EP-ESE Seminar

31 May 2016

Recent Developments in the TTC-PON System

S. Baron, E. Mendes
on behalf of the TTC-PON team
(S. Baron, D. Kolotouros, E. Mendes, C. Soos)

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TTC PON

Timing
Trigger
Control
Passive
Optical
Network

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Outline

TTC PON

- Introduction to FTTx & PON
- From TTC to TTC-PON(s)
- Final Scheme for Phase-1 Upgrades
    - Downstream Path
    - Upstream Path
    - System Performance
- Integration with GBT & legacy TTC
- On-going developments
- Potential developments for Phase-2

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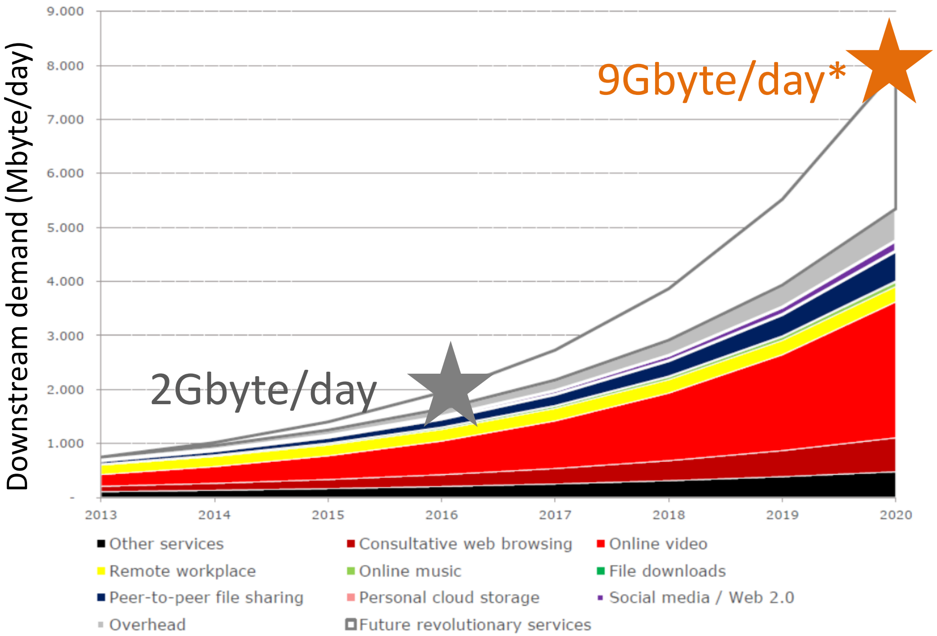
A few figures to start with

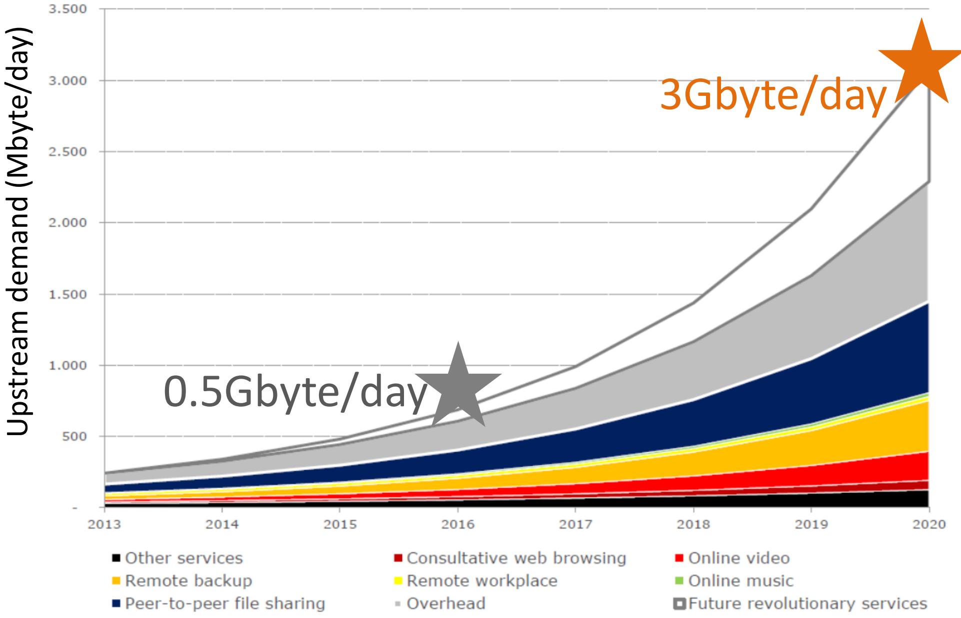
Increasing Global Demand on Ethernet

DOWNSTREAM
getting data from the Internet to your home/devices

UPSTREAM
moving data from your home/devices to the Internet

Projected **average** daily volume of down & up-stream traffic per residential subscription for the years 2013-2020





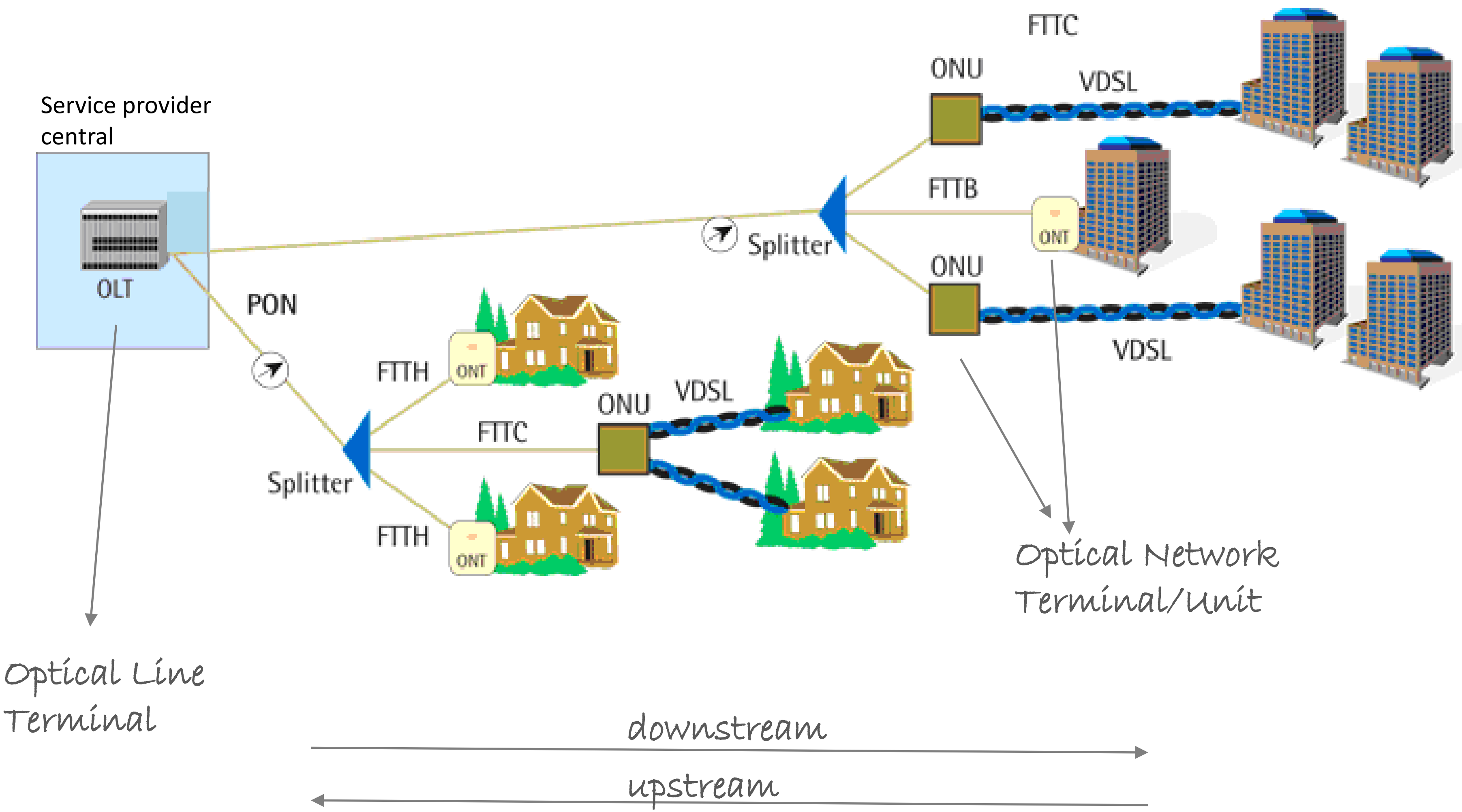
*Power users downstream estimation 2020: 80Gbyte/day

