Ethernet PHY Transceiver Characterization
ESA AO/1-8074/14/NL/LF

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Overview

- International context and ESA/Airbus DS vision
- Project layout
- Developments: electronics (PCB motherboards) and software (data acquisition)
- Environmental and radiation test results
- Conclusion and Outlook

International Context as Motivation

•Time Triggered Ethernet (TTECH) technology gained worldwide momentum in the automotive and (aero)space industry.

•NASA and Honeywell promote TTECH as baseline for the on board data bus system. Honeywell technology is rad-hard and ITAR protected.

•Large scale space projects deploying TTECH:
-NASA/ESA Orion lunar mission to the Moon
-ESA next generation launcher Ariane 6

•Strategically important to safeguard and adapt commercial ITAR free technology with respect to one of the building blocks of TTECH which is PHY transceiver.

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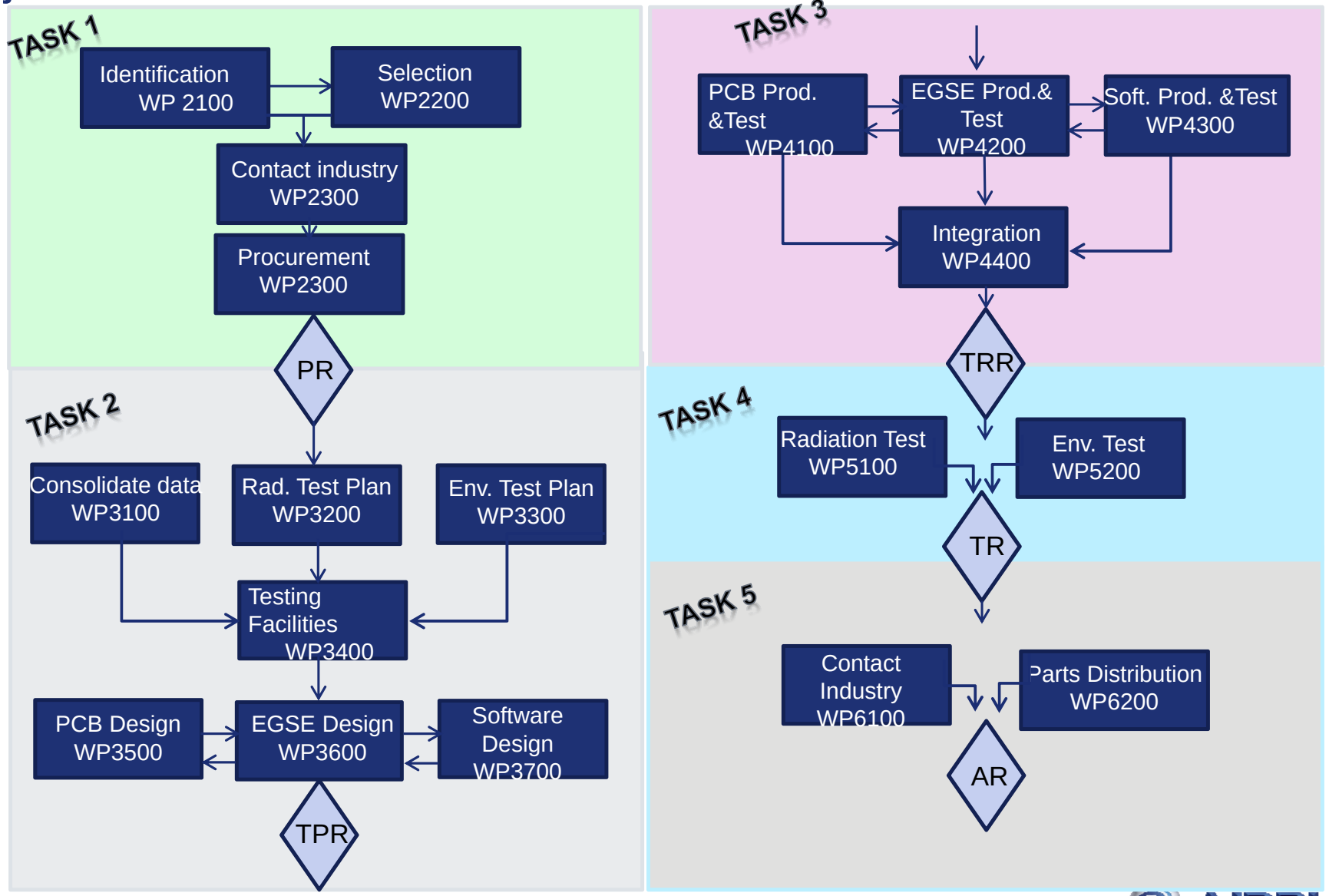
Objectives

- Investigate the possibility to use commercial off the shelf Ethernet transceivers components for space use to circumvent the costly radiation-hardened development
- Perform a trade off and choose three-best transceiver manufacturers in a defined metric
- Run a full space qualification campaign on the parts
- Identify the parts/manufacturers with good/acceptable performance

Project Work Flow



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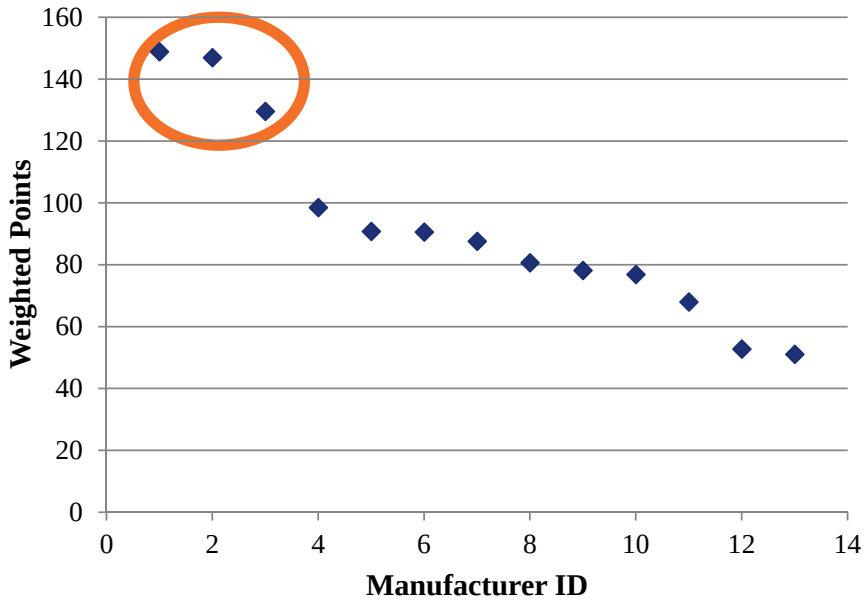
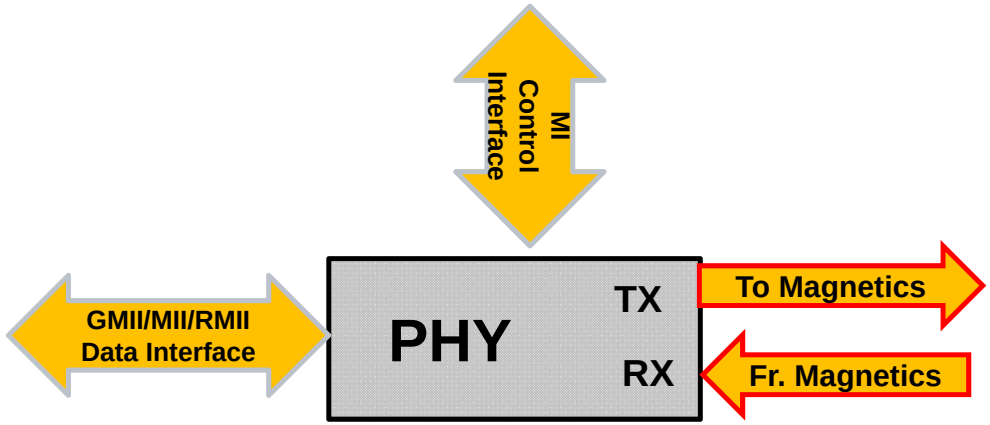
Ethernet PHY Transceivers Trade-off

- Many selection criteria were taken into account and weighted according to their importance (e.g 1 for a SOW requirement and 0.2 for softer design considerations)
- Functional: IEEE802.3 compliant, Interfaces(GMII, RGMII), Interrupt generation capabilities, autonegotiation
- Electrical: Copper based medium (10/100/1000MB/s), power consumption and management, auto pair correction
- Mechanical (package soldering, temperature range)

Manufacturer Part	Weighted Points	No.
Vitesse/VSC8501	148,9	1
Marvell/88E1111	147	2
Lantiq/PEF7071	129,6	3
Avago/ET1011C	98,5	4
Micrel/KSZ9031MNX	90,8	5
Texas/DP83867	90,6	6
Micrel/KSZ9031RNX	87,6	7
Microchip/LAN8810	80,7	8
Texas/DP83865	78,2	9
Microchip/LAN8820	76,9	10
Broadcom/BCM5461	68	11
Realtek/RTL8211BG	52,8	12
Realtek/RTL8211DN	51,1	13



Ethernet PHY Interfaces

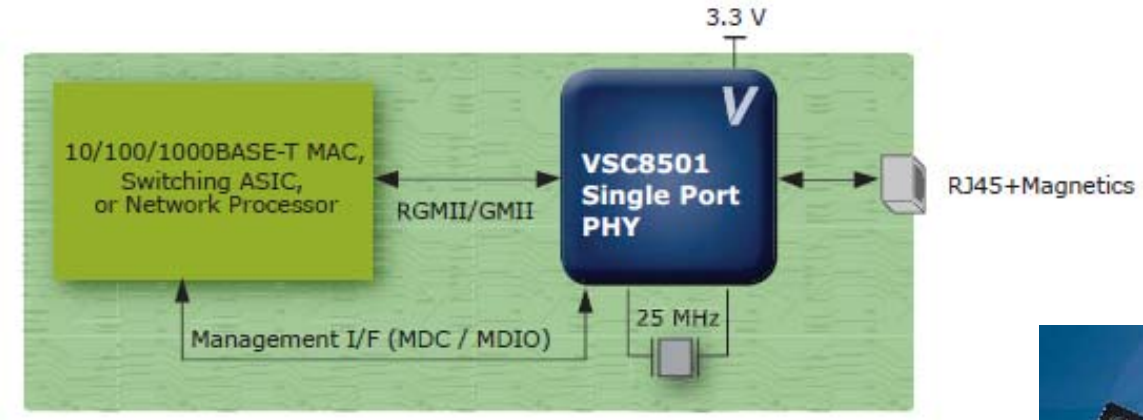


Data Interface (xMII)

- High speed parallel interface
- Used to send/receive data

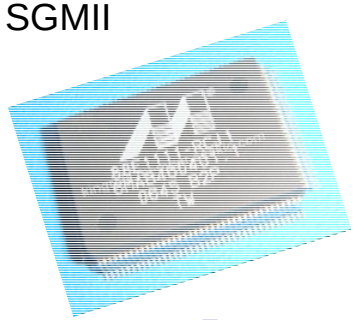
Management Interface (MI)

- Serial slow interface
- Used to program/monitor the PHY
- Basic MI registers are defined in the standard



Choosen Transceivers

- Vitesse: RGMII, GMII
- Marvell: RGMII, GMII, SGMII
- Lantiq: (R)GMII, RMII, SGMII



