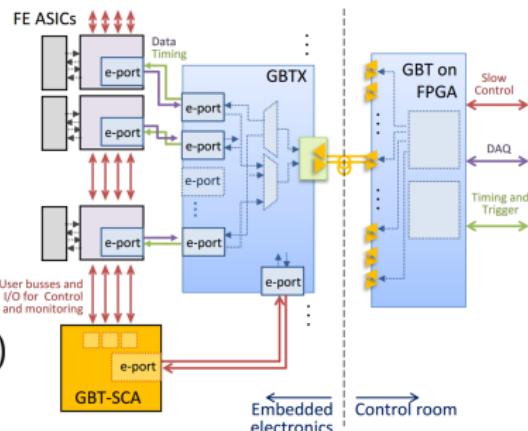
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Gigabit Transceiver System

- On-detector - Custom ASICs
 - GBTx, GBT-SCA, VTTx/VTRx
 - E-links
- Off-detector - Control room
 - CRU (FPGA)
 - > 4.8 Gbit/s transceivers
 - GBT-FPGA
- Optical communication
 - Timing and Trigger Control (TTC)
 - Data Acquisition (DAQ)
 - Slow Control (SC)



GBT - Gigabit Transceiver, CRU - Common Readout Unit

SCA - Slow Control Adapter, FPGA - Field-Programmable Gate Array



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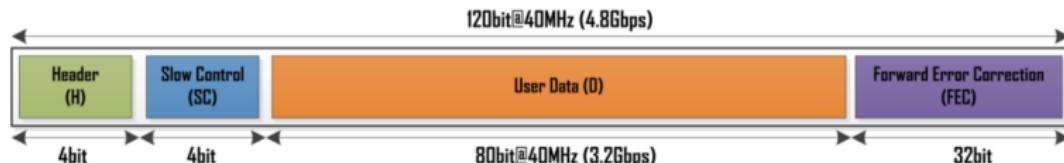
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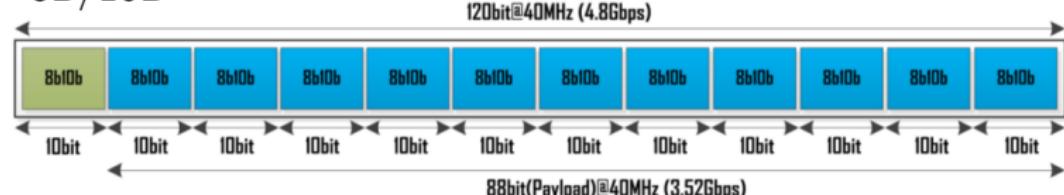
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GBTx encoding modes

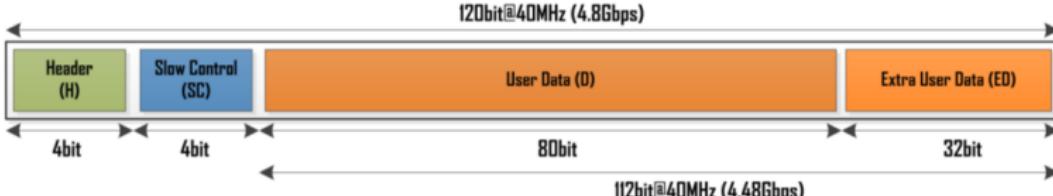
- GBT-Frame - Standard



- 8B/10B



- Wide-Bus



(figures taken from the GBT-FPGA User Manual)



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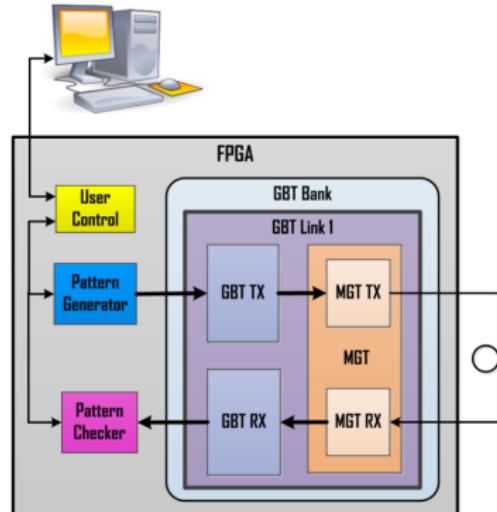
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GBT-FPGA

- Firmware library for Altera/Xilinx FPGAs
- GBT Link
 - "Standard", "Latency-Optimized"
 - GBT Rx, GBT Tx, GBT MGT
- GBT-example Design