Source: FTTH Council Europe, 2016

The solution: FTTx → *Fiber To The x*

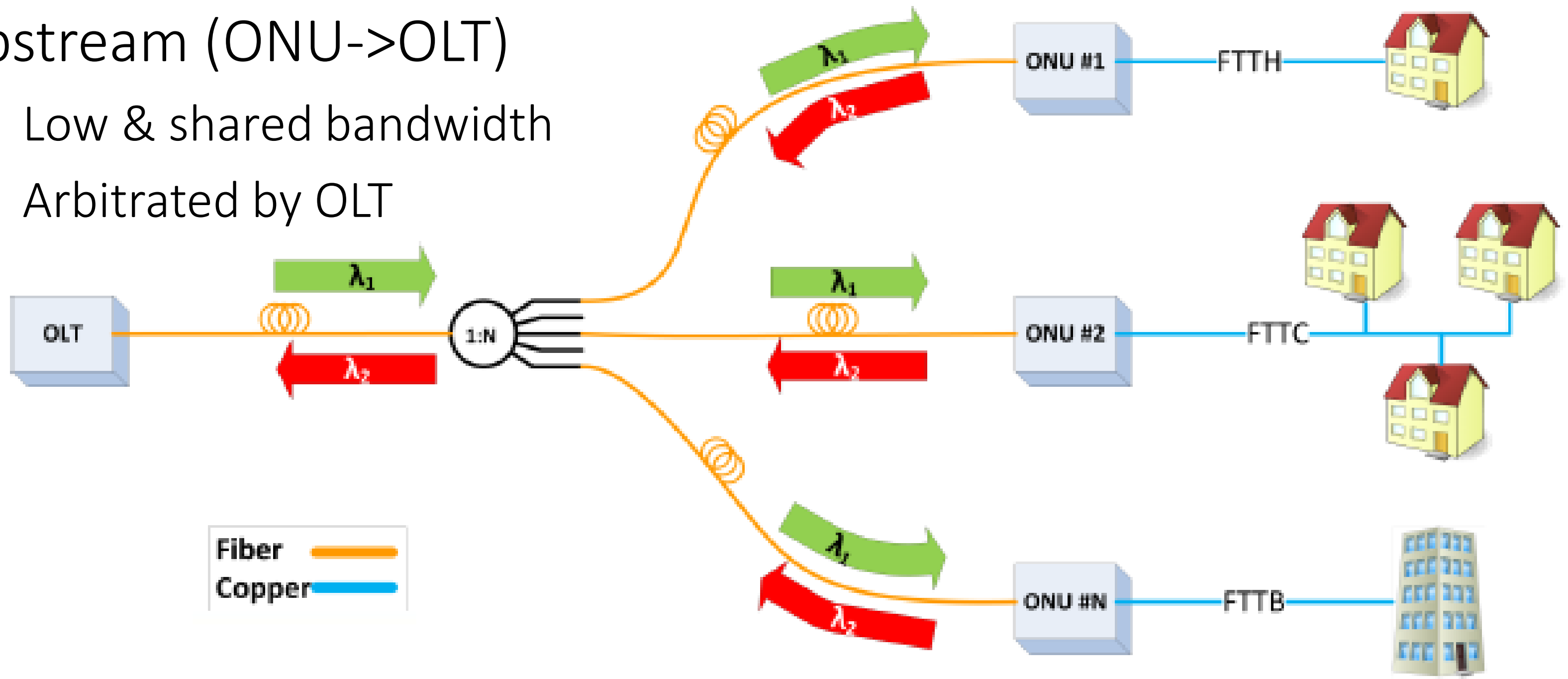
…and PON → *Passive Optical Network*

TTC PON



PON Principle

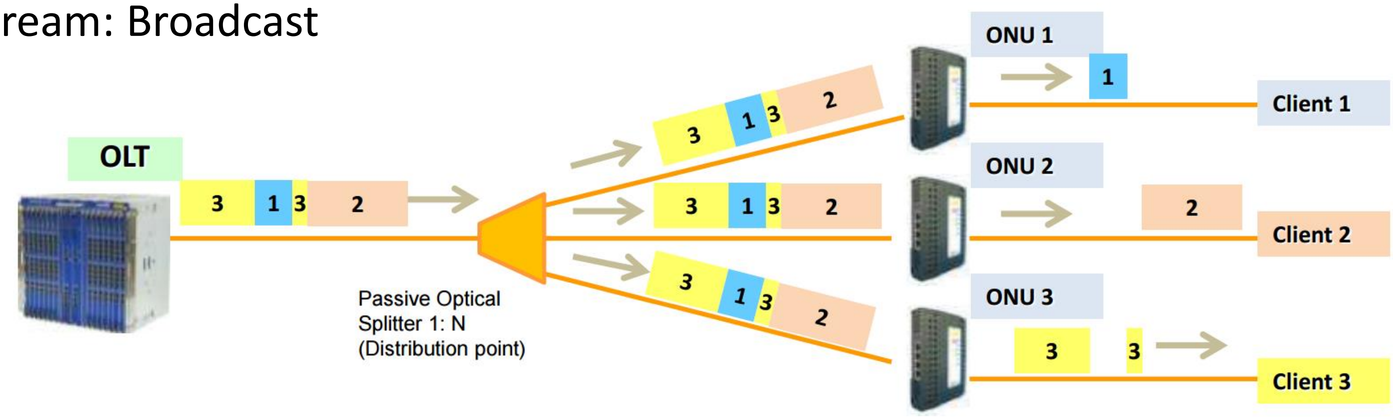
- Point to Multipoint Network (P2M)
  - Bidirectional
  - Wavelength Division Multiplexing: 1 fiber, 2 wavelengths (1 Up, 1Down)
- Downstream (OLT->ONU)
  - High bandwidth
- Upstream (ONU->OLT)
  - Low & shared bandwidth
  - Arbitrated by OLT