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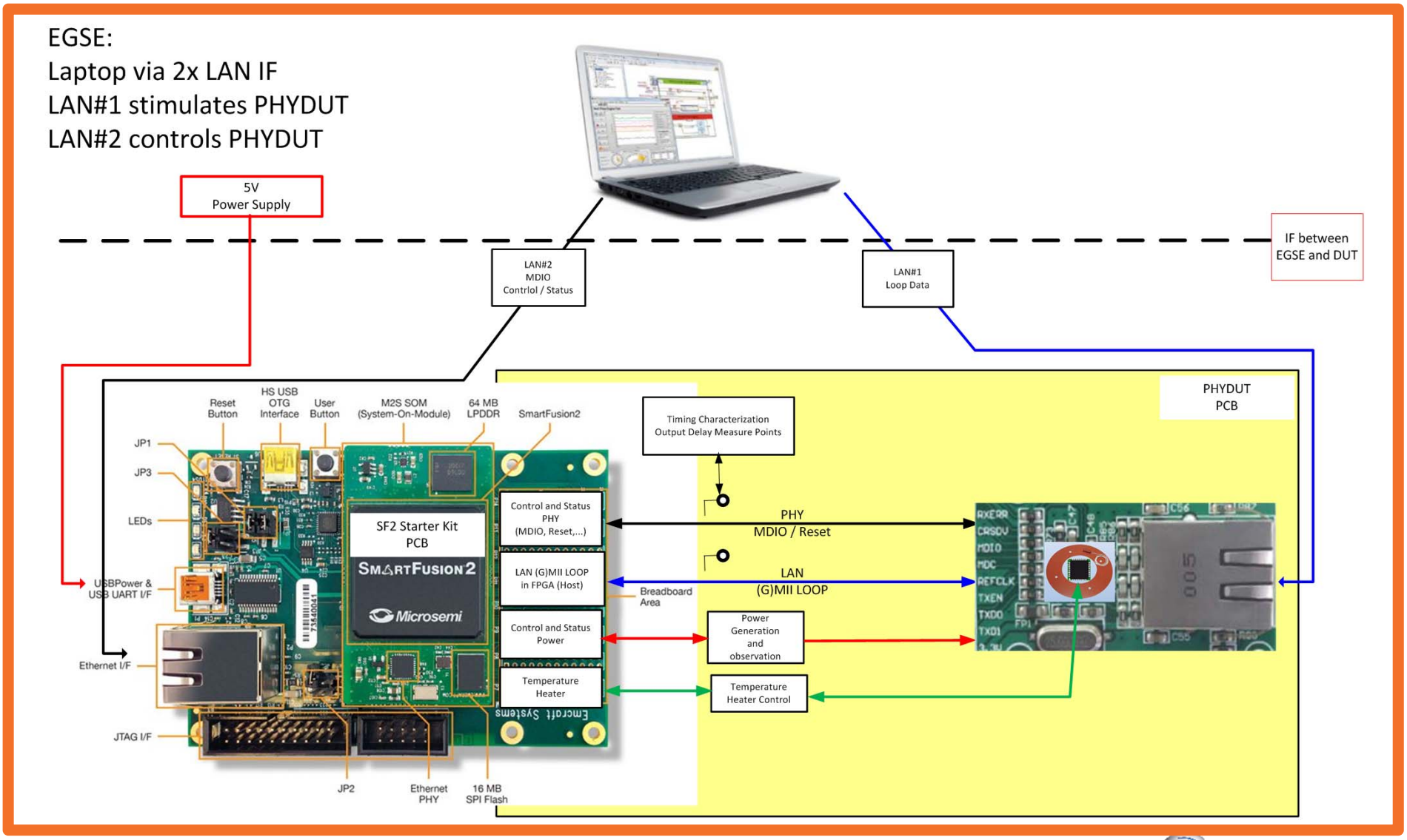
PHY testing concept



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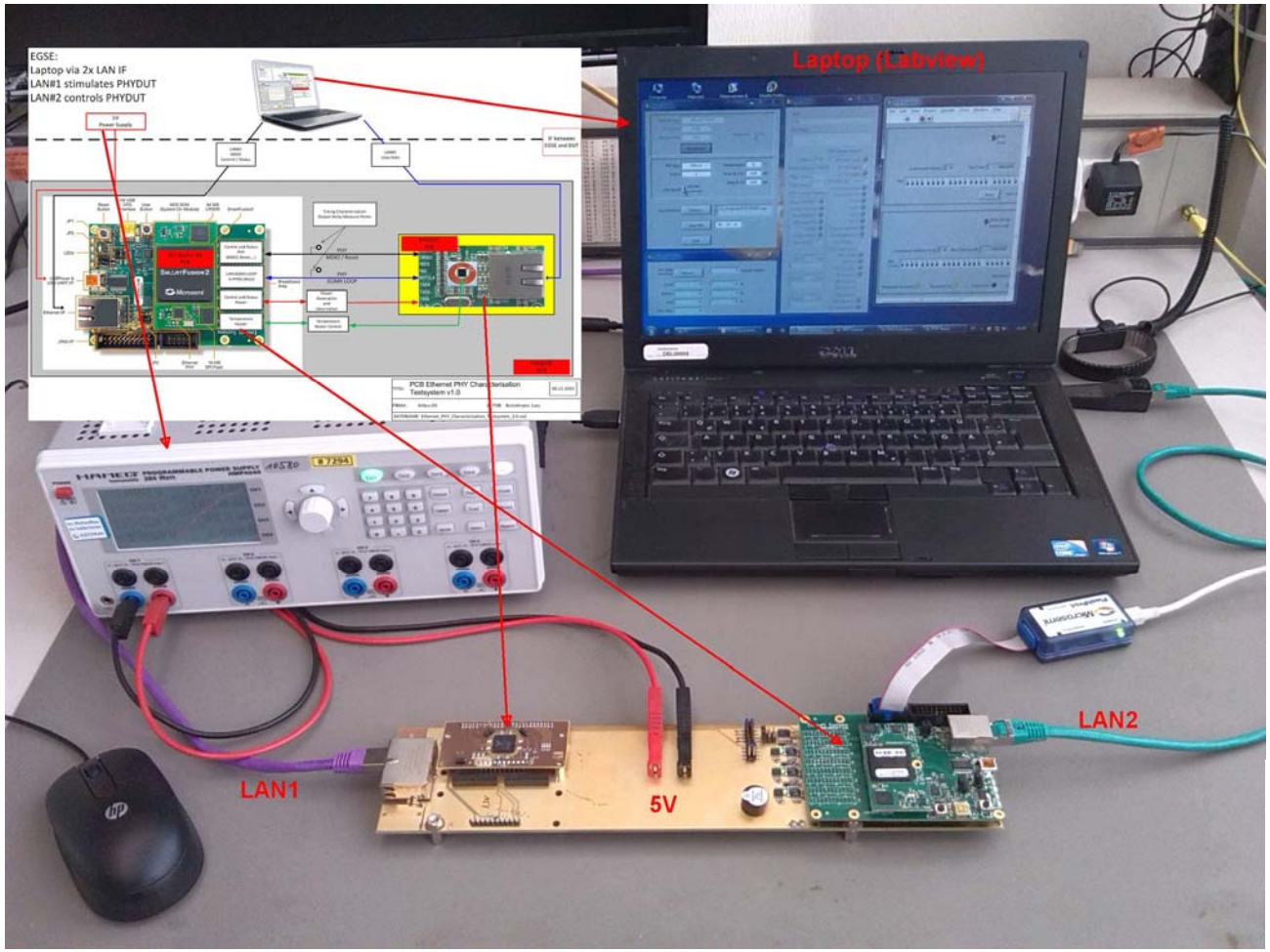
PHY testing realisation



PHY DUT Control/Configuration

- Control and status registers for the EGSE implemented in the SF2 FPGA
- EGSE software can execute read/write accesses to internal PHY registers
- FPGA provides a register to reset PHY (after power on/after error)

PHY DUT (G)MII Loop

- No need for an Ethernet MAC controller
- Replaced by a simple loop inside FPGA

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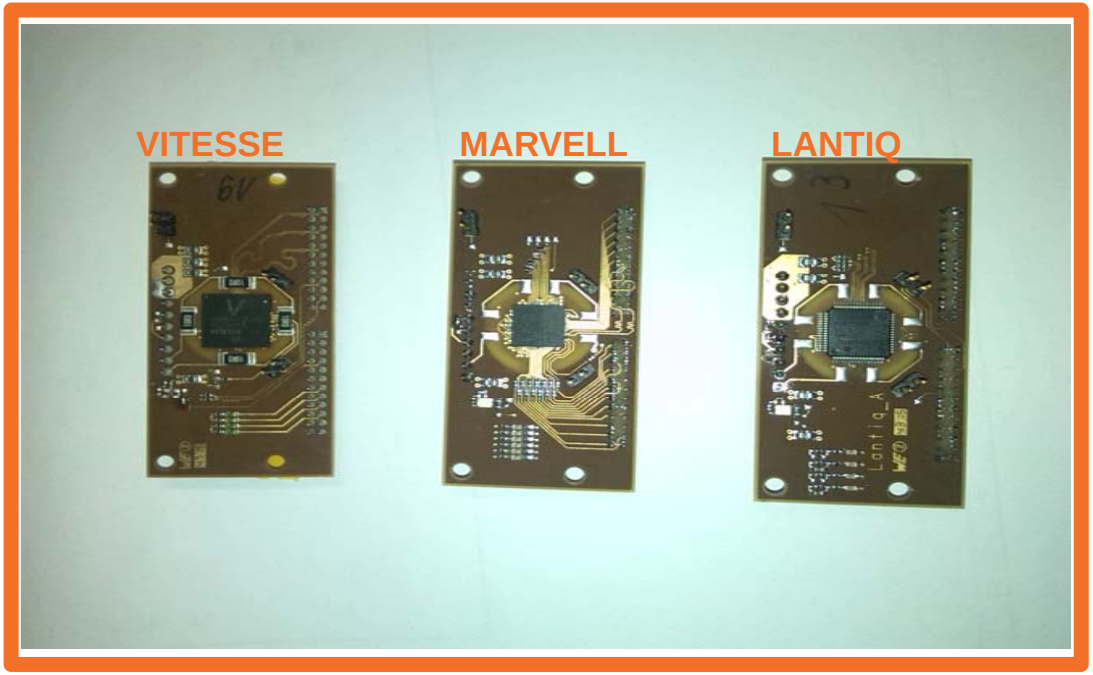
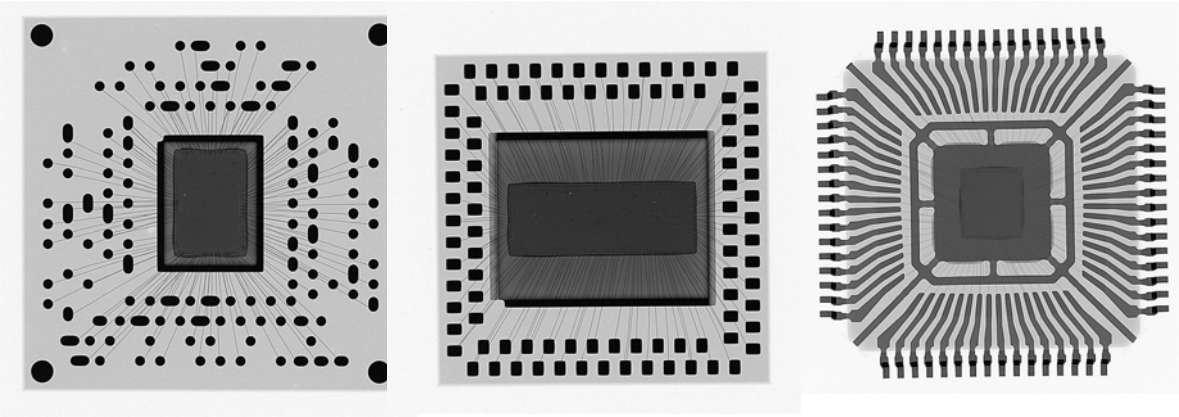
PCB Motherboards: PHY DUT



Packaging and Integration

- Transceivers have different packages, baseline is Quad Flat No-leads (QFN).
  135 QFN, 96a QFN double row, 48QFN
- QFN multi row is difficult to solder, but Airbus took the challenge.
- A total of approx. 120 PHY DUT boards were manufactured, in two iterations.