MGT - Multi-Gigabit Transceiver



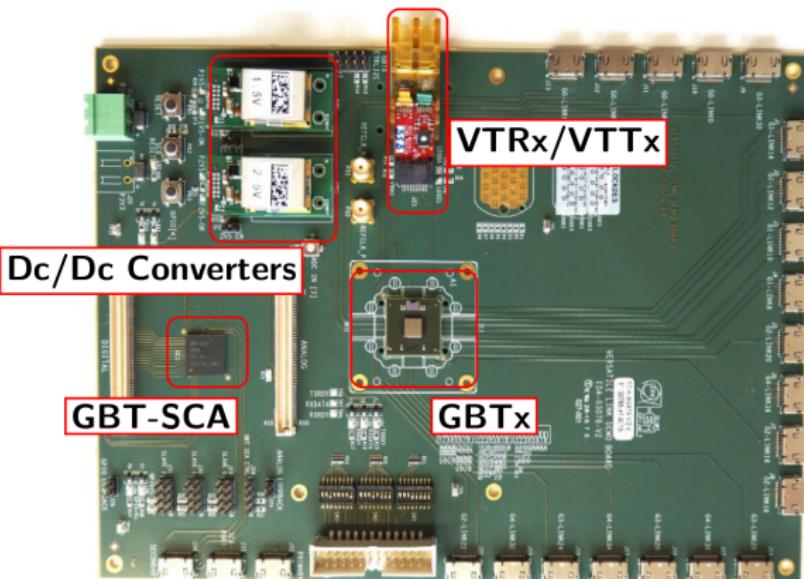
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Versatile Link Demo Board (VLDB)



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Primary Objective

- Software Design
 - Serial communication between PC and CRU
 - Interface allowing control over CRU
- PCB Design
 - Connection between CRU and VLDB
 - HDMI for e-link communication
 - High-speed Optical-Fiber module for GBT-frame



CRU - Common Readout Unit

VLDB - Versatile Link Demo Board

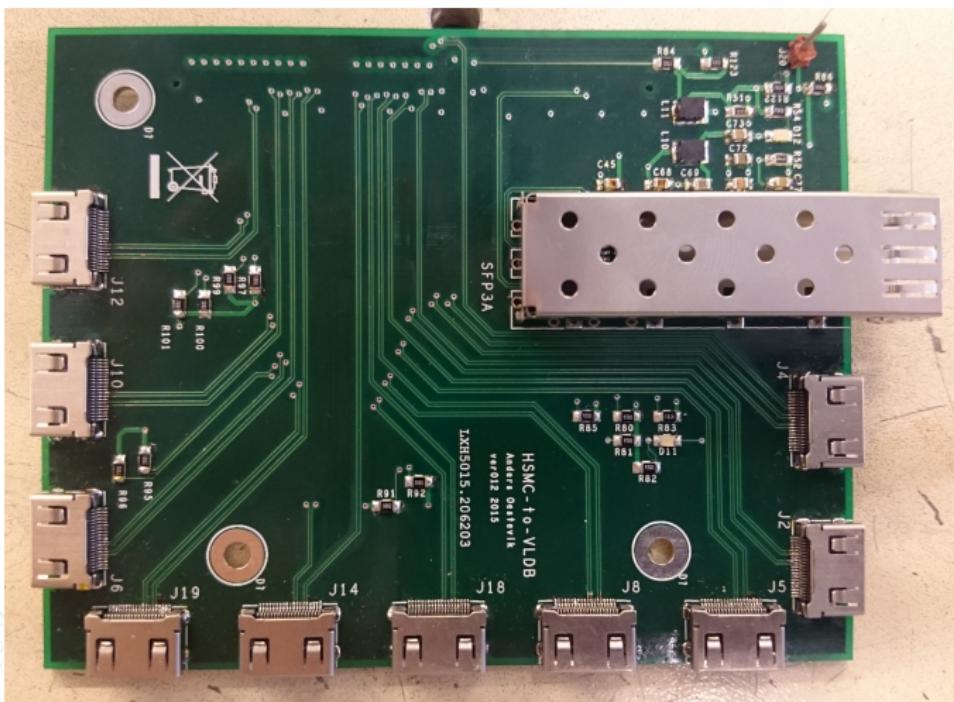
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PCB Design



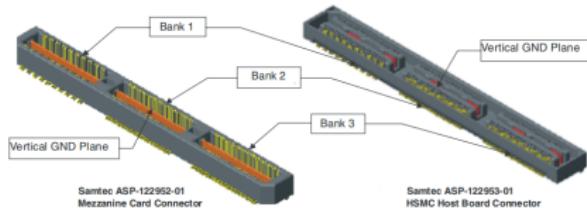
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PCB Design



Specifications:

- Connect board between CRU and VLDB using HSMC-connector
- E-links → 320 Mbit/s detector data → LVDS
- Optical-Fiber → 4.8 Gbit/s GBT data → PCML



HSMC - High-Speed Mezzanine Card

LVDS - Low-Voltage Differential Signaling

PCML - Pseudo Current Mode Logic

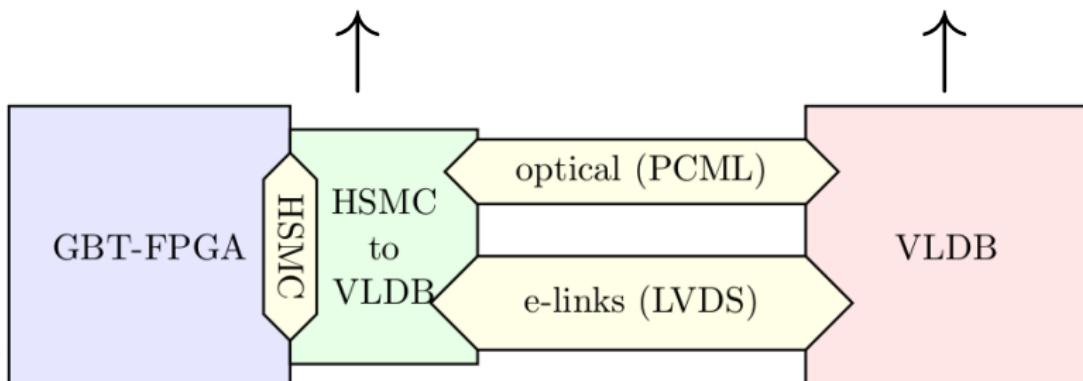
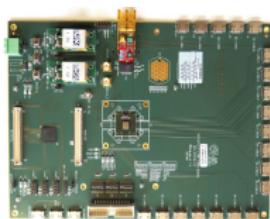
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PCB Design



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PCB Design

- Each HDMI has an input pair and an output pair
- J4 has an additional pair for input clock from VLDB

SFP HSMC board



(<http://www.terasic.com.tw/>

attachment/archive/342/image/SFP_003_800.jpg)

SFP - Small Form-Factor Pluggable
HSMC - High-Speed Mezzanine Card



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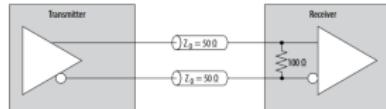
Transmission Lines

$$v = \frac{c}{\sqrt{\epsilon_r}}, \quad \epsilon_r \approx 4$$

- $v = 15 \text{ cm/ns}$
- 4.8 Gbit/s (0.2 ns) → transmission line if trace < 3.1 cm
- Characteristic impedance, $Z_0 = 50$
- Differential impedance, $Z_{diff} = 100$

Figure 5-17: Differential Input OCT

The Cyclone V devices support OCT for differential LVDS and SLVS input buffers with a nominal resistance value of 100 Ω , as shown in this figure.



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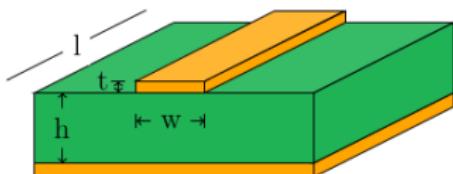
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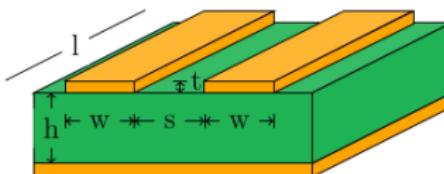
Transmission Lines

$$Z_0 = \frac{60}{\sqrt{0.475\epsilon_r + 0.67}} \times \ln \frac{4h}{0.67(0.8w + t)}$$

$$Z_{diff} = 2 \times Z_0 [1 - 0.48e^{(-0.96 \times \frac{s}{h})}]$$



(a) Single-ended.



(b) Differential.



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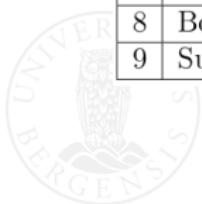
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Design Parameters

- Routing differential signals:
 - Equal trace lengths on each pair
 - As close as possible, but keep distance to other pairs
 - As straight paths as possible

	Layer	Type	t [μm]	ϵ_r	w [μm]	$Z_0[\Omega]$	Spacing [μm]	$Z_{diff}[\Omega]$
1	Surface	Air		1				
2	Top	Conductor	18		100	51.3	300	102
3		Dielectric	65	4.05				
4	Voltage	Plane	35					
5		Dielectric	1400	4.05				
6	Gnd	Plane	35					
7		Dielectric	65	4.05				
8	Bottom	Conductor	18		100	51.3	300	102
9	Surface	Air		1				