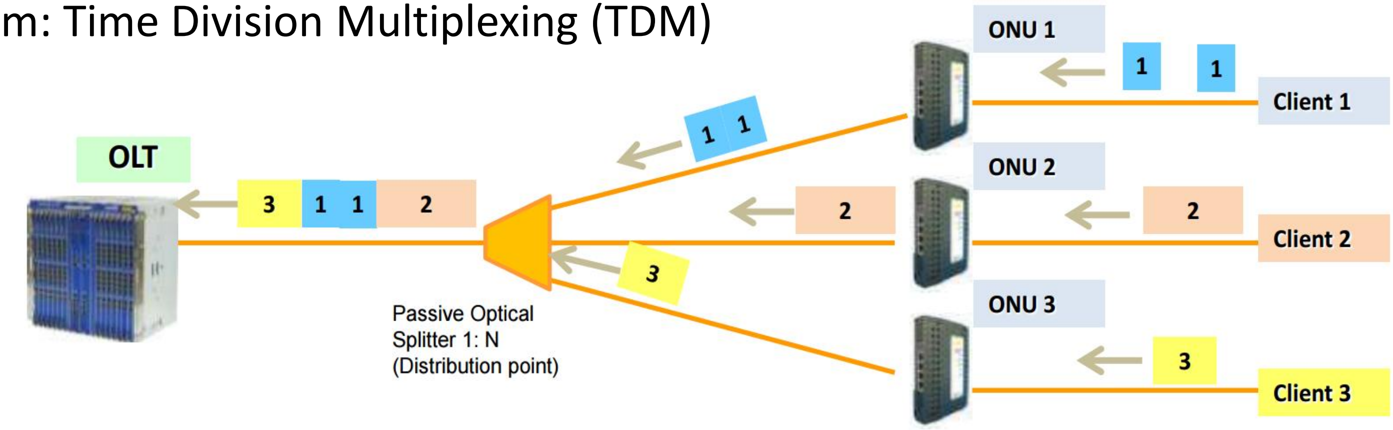
PON Principle

TTC PON

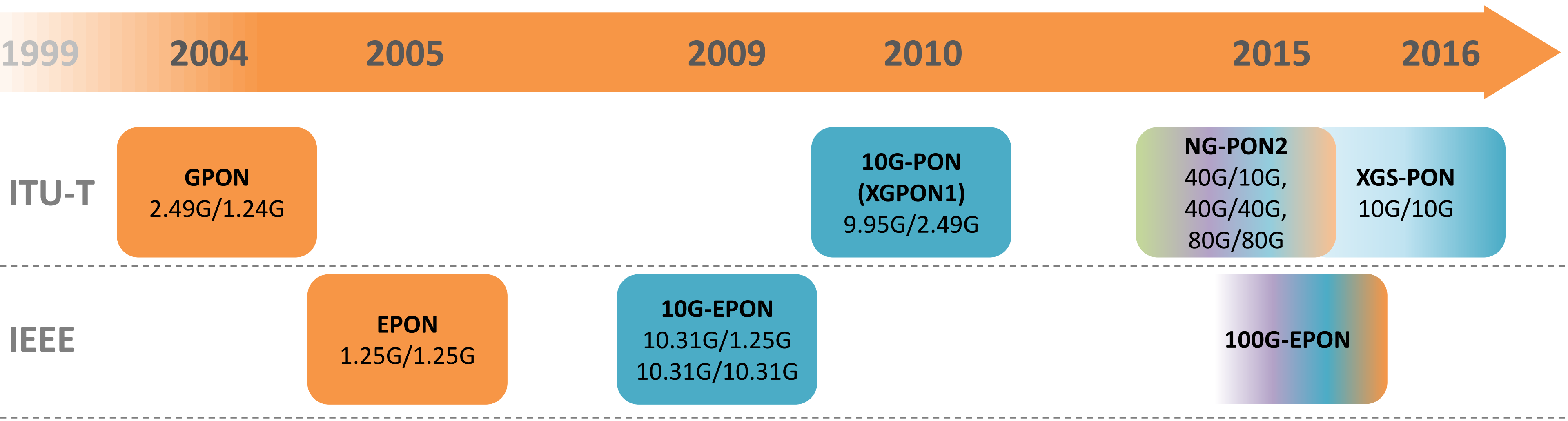
Downstream: Broadcast



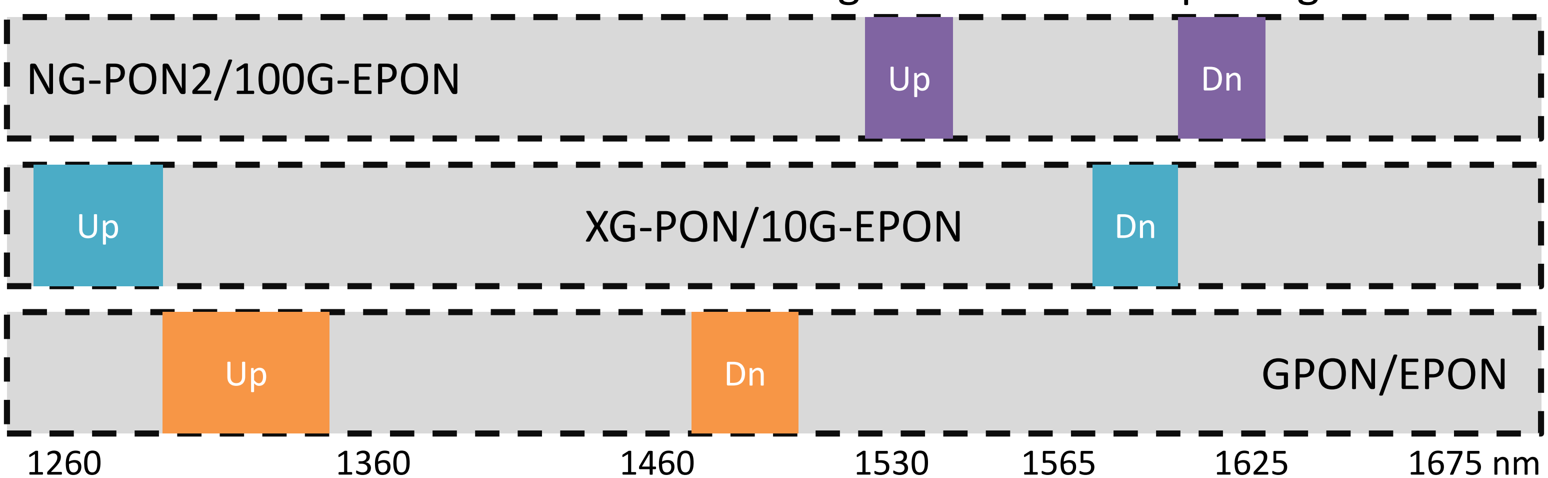
Upstream: Time Division Multiplexing (TDM)



PON Standards



«Future Proof» thanks to Wavelength Division Multiplexing



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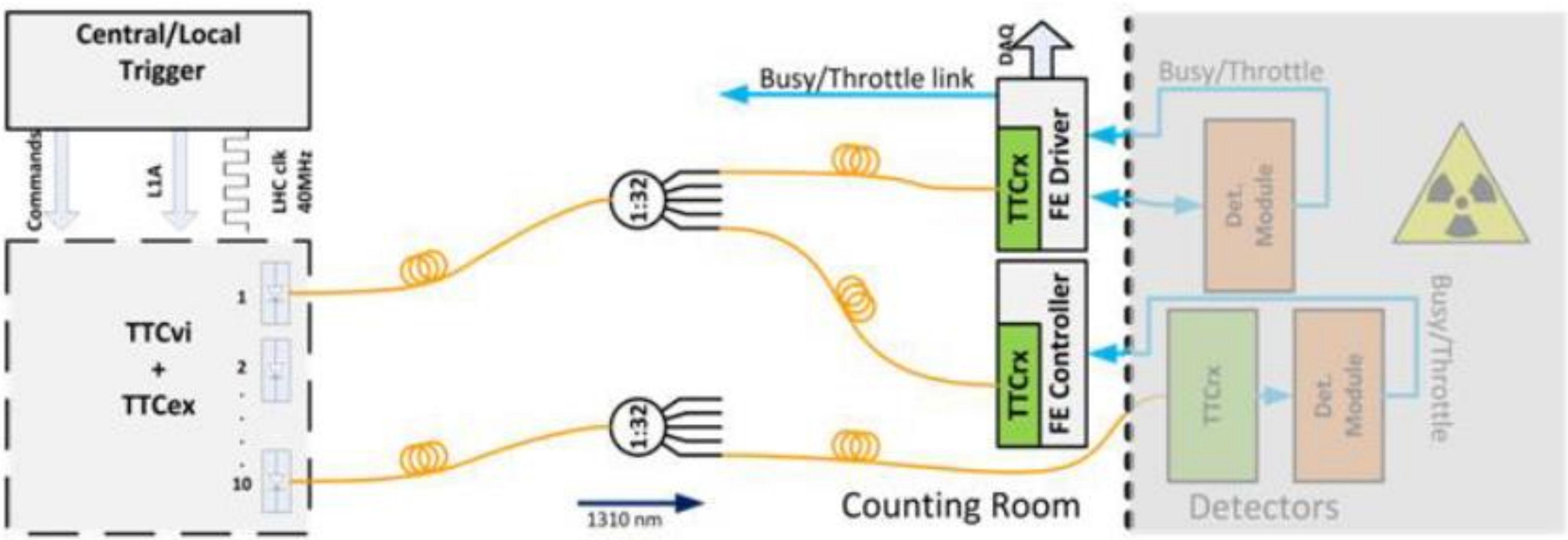
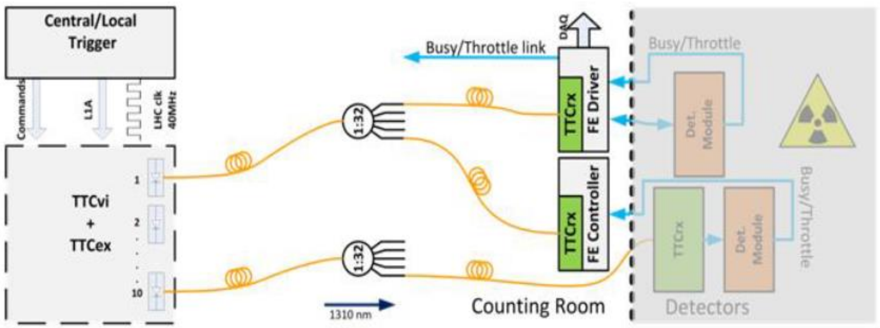
Current TTC System

- Unidirectional system (downstream only)
- 1:32 split ratio maximum
- 1310nm
- Low bandwidth: 40Mb/s per channel
- Busy/throttle on a separate link