PCB Motherboards: PHY DUT Highlight

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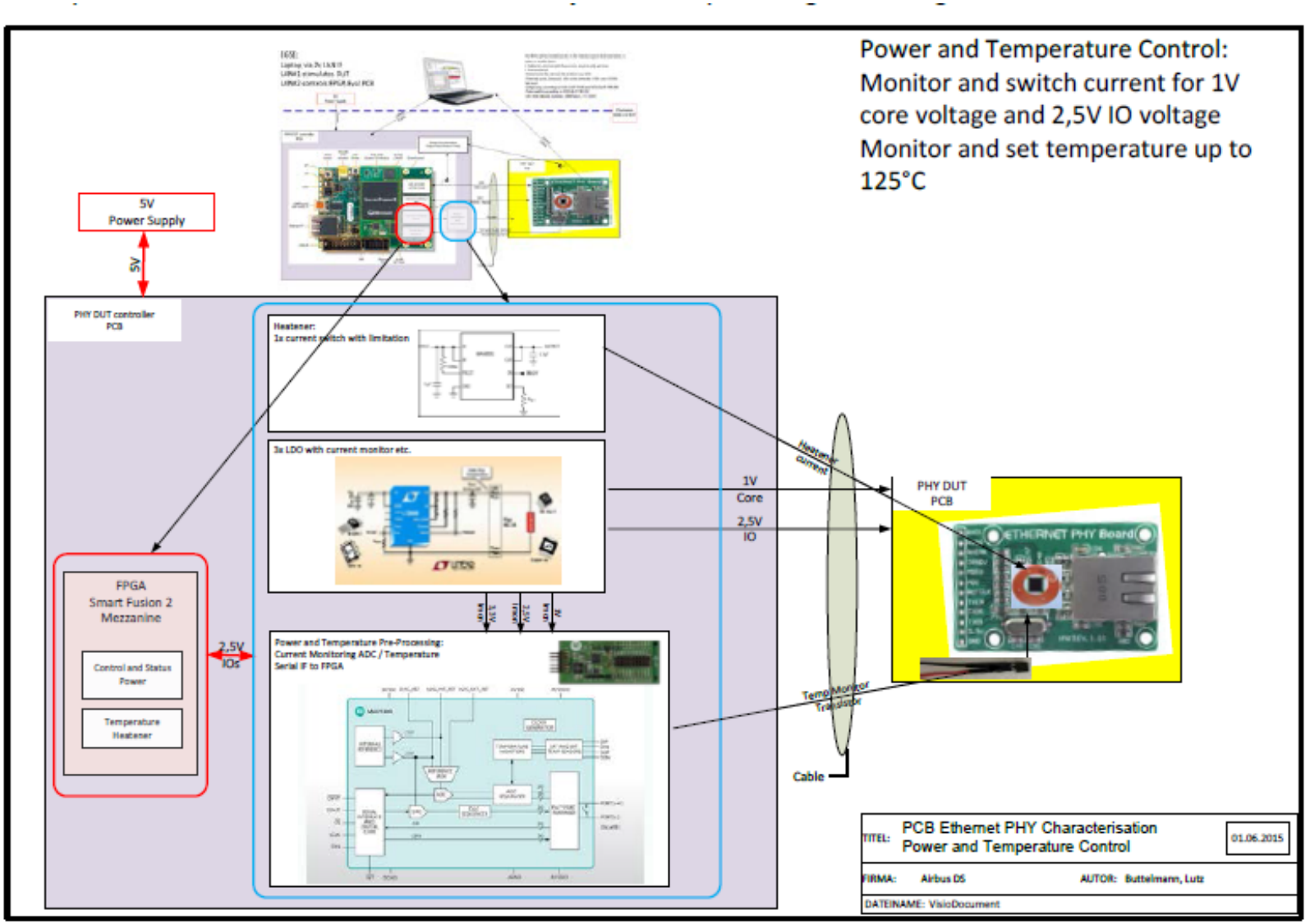

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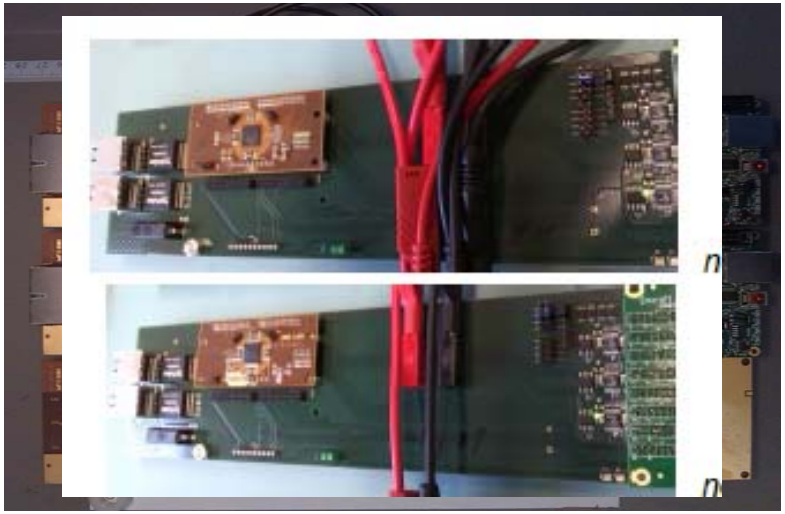
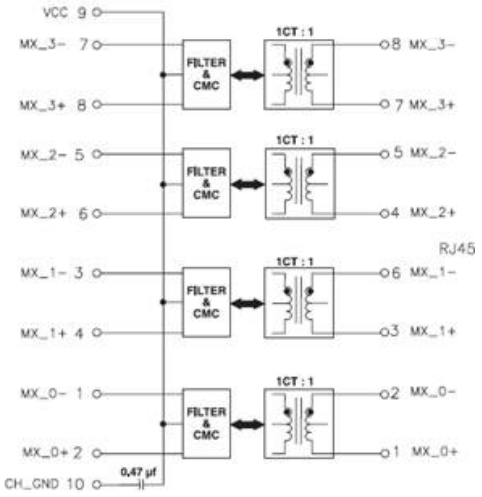
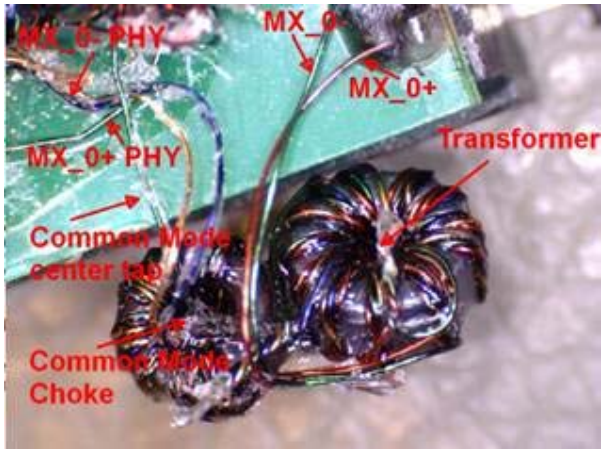
Motherboards: PHY Base

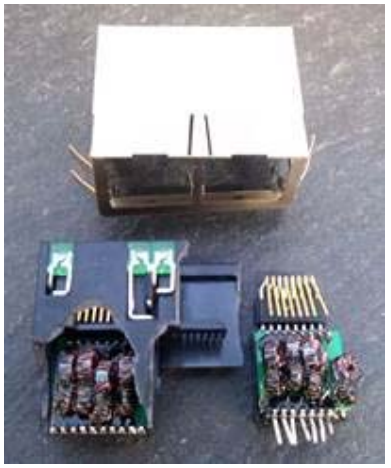


Magnetics and redesign

- For the first boards, the Vitesse transceivers did not send/receive packets at 1Gb/s while Lantiq did not send/receive any packets.
- Very fine design details matter! LAN socket deployed an integrated 8 core module, Vitesse recommends no integrated module, but instead a discrete socket with 12 core magnetics plus other small differences to the design.







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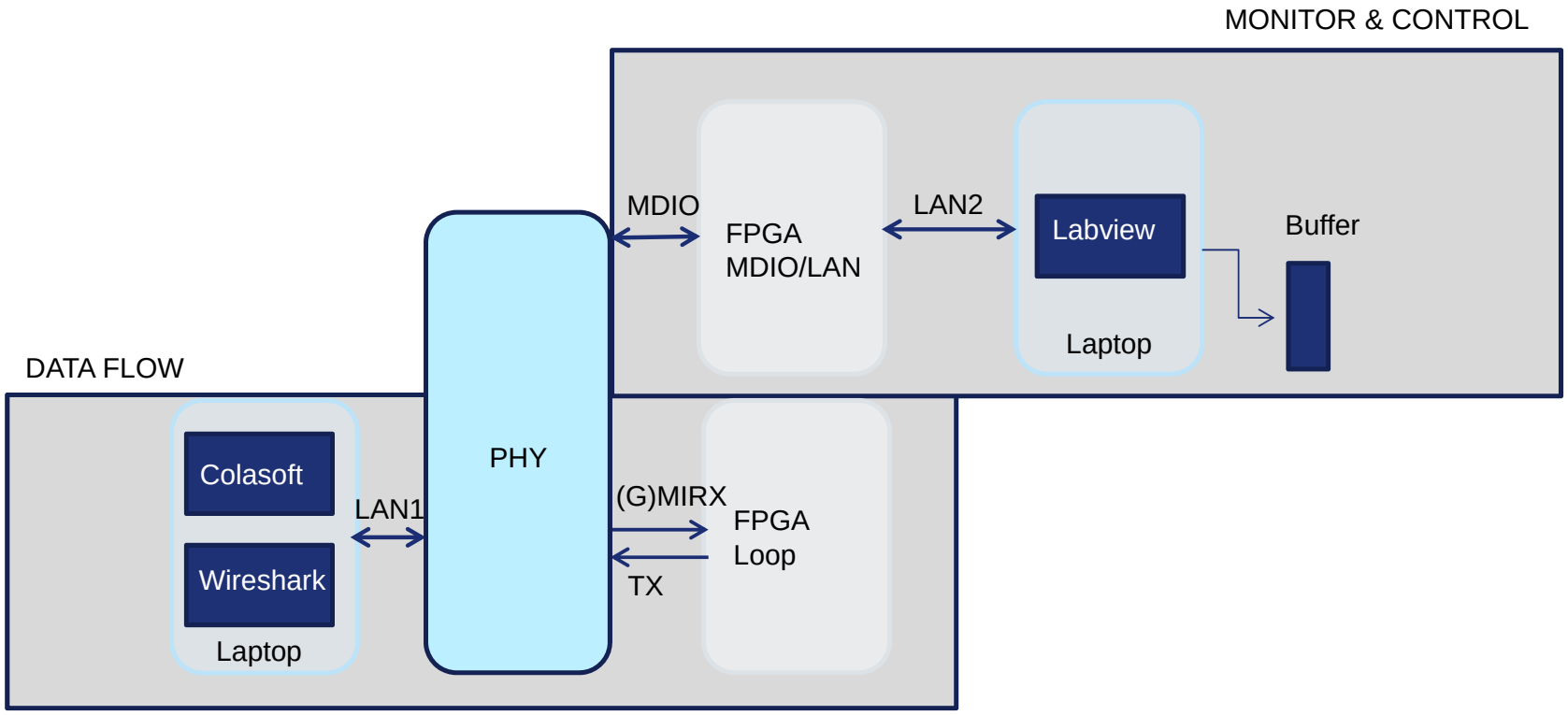
Data acquisition

Software architecture needed more layers in order to perform the communication with PHY DUTs:

- Colasoft Network package builder sends custom network packets to PHYs.
- Wireshark reads/analyzes pcap logfiles containing network packets sent/reflected by PHY.
- PHY is configured via the MDIO interface and controll over all registers .



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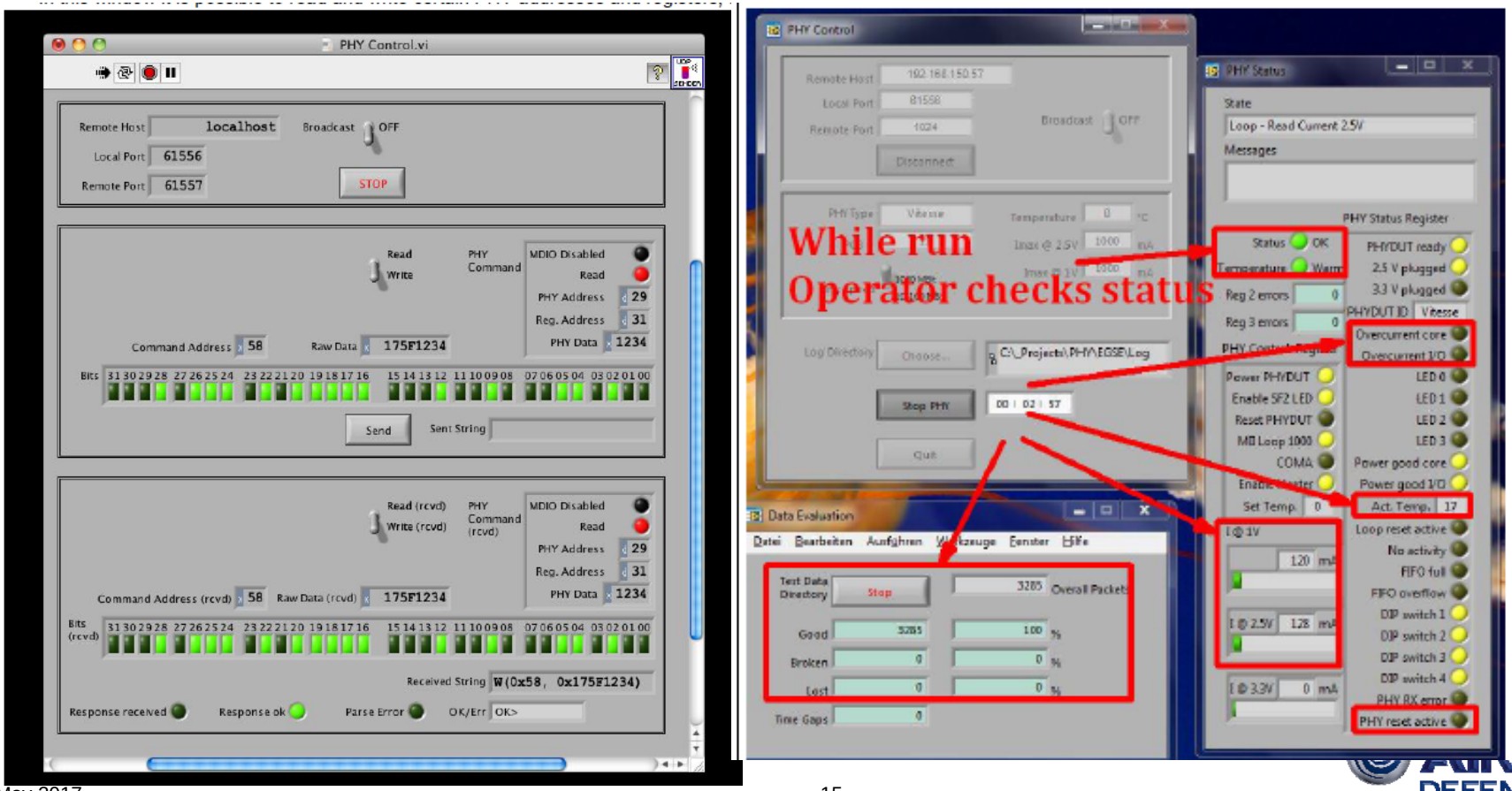
Data acquisition