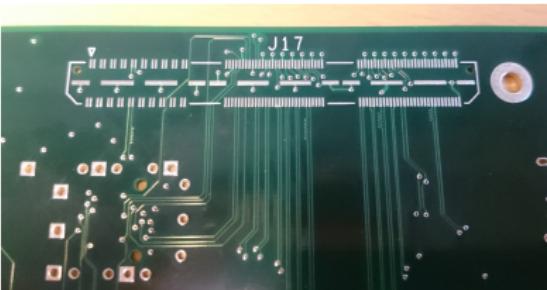
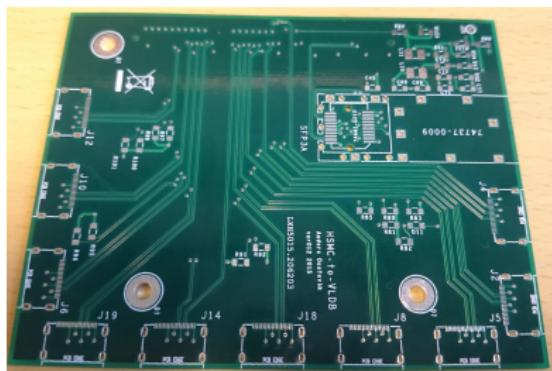
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Result



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Result



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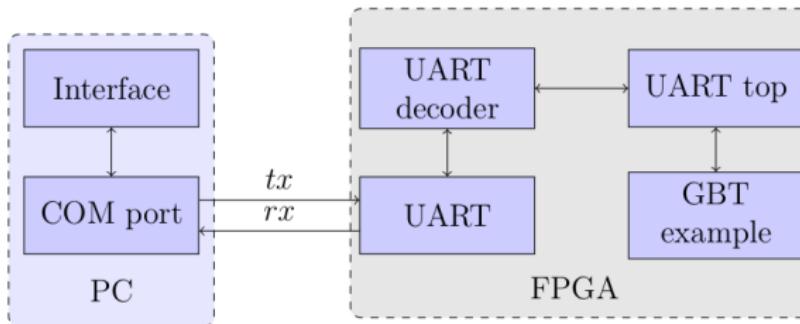
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GBT Control Software

Specifications:

- Provide communication between PC and FPGA
- Read and write GBT control signal information
- Provide a simple User Interface



	Switches	Probes
GBT register	0x00...0x23	0x24...0x41



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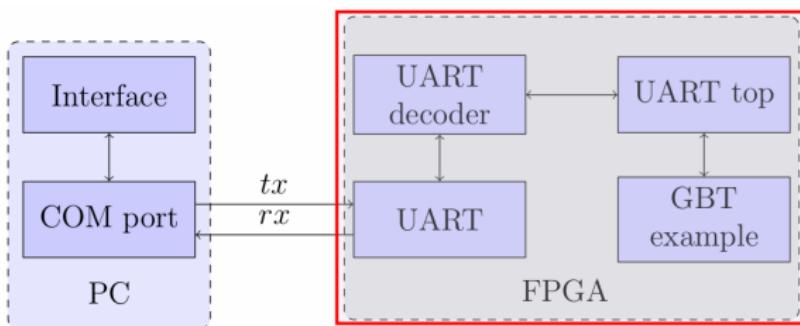
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Hardware

- Treat incoming requests sent from PC
- Components:
 - UART (RX, TX, Buffers, baudrate generator)
 - Decoder
- Goal: implement into GBT Example Design



	Switches	Probes
GBT register	0x00...0x23	0x24...0x41



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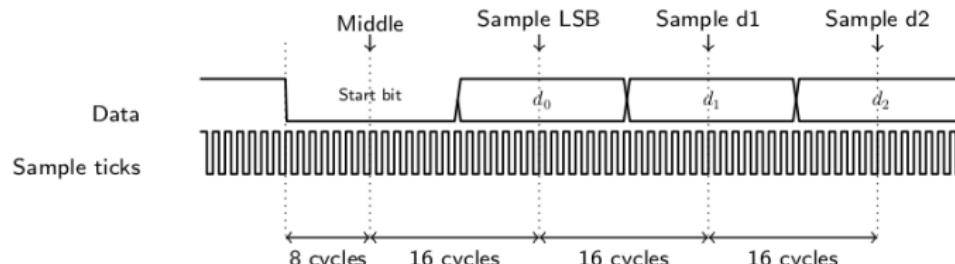
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UART