TTC-PON system



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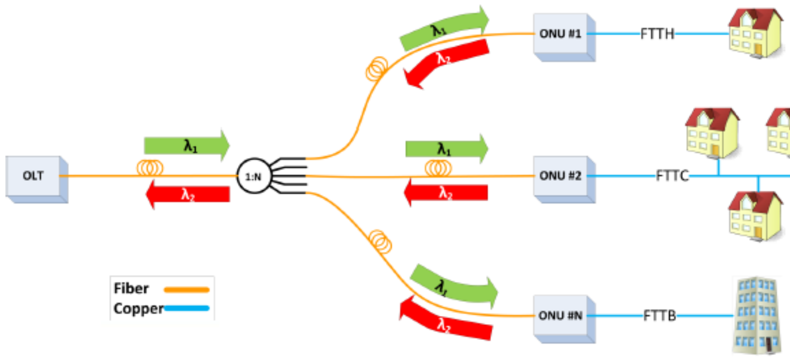
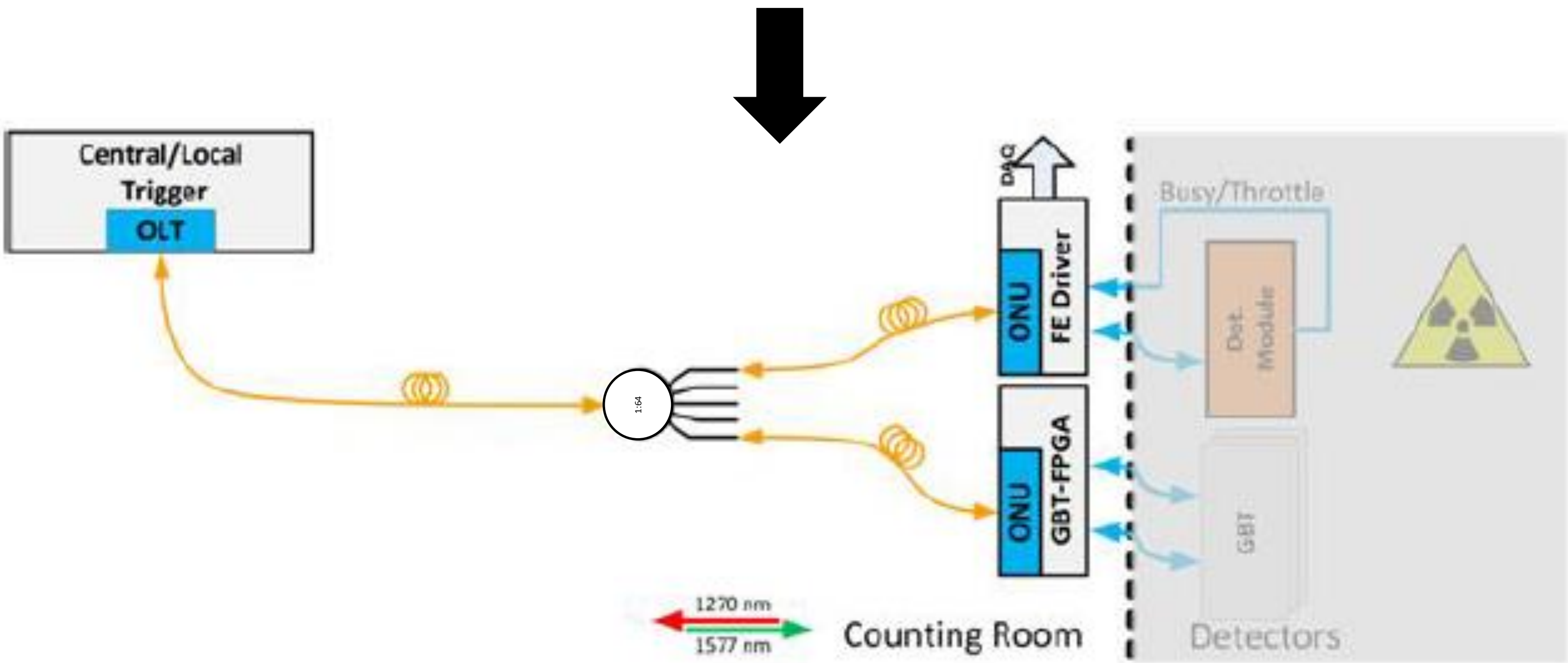
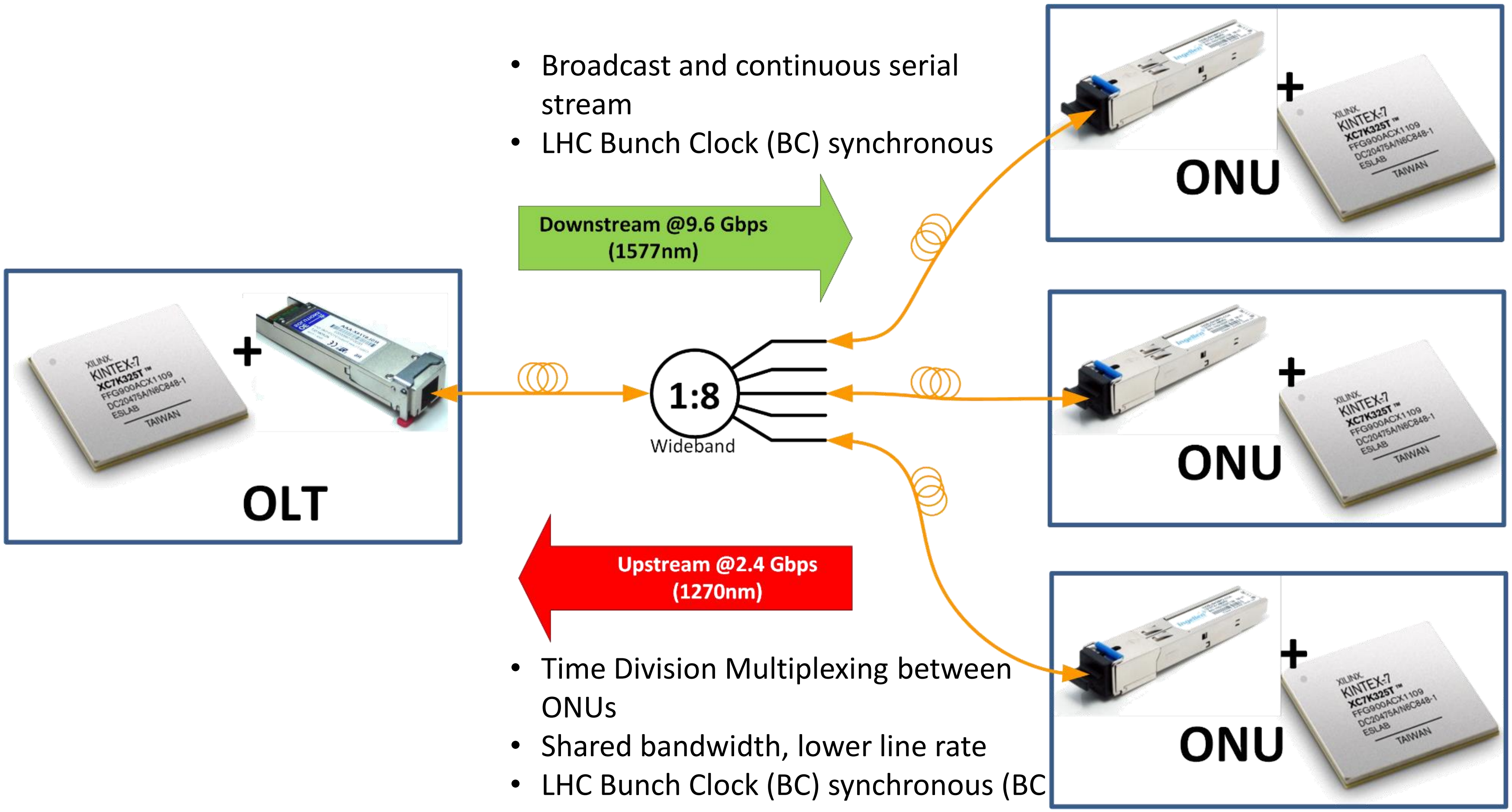




TTC-PON system

- Broadcast and continuous serial stream
- LHC Bunch Clock (BC) synchronous



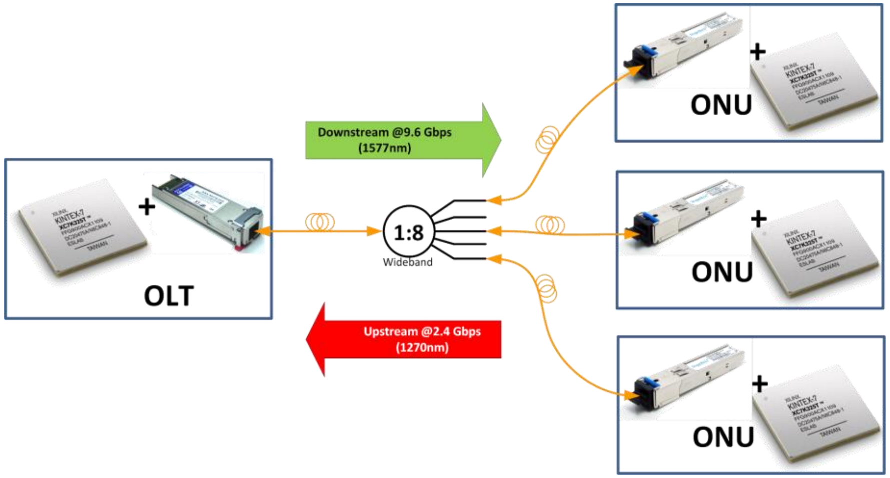
- Time Division Multiplexing between ONUs
- Shared bandwidth, lower line rate
- LHC Bunch Clock (BC) synchronous (BC

Main figures of merit of TTC-PON

- System
  - *High* Split ratio (*Large* Power Budget)
  - *Low* Level of customization wrt standard
- Downstream (broadcast)
  - *Low* & *deterministic* Trigger latency
  - *High* Bandwidth
  - *Excellent* Clock quality