Software architecture

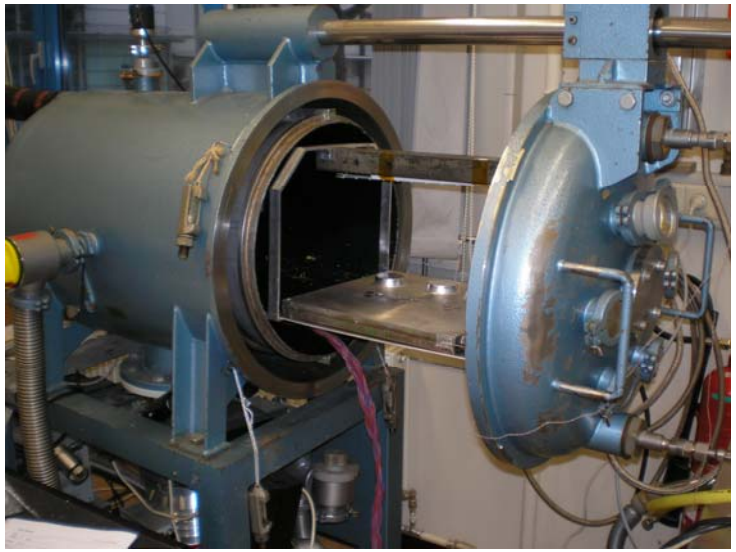
- Wireshark stores the captured packets locally on the laptop.
- Files are processed offline by the Labview Data Evaluation Application

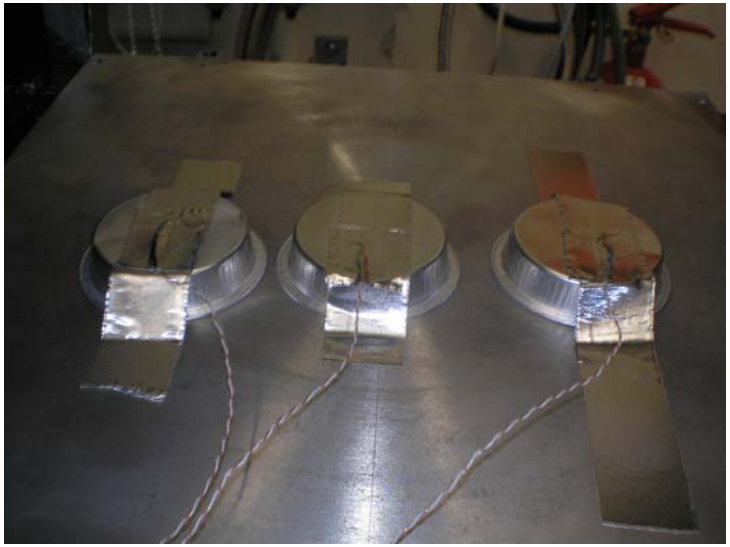


Environmental Tests

- Vacuum testing
- Thermal testing
- Outgassing test in accordance with ECSS-Q-70-02C
- Offgassing test in accordance with ECSS-Q-70-29C
- ESD Testing
- Life testing
- Radiation (Total Ionising Dose, Heavy Ions, Protons)

Vacuum Testing





Thermocouples: Type T IEC 584-3
Specified for: -40°C < T < 125°C
Tolerance: +/- 0,004*T
Test T = 55°C +/- 0,22 °C
P = 1E-5 mbar

Thermocouples (TC) were attached to the upper part of the small plates
Each group has got 1 TC.

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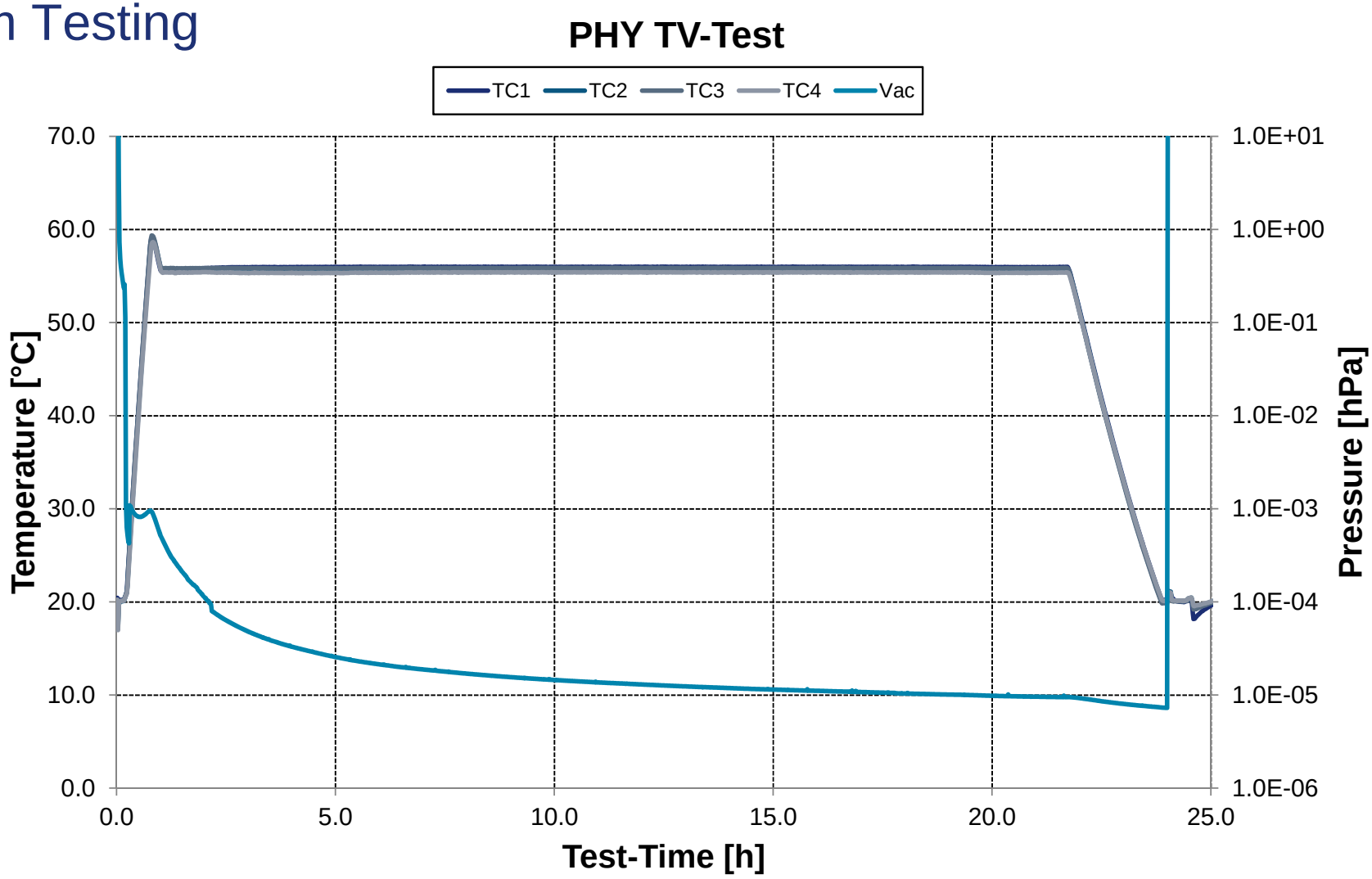
Vacuum Testing



There is no indication on the offgasing during the test, because there is no spike in the pressure.
All parts were inspected after the test and showed no deterioration. All parts passed the test.

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Outgassing

Test conditions ECSS-Q-ST-70-29C

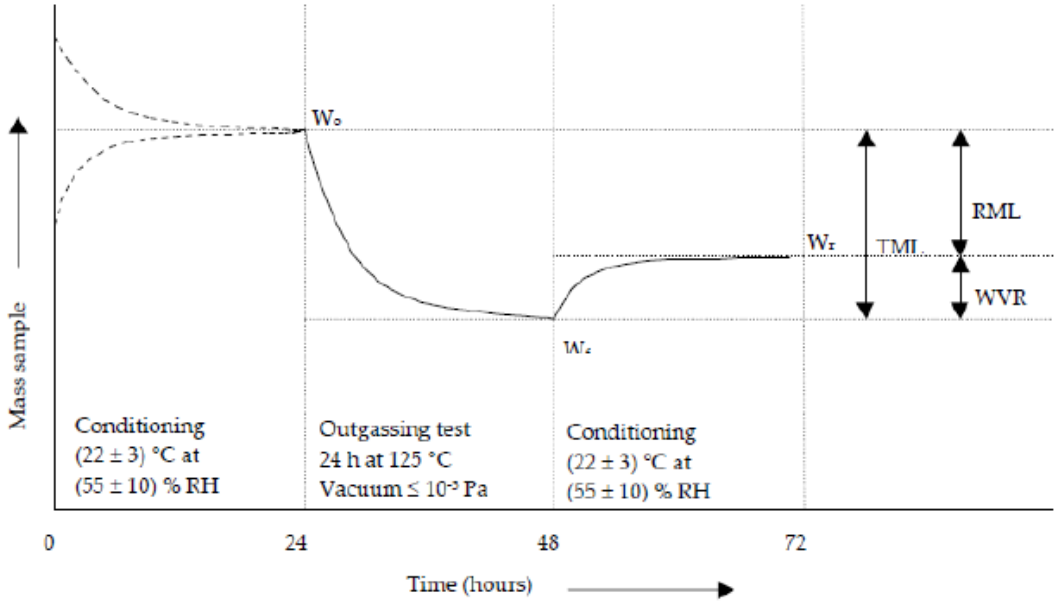
- T = 125°C P = 1E-5 mbar
- Duration 72 hours
- Conduction: Airbus DS certified laboratory

Parameters measured

- Total Mass Loss (TML)
- Recovered Mass Loss (RML)
- Water Vapour Regained
- Collected Vollatile Condensed Material (CVC)

Samples

- 13 from each supplier necessary to reach the critical mass Vitesse/Marvell/Lantiq



Results

- All measured parameters smaller than the limits given in the standard
- All manufacturers compliant

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Offgassing

Test conditions ECSS-Q-ST-70-02C

- T = 50°C, N2 atmosphere
- Duration 72 hours
- Samples are subjected to air flow and offgased substances will be coolled down to 25°C and adsorbed on tubes
- Analysis of chromatograms
- Conduction: Bremen Environmental Institute

Parameters measured

- Carbon monoxide
- Volatile organic compounds
- Mass
- Projected Spacecraft concentration
- Individual Toxicity Value