- Synchronisation → Oversampling
- $16 \times \text{baudrate}$ - fixed
- Stores bytes in FIFO-buffers
- $19200 - 8 - N - 1 \rightarrow 307200$ sample clock



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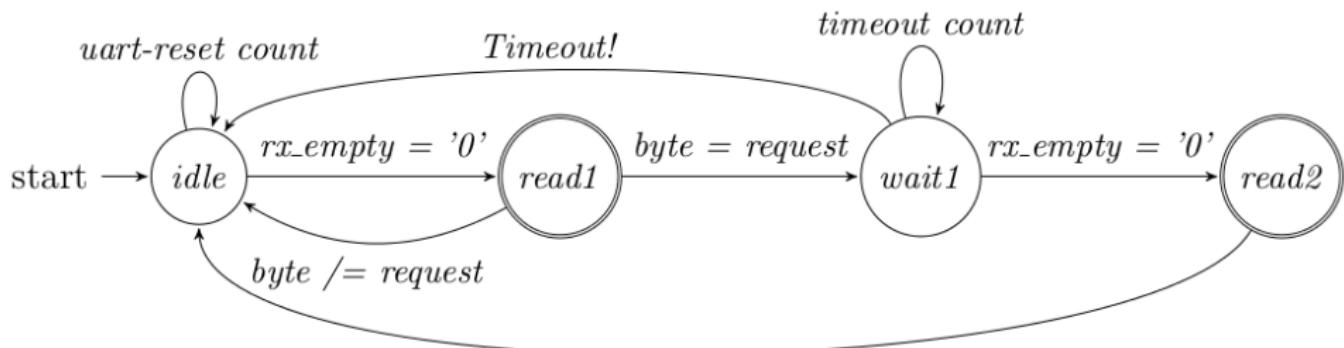
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Decoder

- Requests:
 - read → 0xDD
 - write 0 → 0xEE
 - write 1 → 0xFF
- Legal addresses:
 - 0x00 → 0x41
- Bytes sent to PC:
 - 0x00 → 0xC1



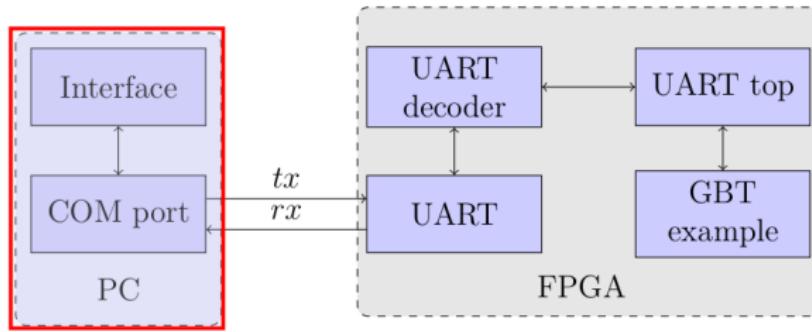
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Software



	Switches	Probes
GBT register	0x00...0x23	0x24...0x41



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Software

Modules:

- Send/Receive
 - RS-232 library
 - Continuously transmits pattern to GBT-registers
 - Reads it back for transmit confirmation
- User Interface
 - ncurses library
 - User commands: write, read, status, open, close, exit
 - Dummy registers instead of real GBT-registers
- GBT register data → stored and maintained using a custom *Signals*-library



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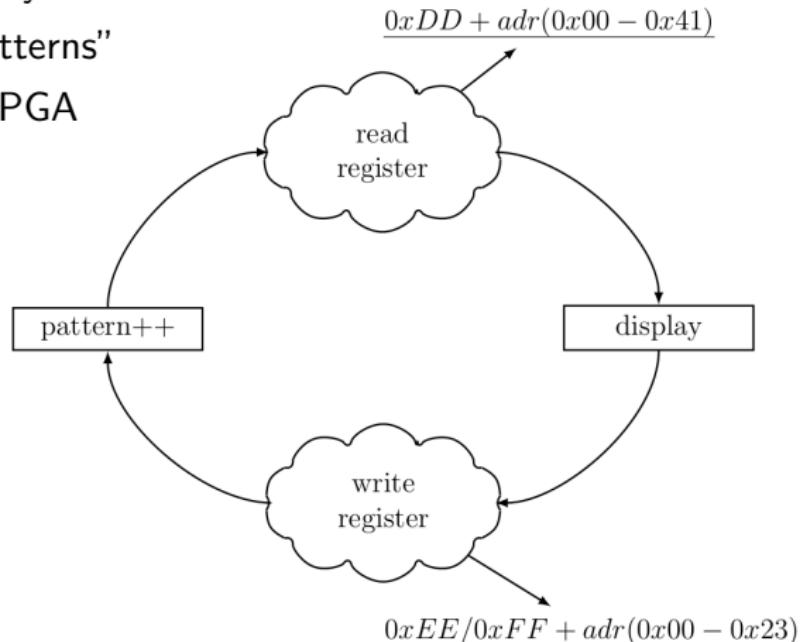
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Send/Receive Module