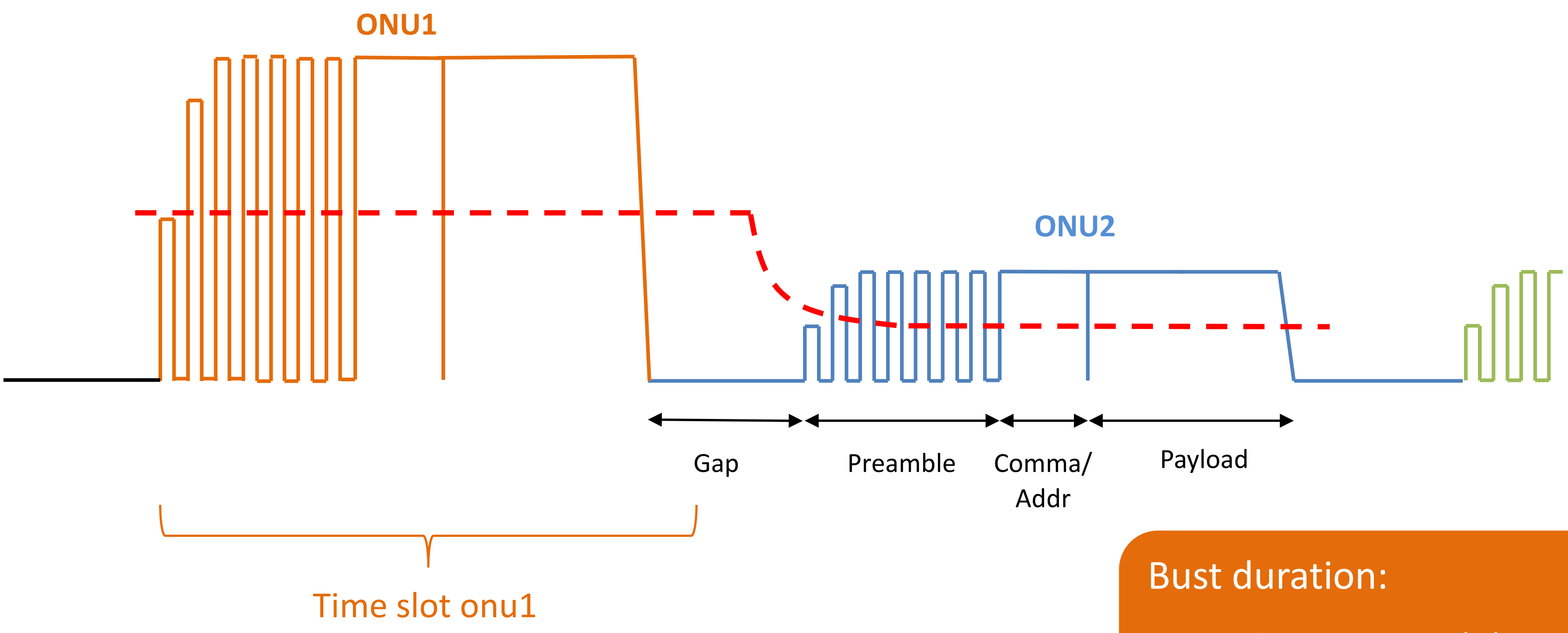
  => Classic Optical Link
- Upstream (TDM)
  - *Low* Busy latency
  - *High* Dynamic range
  - *High* Payload

  => Challenging



Upstream path: the challenging one

- Serial stream composed of contiguous bursts from different ONUs



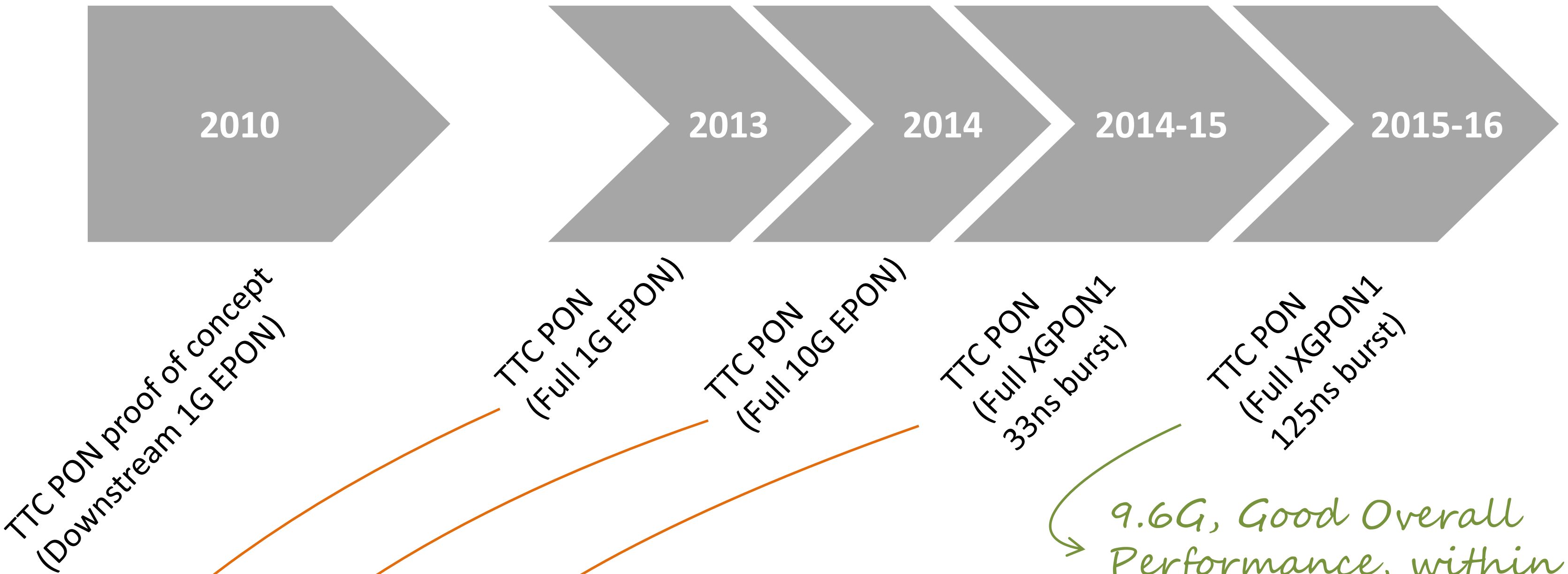
Bust duration:

Typical FTTx PON: (o)10us

Target TTC-PON: <=100ns

Short gaps, Short bursts => synchronisation + round robin arbitration

TTC-PON project evolution



9.6G, Good Overall Performance, within XGPON1 standard

9.6G, low latency down & up,
Customization required, little dynamic range

11.2G, low latency down,
Much too far from EPON standard (line rate, short bursts)