Samples

- 8 from each supplier

CAS-Nr.	Substance	Test chamber concentration [µg/m³]	SMAC [µg/m³]	Mass [µg]	PSC [µg/m³]	T ind
630-08-0	Carbon monoxide	49	63.000	0,0691	6,9E-04	1,1E-08
74-82-8	methane	n.d.	3.500.000	--	--	--
110-54-3	n-Hexane	44	176.000	0,0620	6,2E-04	3,5E-09
38640-62-9	Diisopropyl naphthaline	22	100	0,0310	3,1E-04	3,1E-06
84-69-5	Diisobutyl phthalate	7	100	0,0099	9,9E-05	9,9E-07
124-19-6	n-Nonanal	16	29.000	0,0226	2,3E-04	7,8E-09
64-19-7	Acetic acid	14	7.400	0,0197	2,0E-04	2,7E-08
541-05-9	D3 (Hexamethylcyclotrisiloxan)	64	90.000	0,0902	9,0E-04	1,0E-08
556-67-2	D4 (Octamethylcyclotetrasiloxan)	51	280.000	0,0113	1,1E-04	4,0E-10
various	Sum N-aromatic compound	8	100	0,0113	1,1E-04	1,1E-06

Results

- **T-value =** Sum (**T ind) < 0,5**
- All manufacturers compliant

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Electrostatic discharge testing

Test conditions

- The spark generator 2000 V pulse
- Pulse repetition rate 1, 5, 10 Hz
- Test duration per test condition 5 min
- Data rate: 100MB/s, 1Gb/s
- Conduction:ESA certified Airbus DS EMI laboratory
- Standard: Columbus EMC and Power Quality Requirements, COL-ESA-RQ-014, Issue 2, Rev. E, 10.12.2001

Parameters measured

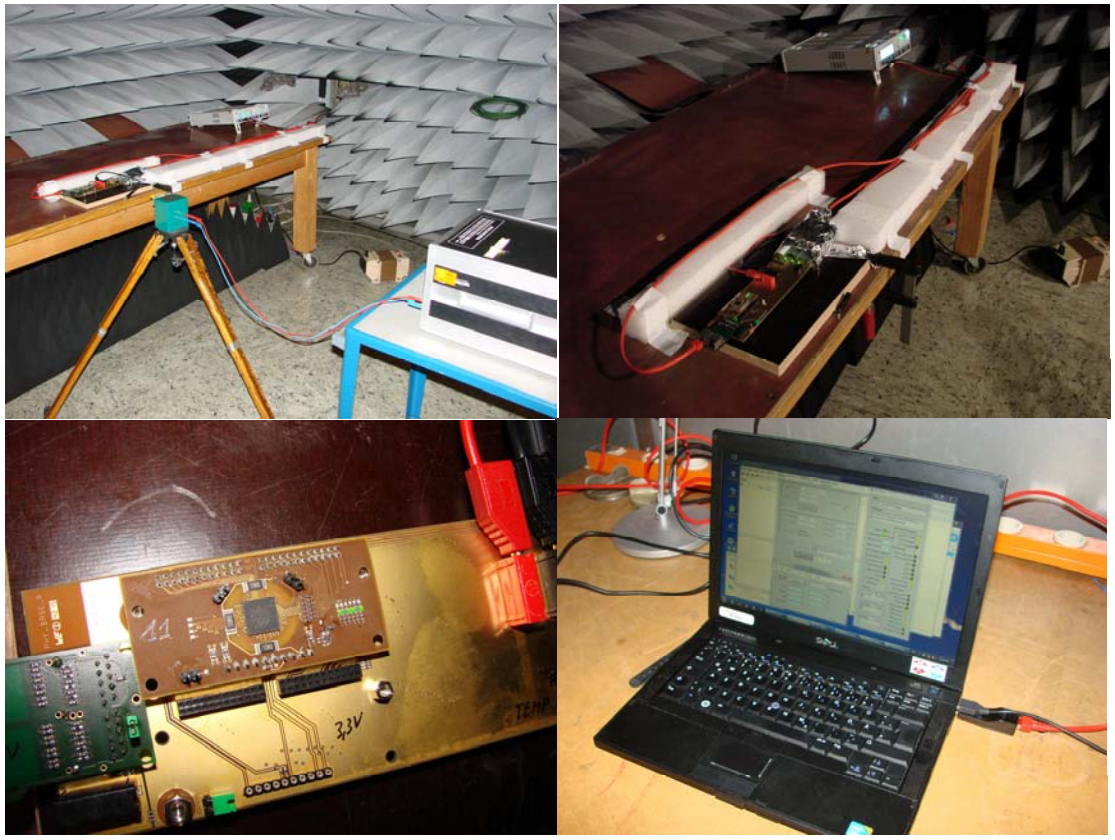
- PHY Functionality (packets sent/received)
- Current consumption

Samples

- 3 from each supplier

Results

- All samples fully functional at all repetition rates and both data rates



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Life testing

Test conditions

- Substrate heating T = 115°C
- Test duration: 1000 hours
- Data rate: 100MB/s, 1Gb/s
- Conduction: Airbus DS Space Laboratory temperature & humidity controlled

Parameters measured

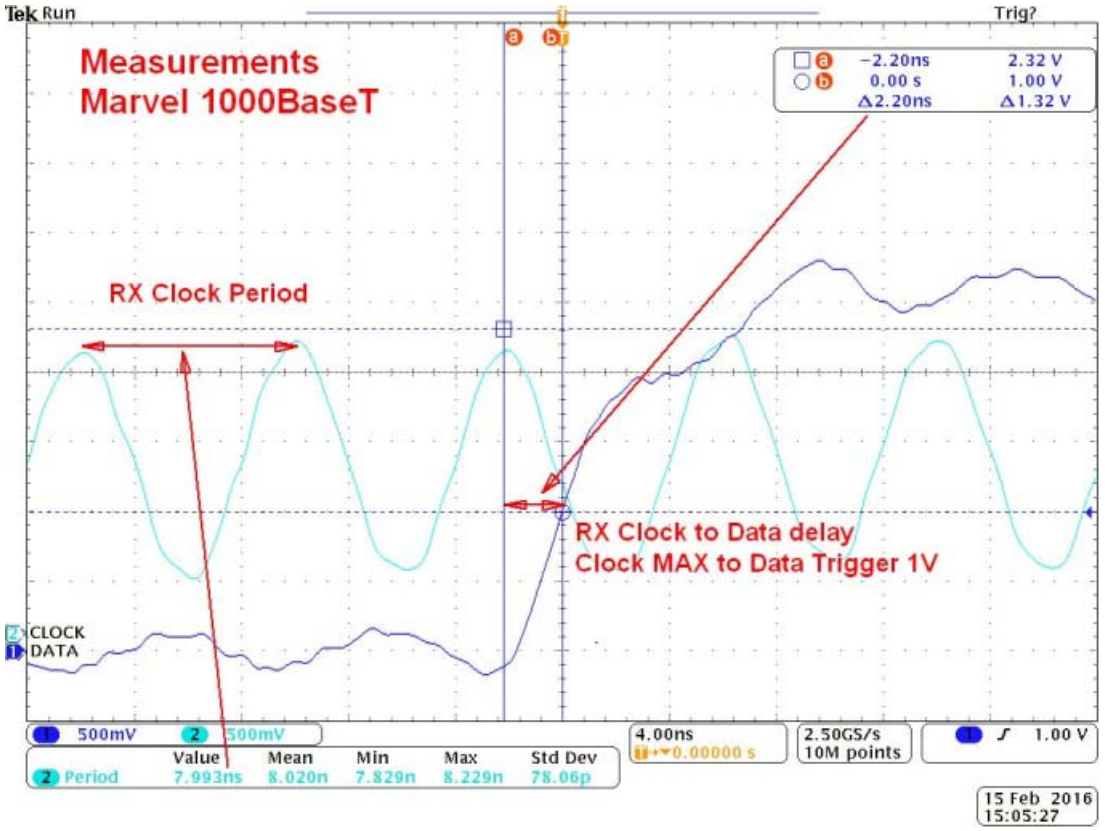
- PHY Functionality (packets sent/received)
- Current consumption
- RX Clock period for both datarates
- Data to Clock delay for both datarates
- Parameters analyzed once per day

Samples

- 3 from each supplier

Results

- All samples fully functional at all both data rates



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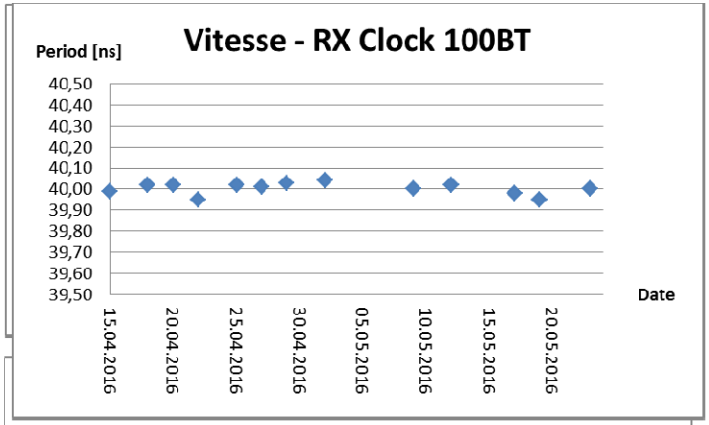
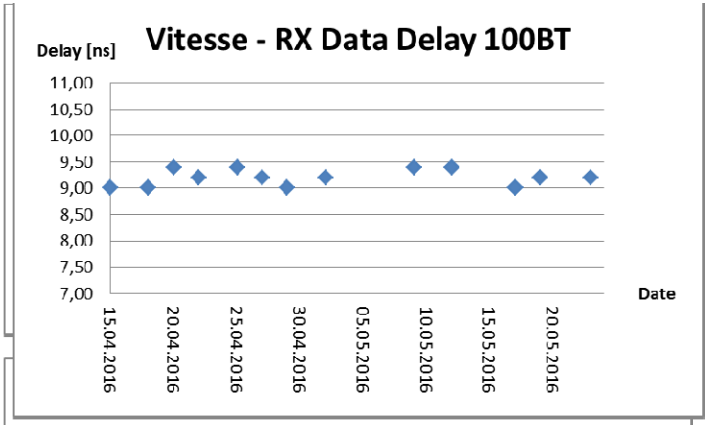
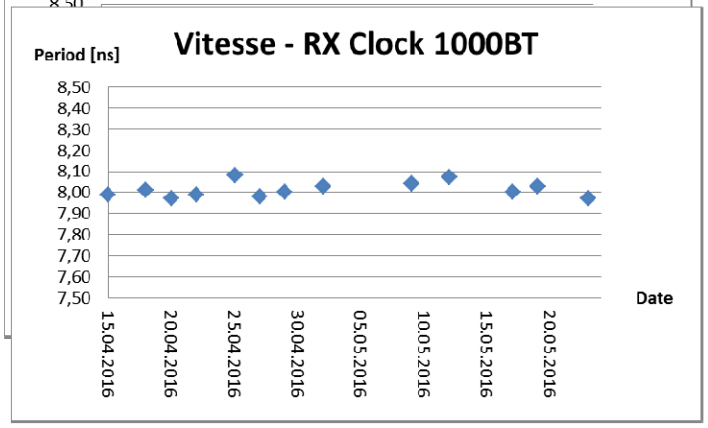
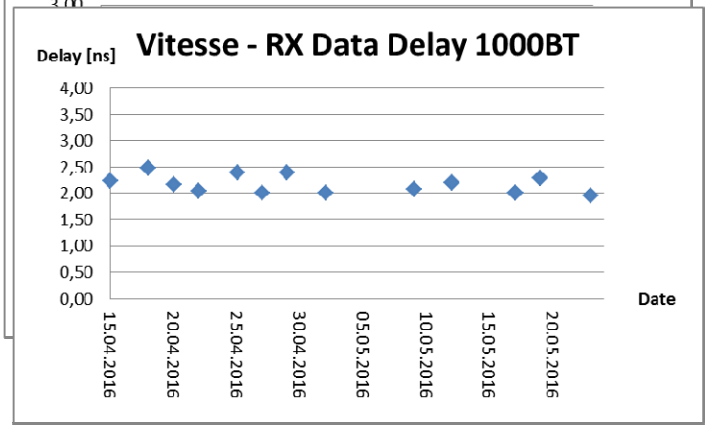
Life testing results