- Read: transmit 2 bytes, receive 1 byte
- Write: transmit 2 bytes
- 2D-array with "patterns"
- COM-port \leftrightarrow FPGA



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User Interface

Command History:-

```
:status
usage: status [settings/comport]
:s
status  [settings/comport]
exit   [status (1 or 0)]
:a
read   [[name0] [name1] ...]
write  [data [name1] [name2] ...]
status  [settings/comport]
exit   [status (1 or 0)]
:r
read   [[name0] [name1] ...]
write  [data [name1] [name2] ...]
status  [settings/comport]
open   [comport]
close  [comport]
exit   [status (1 or 0)]
:e
read   [[name0] [name1] ...]
write  [data [name1] [name2] ...]
status  [settings/comport]
open   [comport]
close  [comport]
exit   [status (1 or 0)]
:status settings
Current settings:
Baud Rate -> 57600
COMport nr.-> 4 (see rs232.c)
COMport node -> 8N1

:status comport
COMport status -> closed
```

Signals:-

Index:	Name:	Data:
S00	LOOPBACK ('0' -> NORMAL '1' -> LOOPBACK)	0
S01	GENERAL RESET	0
S02	MGT TX PLL RESET	0
S03	TX RESET	0
S04	RX RESET	0
S05	PATTERN SELECT ('1' -> COUNTER '2' -> STATIC)	1
S06	PATTERN SELECT ('1' -> COUNTER '2' -> STATIC)	0
S07	TX HEADER SELECTOR ('0' -> IDLE '1' -> DATA)	1
S08	RESET DATA EXTRA DATA ERROR SEEN FLAGS	0
S09	RESET RX GBT READY LOST FLAG	0
S10	TX_FRAMECLK PHASE ALIGNER - MANUAL RESET	0
S11	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S12	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S13	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S14	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S15	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S16	TX_FRAMECLK PHASE ALIGNER - GBT LINK 1 STEPS	0
S17	TX_FRAMECLK PHASE ALIGNER - ENABLE	0
S18	TX_FRAMECLK PHASE ALIGNER - TRIGGER	0
S19	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S20	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S21	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S22	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S23	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S24	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S25	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S26	TX_WORLDCLOCK MONITORING - THRESHOLD UP	0
S27	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S28	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S29	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S30	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S31	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S32	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S33	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S34	TX_WORLDCLOCK MONITORING - THRESHOLD LOW	0
S35	TX_WORLDCLOCK MONITORING - TX RESET ENABLE	0

Commandline:-

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- Ex.: "write 1 s01 s02 s03"

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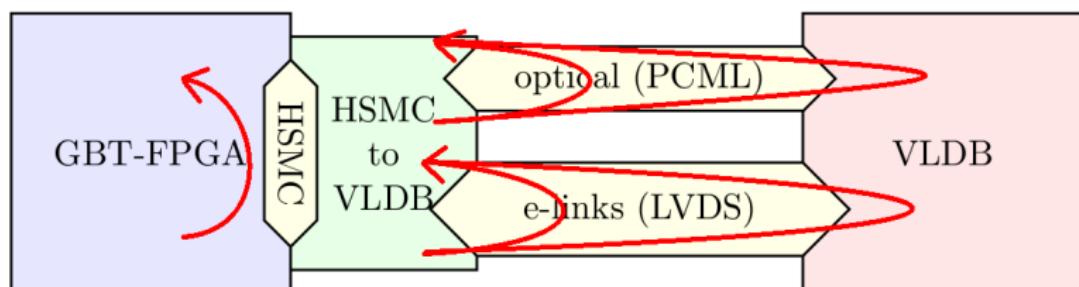
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Testing and Verification

- Internal loopback test using GBT-example
- External Loopback Tests: HDMI and Optical-Fiber
- Testing Software and Hardware