1.2G, First bidirectional proof of concept, too high latency vs TTC

Very first feasibility study – very promising

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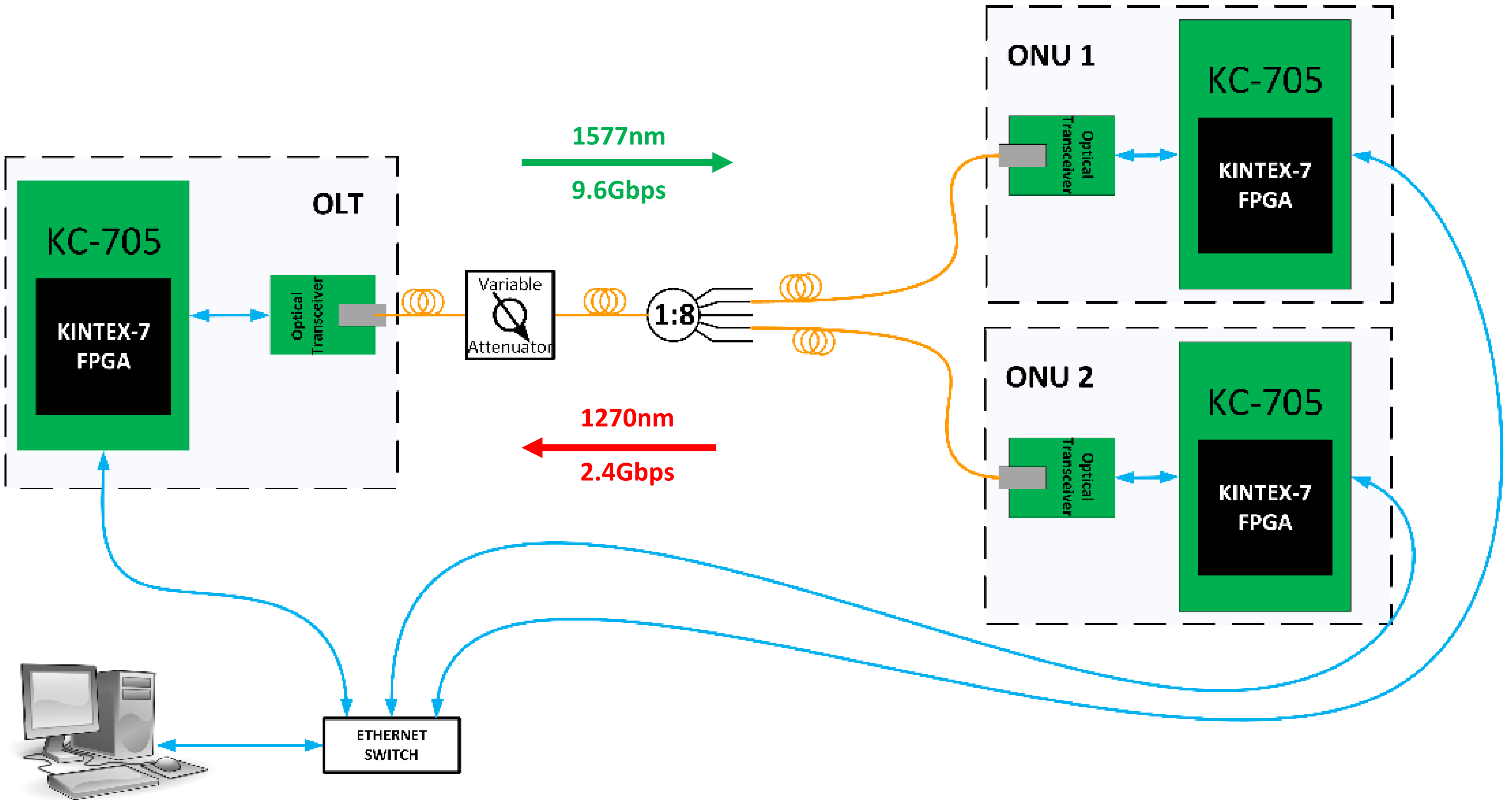
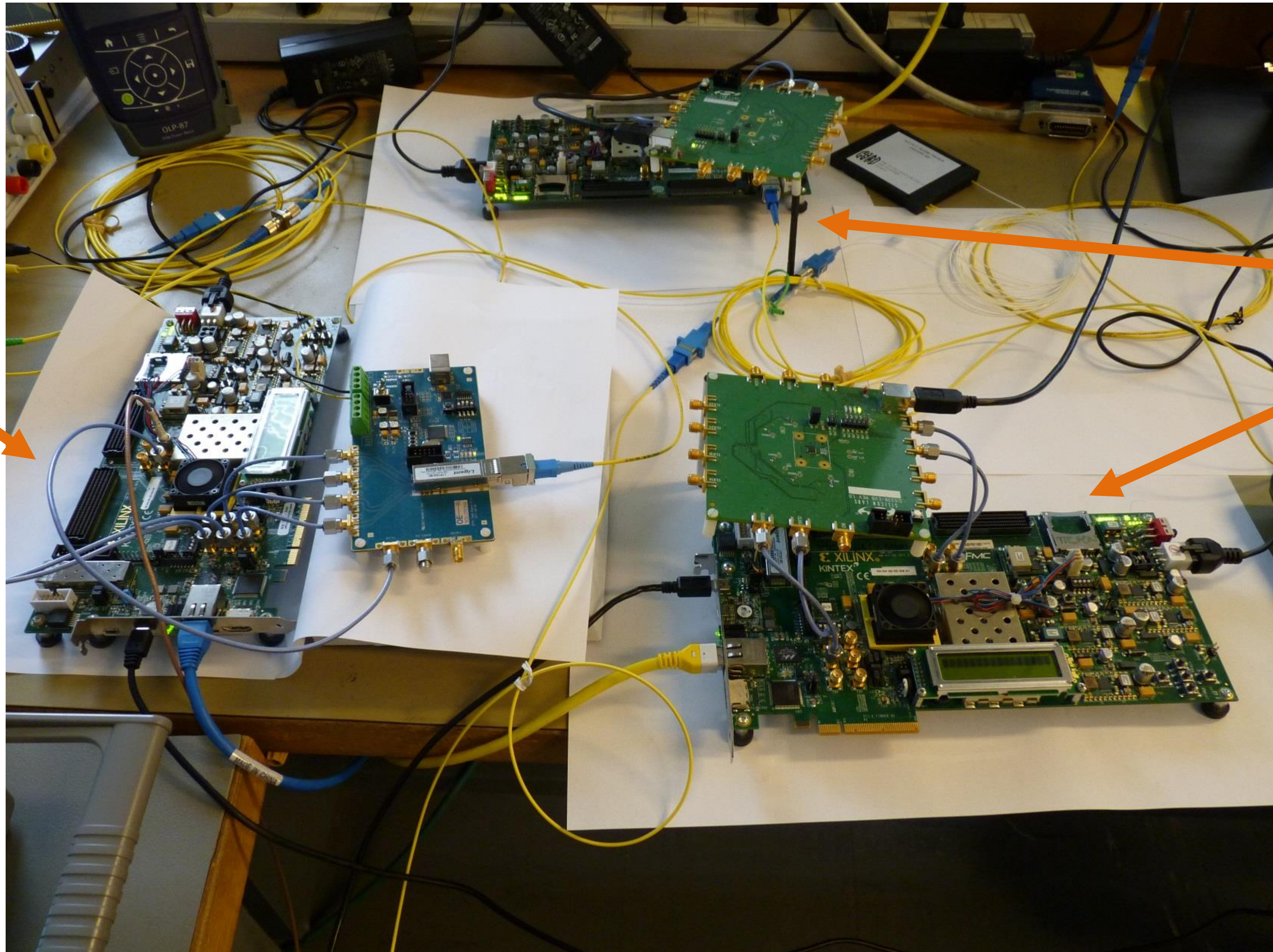
TTC-PON 2016



OLT
KC-705
KINTEX-7
FPGA
Optical
Transceiver
Variable
Attenuator
1:8
1577nm
9.6Gbps
1270nm
2.4Gbps
ONU 1
KC-705
KINTEX-7
FPGA
Optical
Transceiver
ONU 2
KC-705
KINTEX-7
FPGA
Optical
Transceiver
ETHERNET
SWITCH

TTC-PON 2016

TTC PON



OLT

ONU1

ONU2

ONU3

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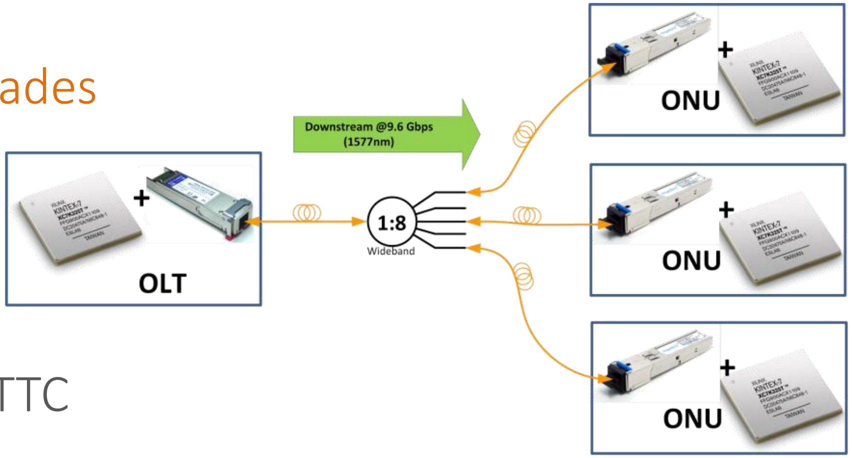
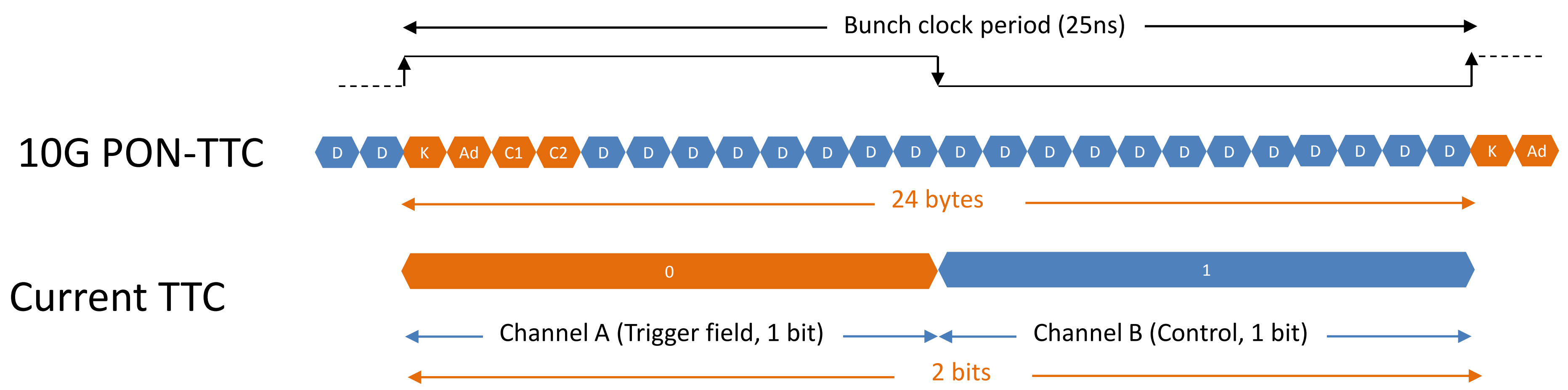