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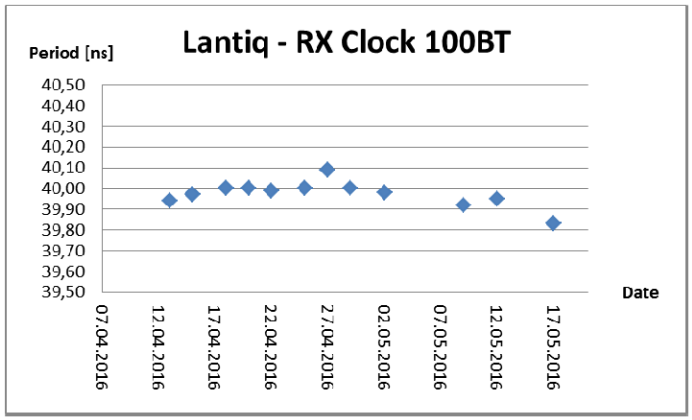
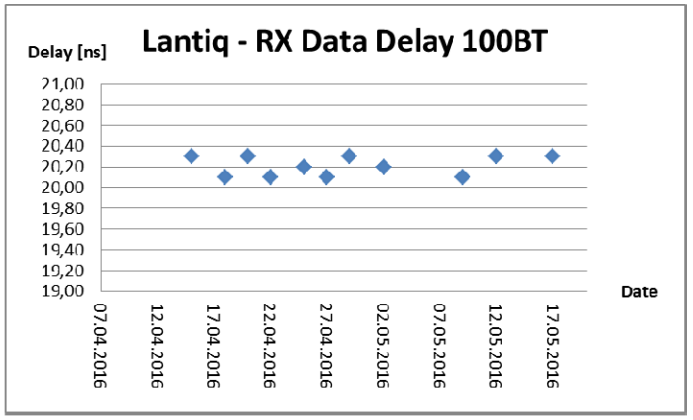
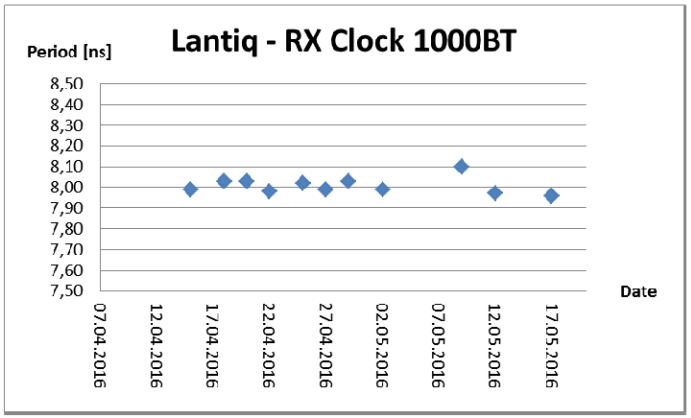
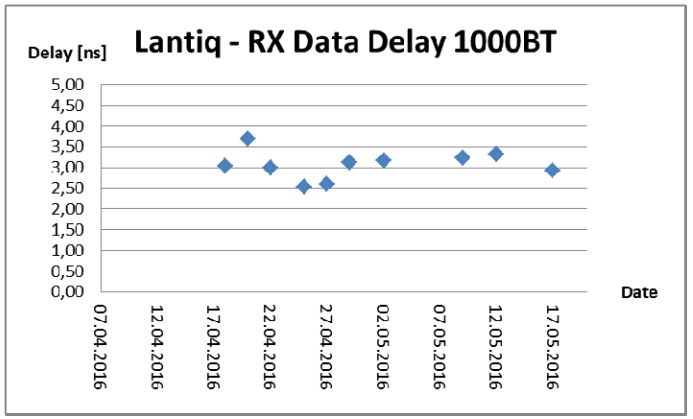
Life testing results









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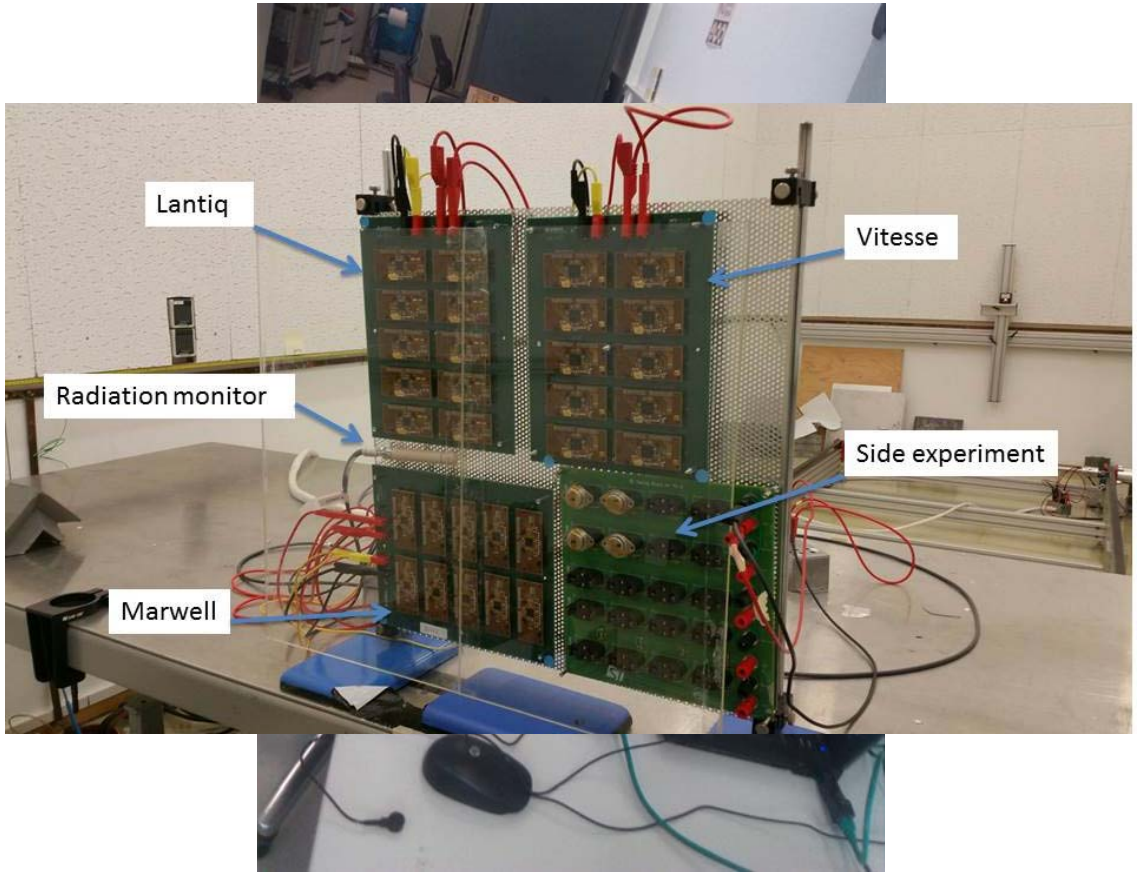
Total Ionising Dose

Test conditions

- 60Co source Activity(02.2016)= 47Tbq
- Four irradiation steps: 6.5 krad, 13 krad, 27 krad, 50 krad
- Average dose rate 309.5 rad/h
- Data rate: 100MB/s, 1Gb/s
- All samples biased
- Conduction: ESA/ESTEC 60Co laboratory
- ESCC 22900 Specification

Parameters measured

- PHY Functionality (packets sent/received)
- Current consumption
- RX Clock period for both datarates
- Data to Clock delay for both datarates
- Parameters measured after each irradiation step and after annealing



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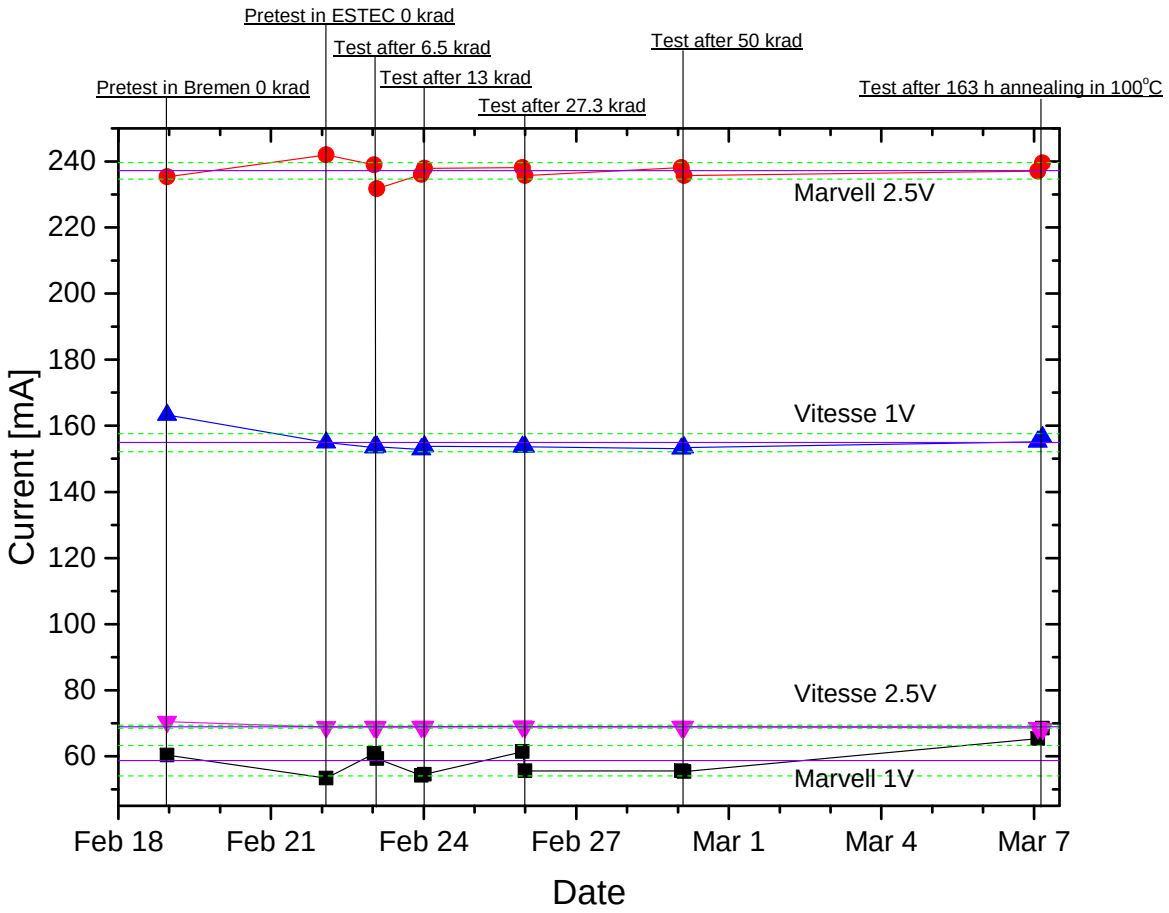
Total Ionising Dose: Key Results