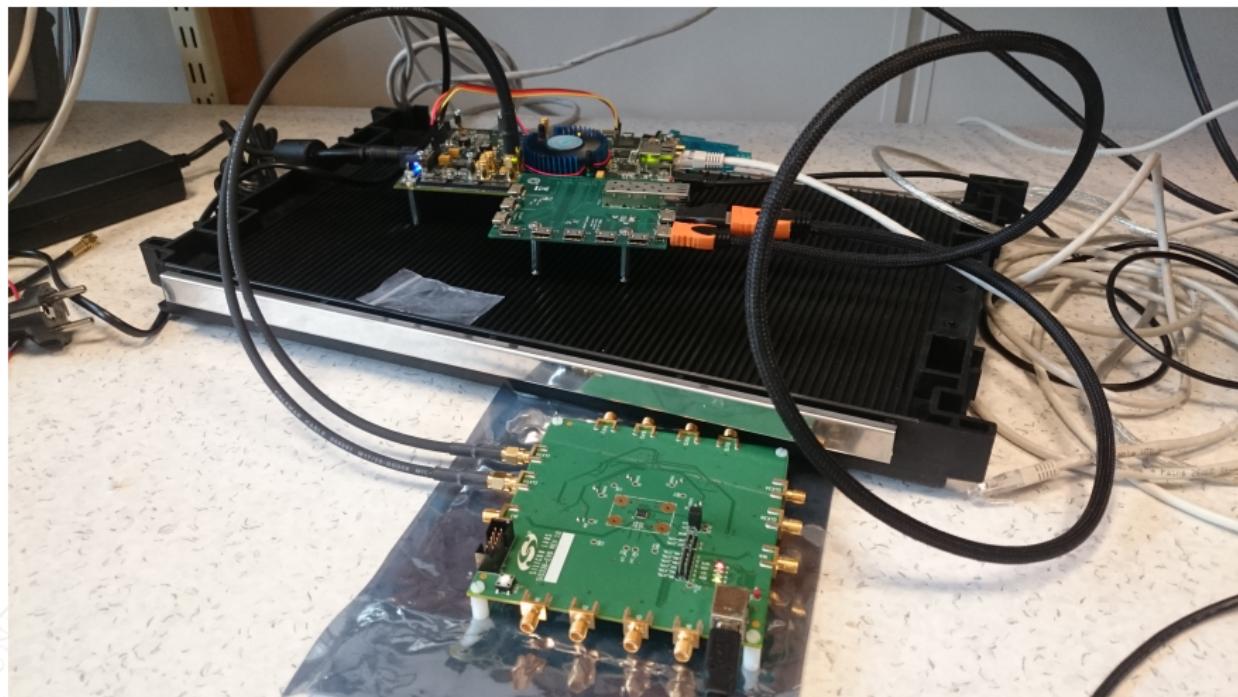
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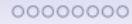
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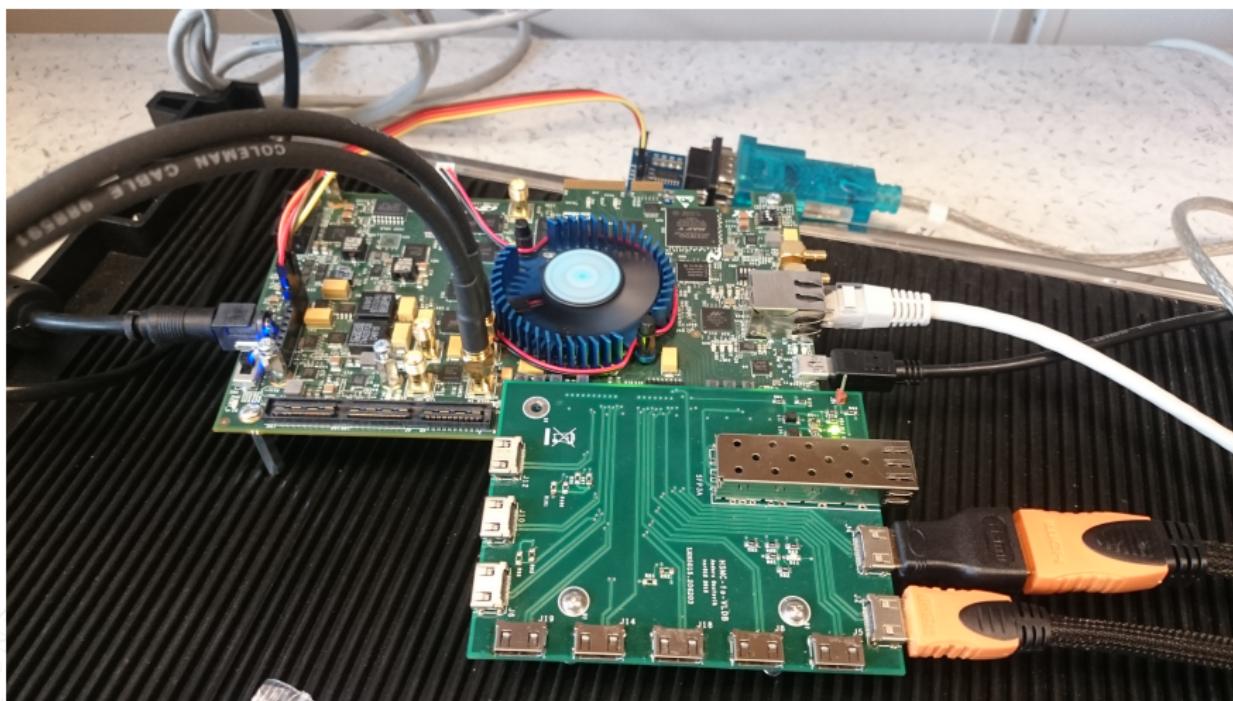
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Test Setup