Downstream Protocol

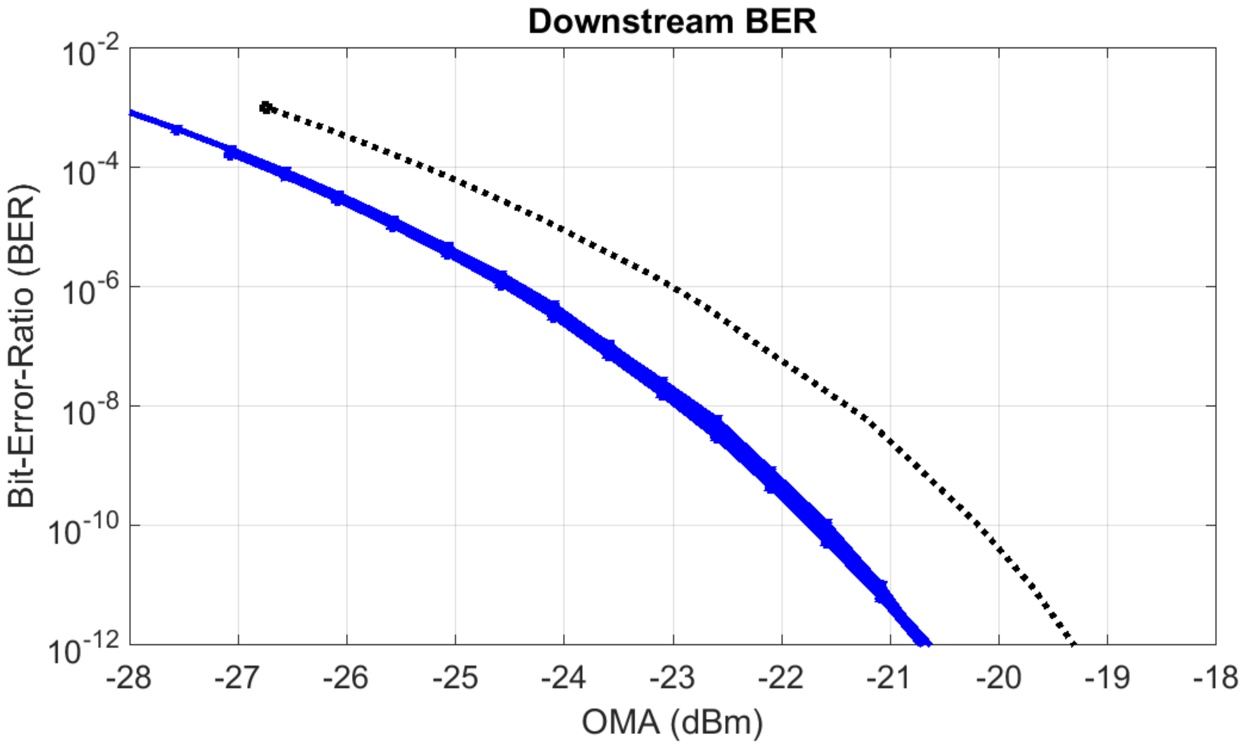
TTC PON

- OLT → ONUs (broadcast)
- LHC Bunch Clock (BC) synchronous
- 9.6Gbps serial link
- 8B10B encoded, K28(.1, .5) comma
- Full Payload: 24 bytes (192 bits) per BC
- Slow Control field: 3 bytes
- **User Data Field: 20 bytes (160 bits)**

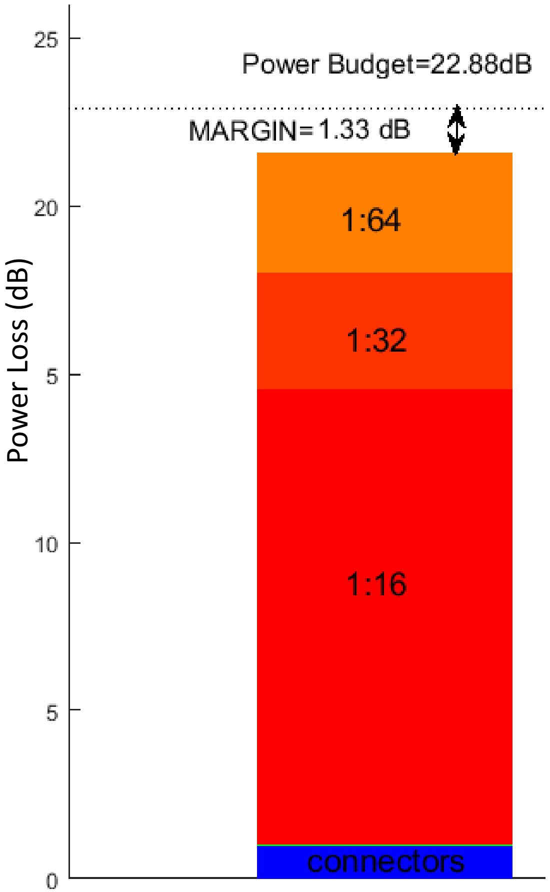


Downstream Power Budget

TTC PON



- Target BER : 10^{-12} - CL: 0.95



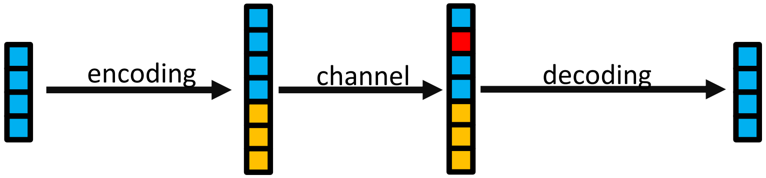
For 100m fiber

➡ A FEC can help gaining some margin

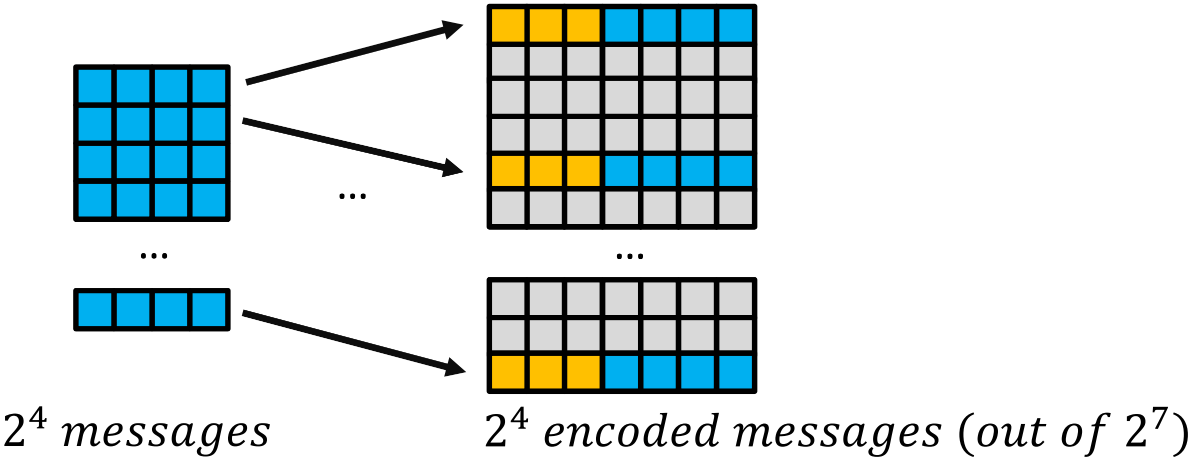
Downstream FEC

TTC PON

- Principle FEC (Forward Error Correction)



  - In its most basic way (add redundancy – sparse representation)



  - Commonly used encoding schemes

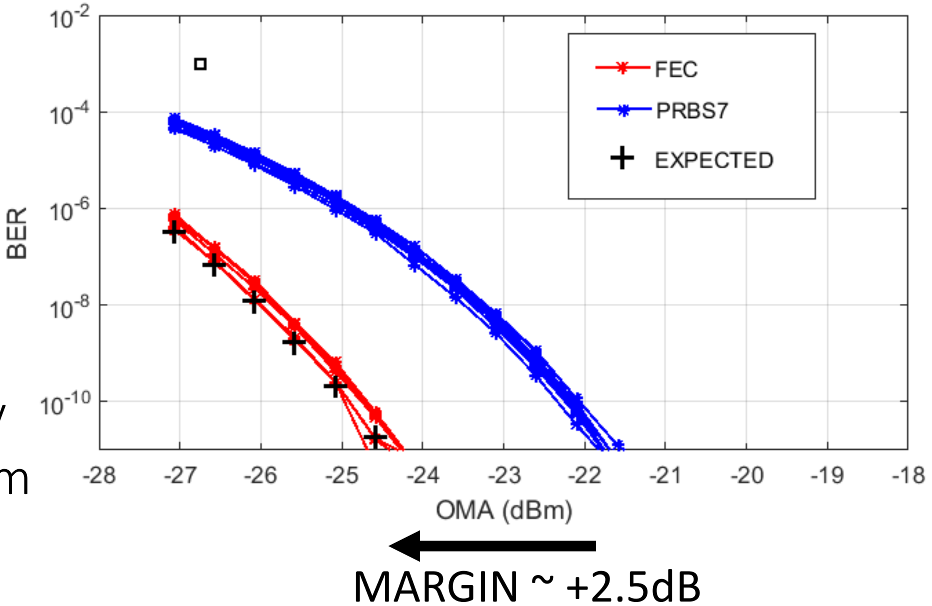
    - Reed-Solomon (GBT)
    - BCH (Bose Chaudhuri Hocquenghem) => for 1 bit error correction = Hamming code (TTC)

    ...