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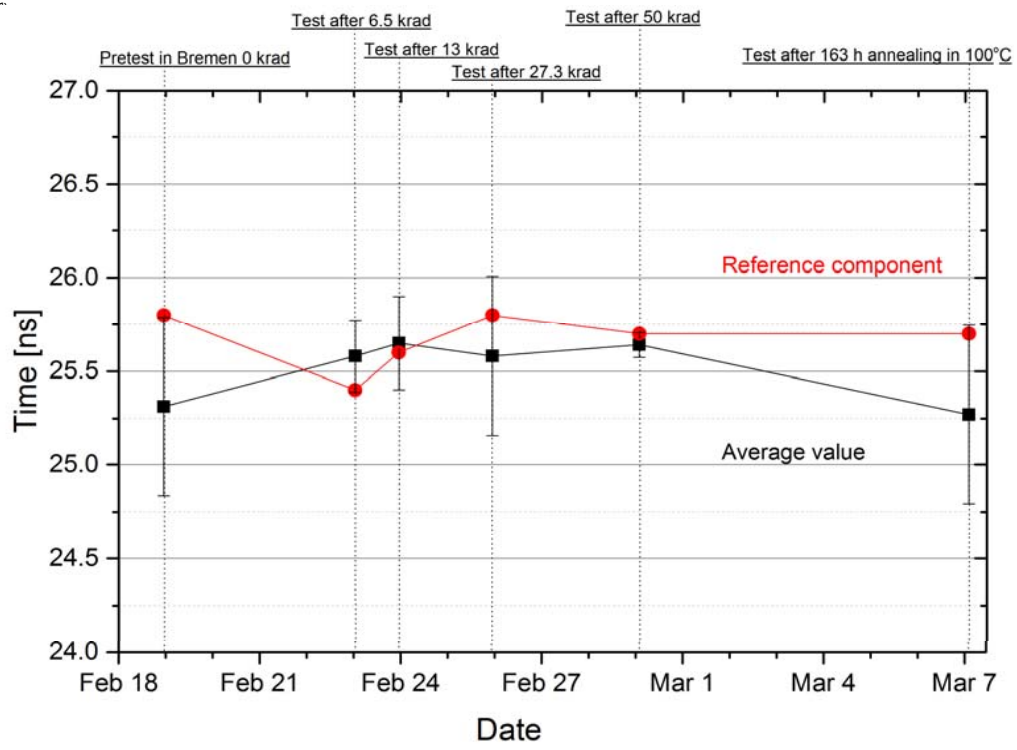
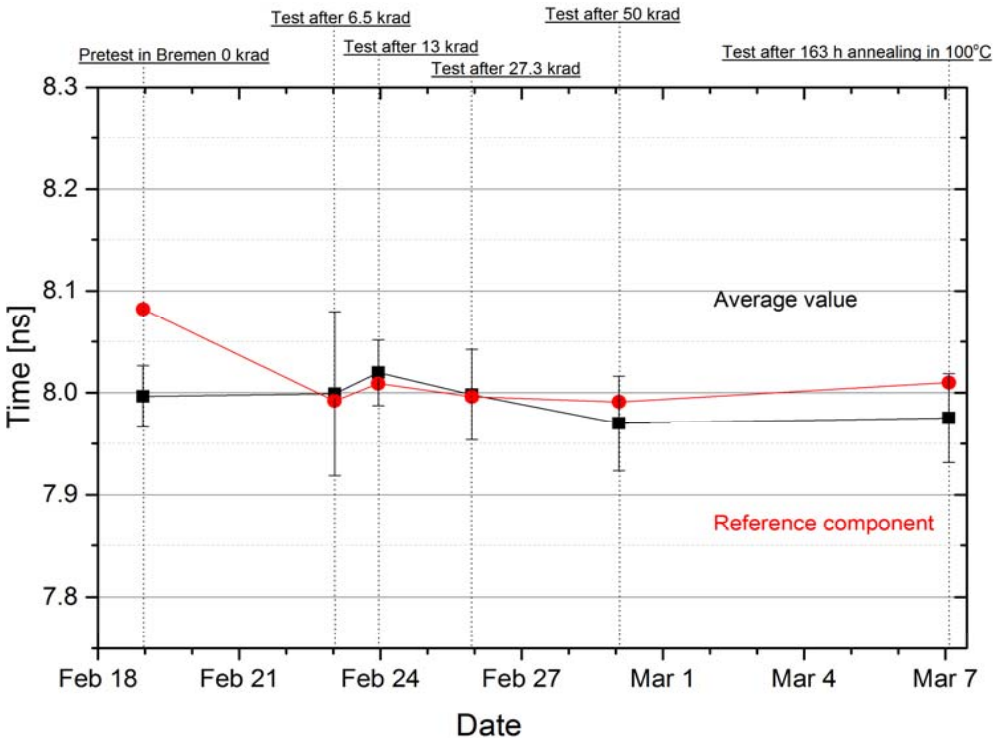
Total Ionising Dose: Key Results

Marvell RX Clock 100Mb/s



Vitesse RX Clock 1Gb/s



No parametric nor functional failures observed. The parts can withstand at least 50 krad(Si).

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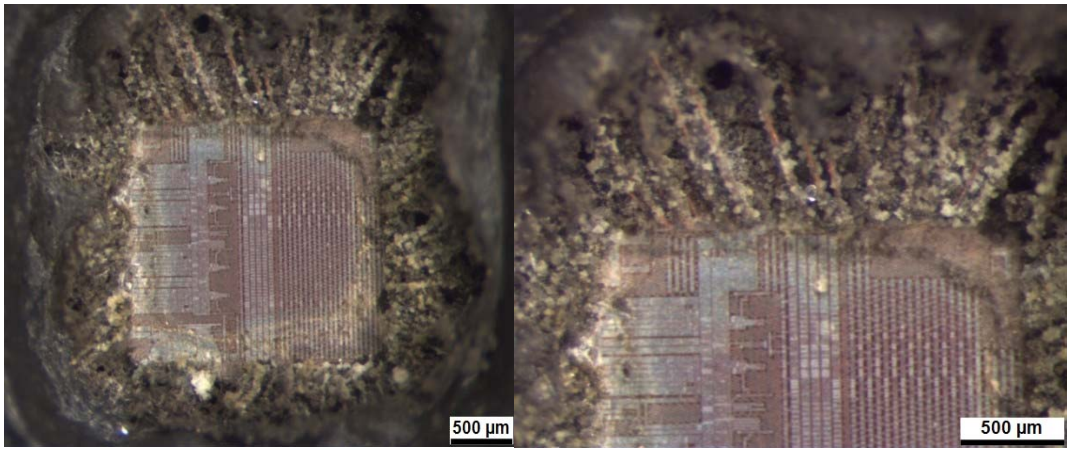
Single Event Effects Testing: Delidding

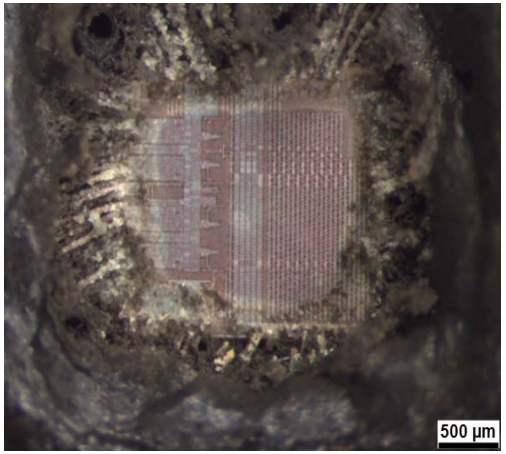
Problems encountered

•Copper wires instead of gold (typical COTS)

•3:1 HNO3:H2SO4



6:1 HNO3:H2SO4



Problem solved

- ESTEC QEC Laboratory
- Special thanks to Alessandra Costantino
- Combination of milling & chemistry

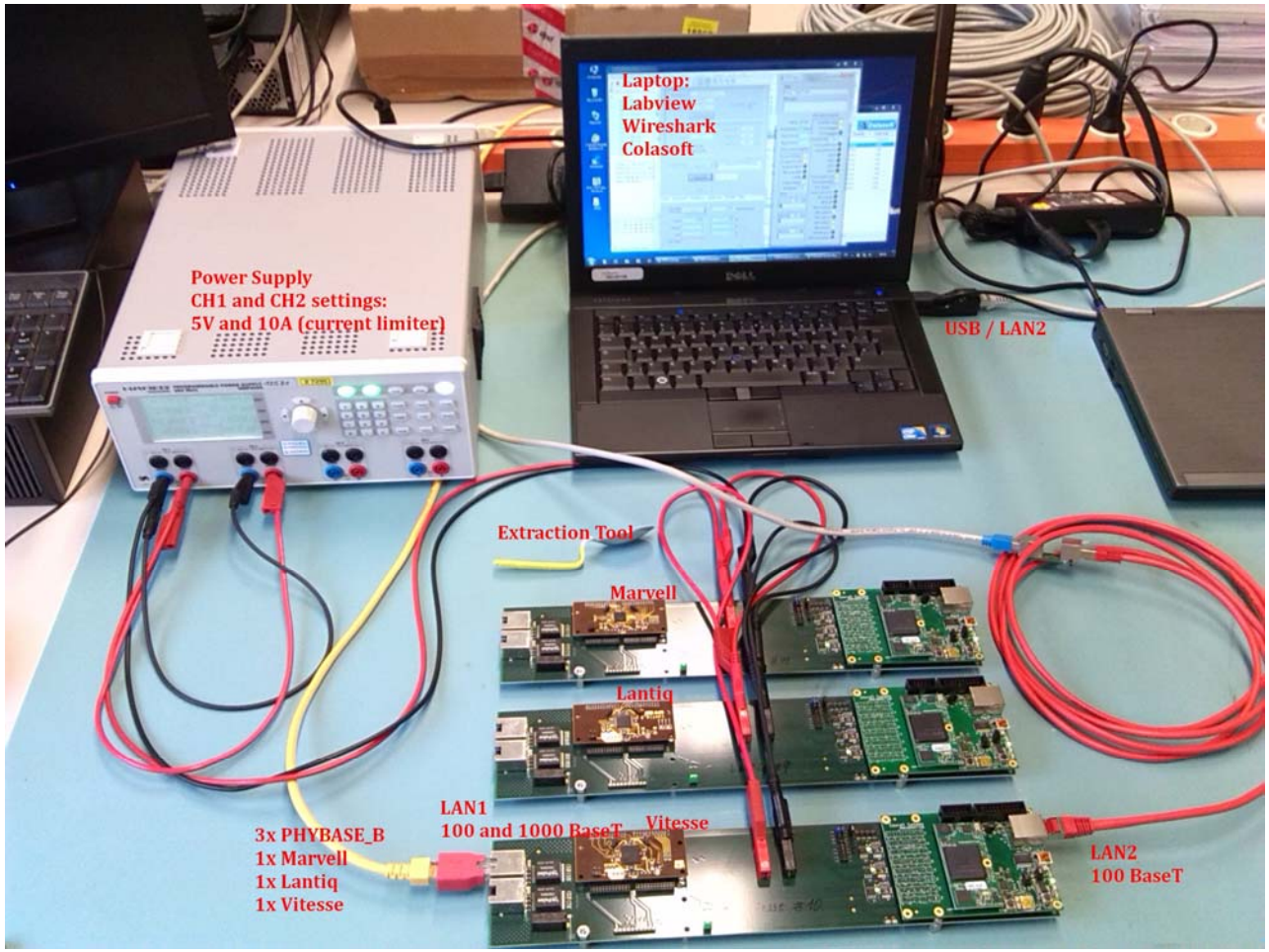
Single Event Effects Testing

Test conditions

- 9.3 MeV/u ion cocktail
- LET = 1.8, 10.2, 18.5, 32 and 60 MeVcm^2/mg
- SEL T = 125°C SEU T = 25°C
- Fluence: 2E6-1E7 particles/cm^2
- Data rate: 100MB/s, 1Gb/s
- Conduction: RADEF K130 cyclotron

Parameters measured

- PHY Functionality (packets sent/received)
- Current consumption
- Number of errors: Data loss, Functional interrupts, Link loss, Latchup events
- Parameters during each run and stored electronically