Test Setup



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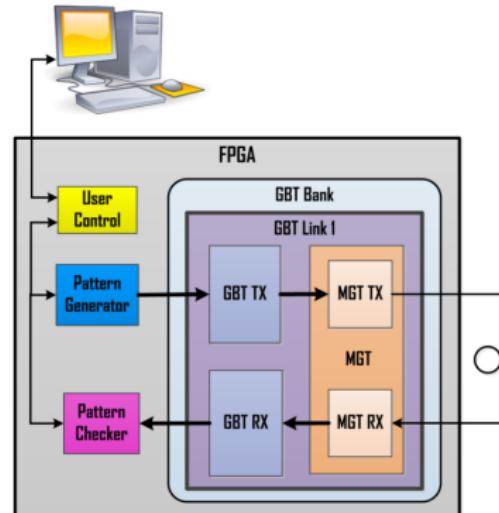
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External Loop-back Test

Optical Fiber Connector (PCML):

- GBT example Design
- 4.8 Gbit/s *counter*
- Internal-, then external loopback
- SignalTap II → sample TX and RX



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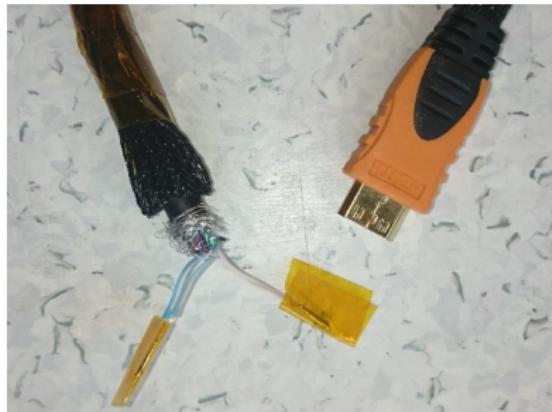
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External Loop-back Test

HDMI connectors (LVDS):

- Purpose: Transmission of 320 Mbit/s E-link detector data
- Test: Loop-back a 300 MHz Pseudo-random counter
- Measure:
 - bit-error count
 - eye-diagram
 - crosstalk
 - reflections



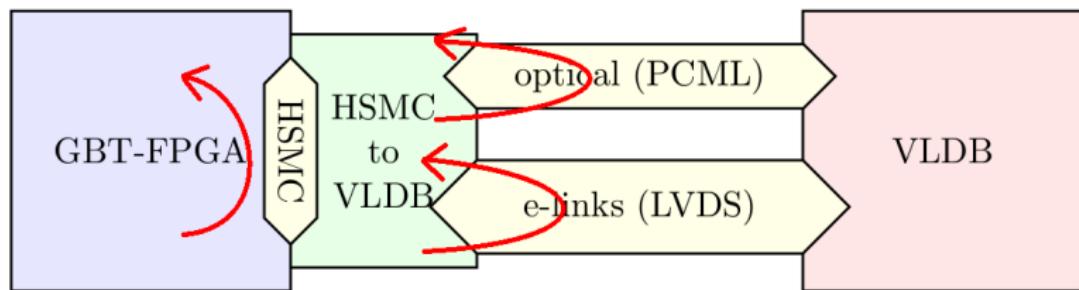
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Testing and Verification



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Testing Software and Hardware

- Verified hardware with a testbench → Bitvis Utility Library
- Verified that the software and hardware were communicating



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Conclusion

- PCB:
 - Optical Fiber module **works** → 4.8 Gbit/s external loopback
 - HDMI LVDS connectors **needs more testing** → eye-diagram, crosstalk, reflections, bit-error count.
- Hardware:
 - UART + Decoder **works**
 - Implementation into the GBT Example Design remains
- Software:
 - Send/Receive and User Interface modules **works**
 - Both needs to be merged
- Final test of the whole system:
 - GBT example + Hardware + Software + PCB-loopback
 - Test system together with VLDB



Introduction

PCB Design

GBT Control Software

Testing and Verification

Conclusion

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Thank you!