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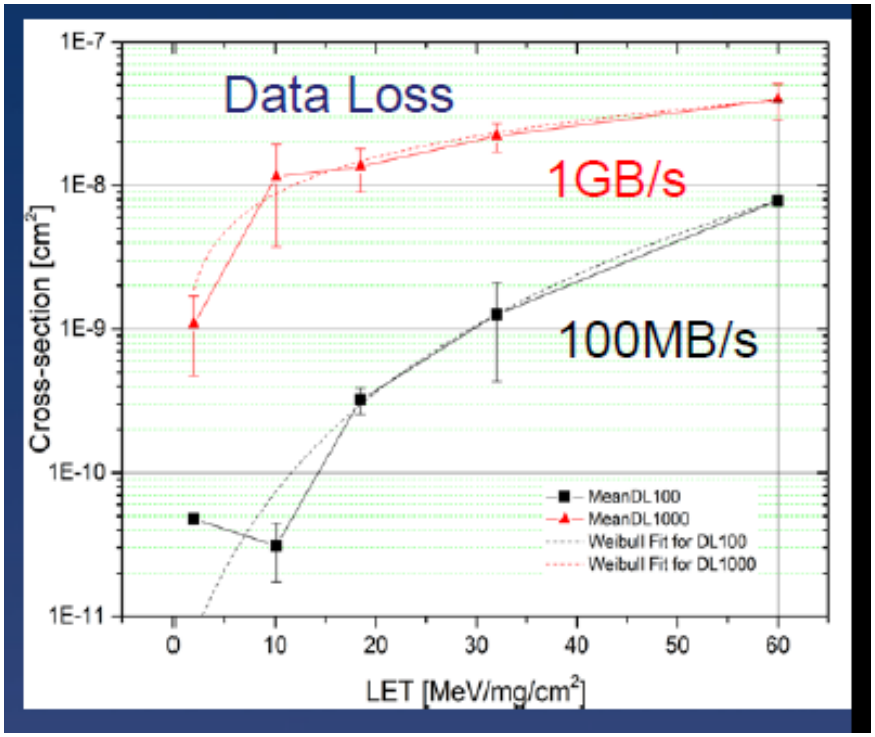
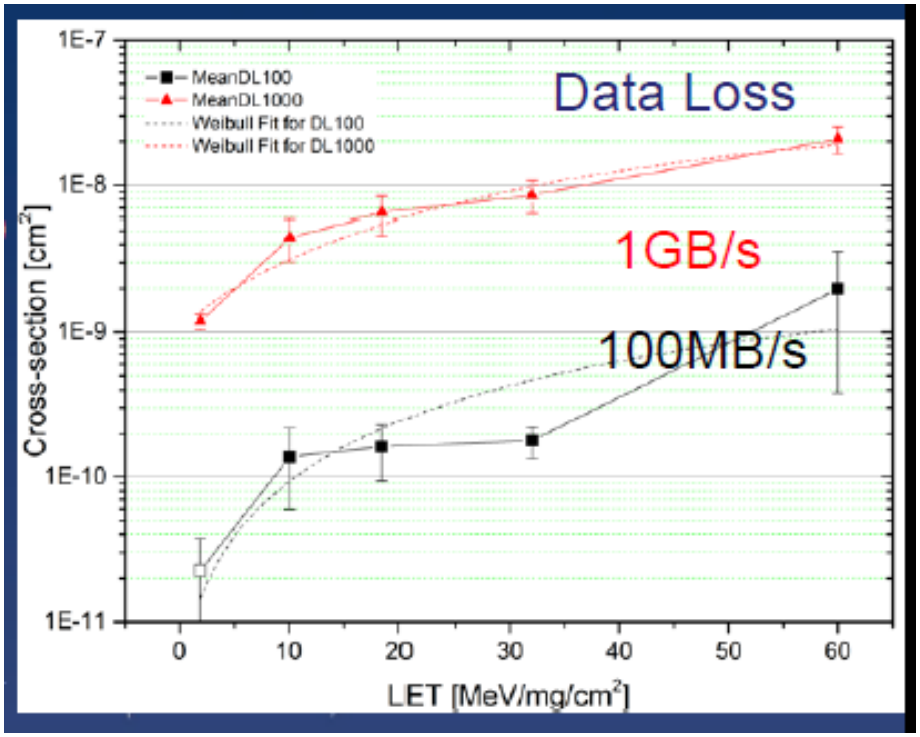
Single Event Effects Results

Marvell



Vitesse



- Vitesse has the lowest data loss rate, followed by Marvel. They do not display any latchup effect.
- Lantiq exhibited latchup and a very high SEU rate.

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Conclusion and Outlook

- Two manufacturers out of three have sucessfully qualified for space deployment.

- The transceivers market is extremely dynamic, triggered by the high demand from the automotive industry: Vitesse aquired by Microsemi and Lantiq acquired by Intel.

- Problems solved

-integration of the transceivers with the QFN double row package
-redesign of the PHY base to address the magnetics problem
-substrate heating for the PHYs for life and radiation test, FPGA controlled
-delidding for the Single Event Effects

- Transceivers could de deployed for future developments:

Airbus internal next generation Open Modular Avionics Computer
ESA GSTP Testbed and Reference End System

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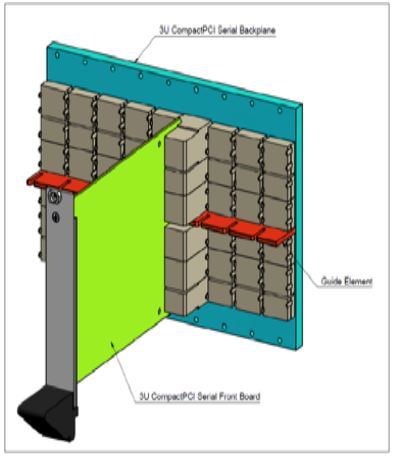
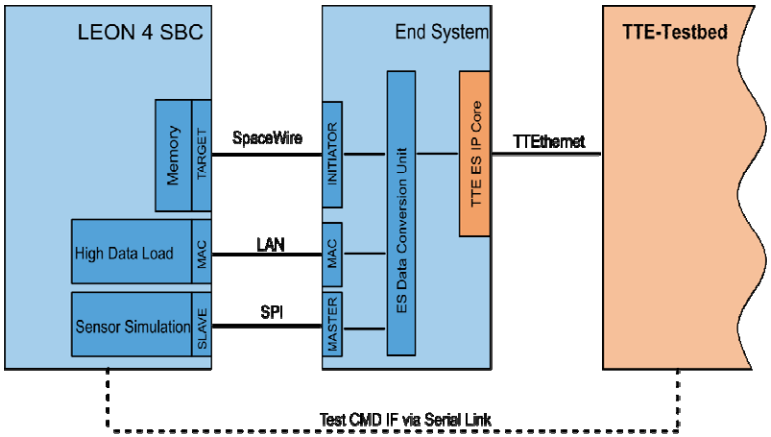
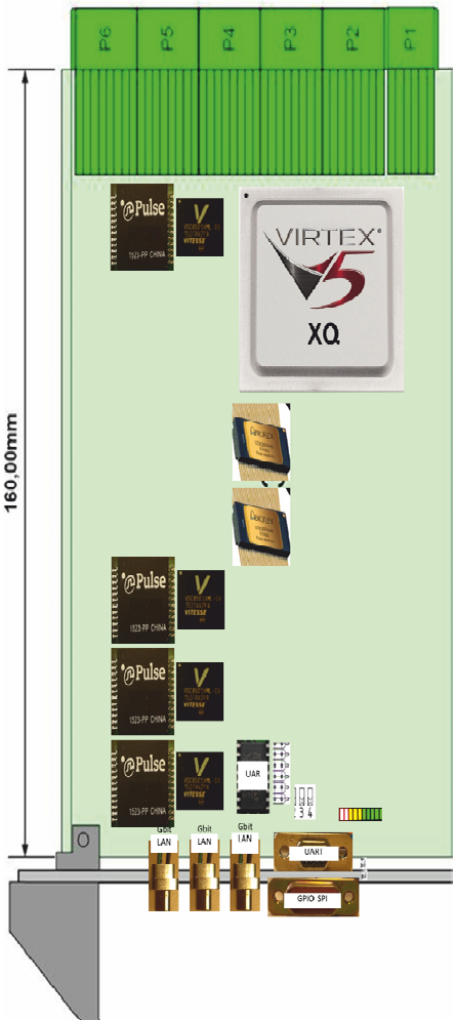
GSTP Testbed and Reference End System

Development of a reference End System for TTE Testbed providing following capabilities:

- Based on Xilinx Virtex 5 VFX130T (QV replaceable)
- Re-Use of
  - TRP ES IP Core
  - PHY selection driven by TRP PHY characterisation results
  - FLPP Switch maturation design experience
- Host Interface: Space Wire, SPI and Ethernet
- 3 redundant Time Triggered Ethernet Interfaces
- Data emulation with LEON4 processor board
- 3U form factor compatible to cPCI Serial „space“ backplane
- ES driver development for PikeOS







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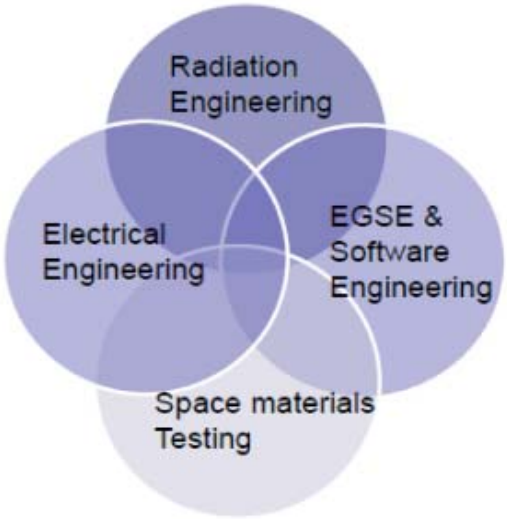
Thank you for a nice collaboration
and
an interesting journey!



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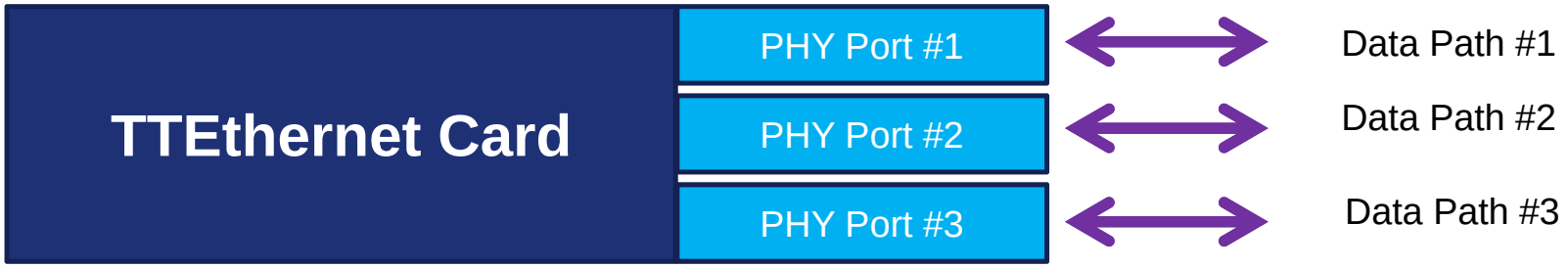
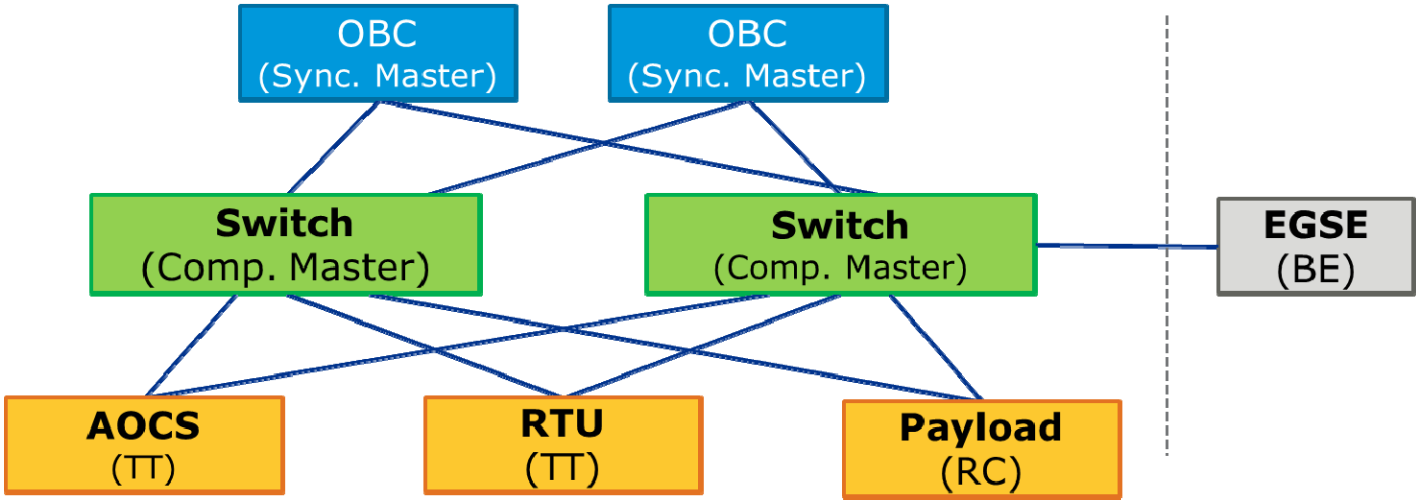
Time Triggered Ethernet- Overview

1. TTEthernet is based on the well-established IEEE 802.3 Ethernet with all of advantages (i.e. 1Gbps speed, availability of know-how)
2. Determinism of the network traffic
   -> communication is time-bounded, time properties of traffic are known
3. One common network for transmitting mixed-criticality data
   -> i.e. control, TM&TC, scientific data
4. Three traffic classes implemented into the same network:
   - IEEE 802.3 Ethernet traffic (Best-Effort),
   - AFDX (ARINC 664 P7) Rate-Constrained traffic, introduction of VLs
   - SAE AS6802 Time-Triggered traffic.
5. Three physical ports, triplication of data paths. The physical layer (PHY) is a building block of the TTEthernet.



Time Triggered Ethernet- Overview

6. Tight time synchronization with division of role (Synchronization Master, Compression Master, Synchronization Client).
7. Redundant architecture by design of the network:



-TTEthernet can be regarded as a successor of MIL-STD-1553 in certain critical applications, e.g. Human Spaceflight.