Downstream FEC

- FEC to TTC-PON
  - Observed errors seem to have a random nature (not like GBT-link which suffers from bursty errors under radiation)
  - BCH encoding is good for correcting random errors with a relatively low complexity
- Main figures of merit
  - Efficiency
  - Coding gain
  - Latency
  - Complexity (area)
- A study is **being carried out** to identify the most suited scheme for our system

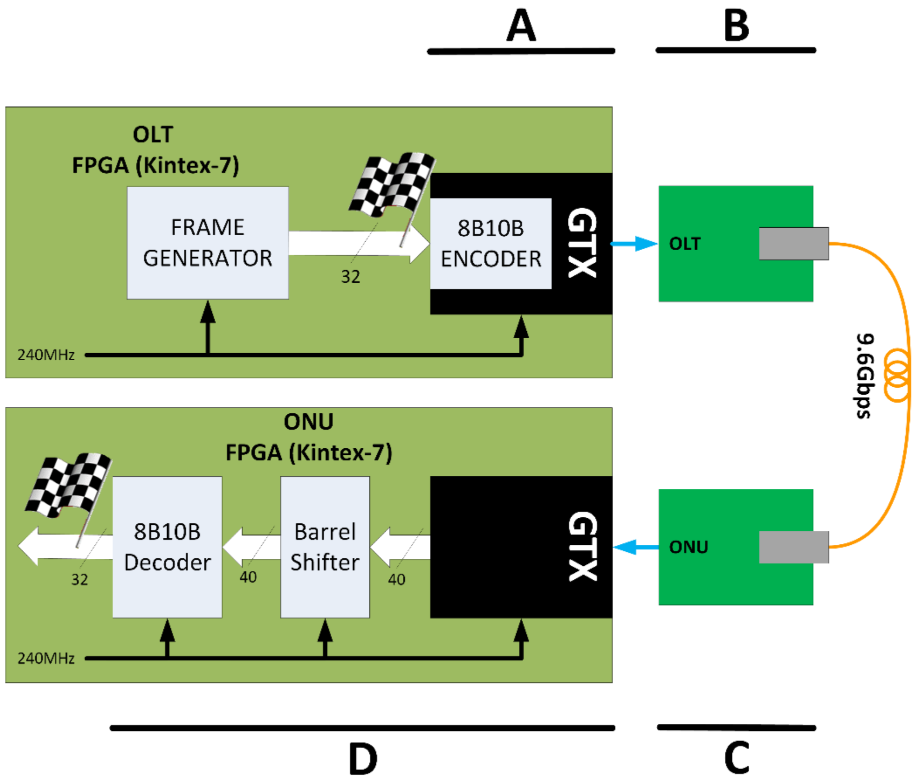
Ex.: correcting one error in 40b packet (eff.=85%)



Downstream Latency

TTC PON

- Fixed & deterministic
- 86ns (Active components only)
- Comparable to current TTC (even a bit lower)



Downstream latency =A + B + C + D <= 86ns

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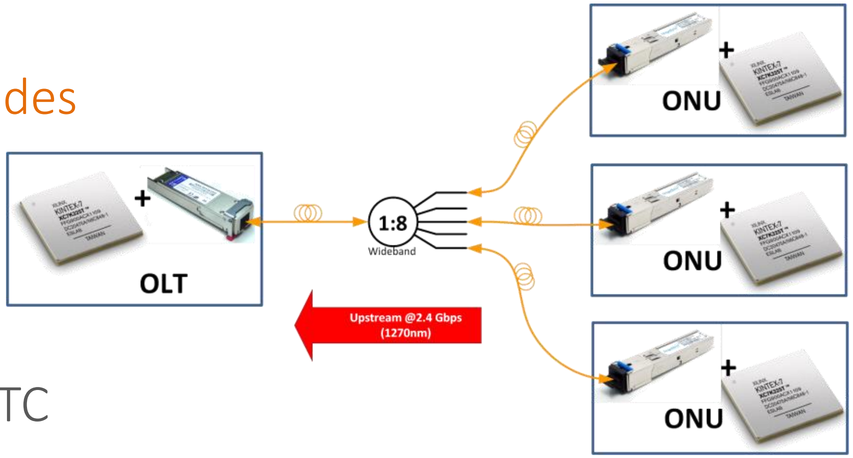
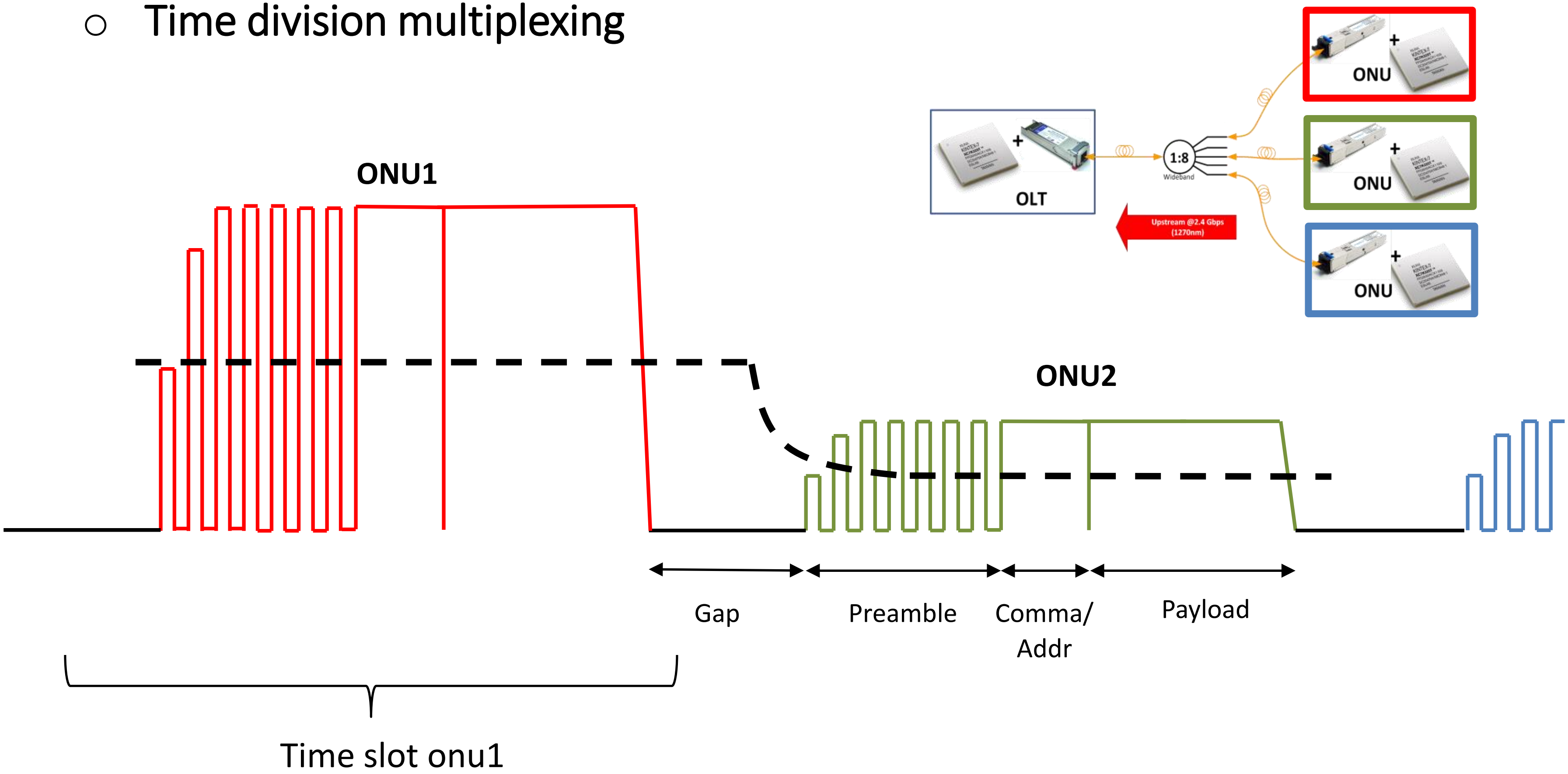


Upstream data transmission scheme

TTC PON

- Time division multiplexing

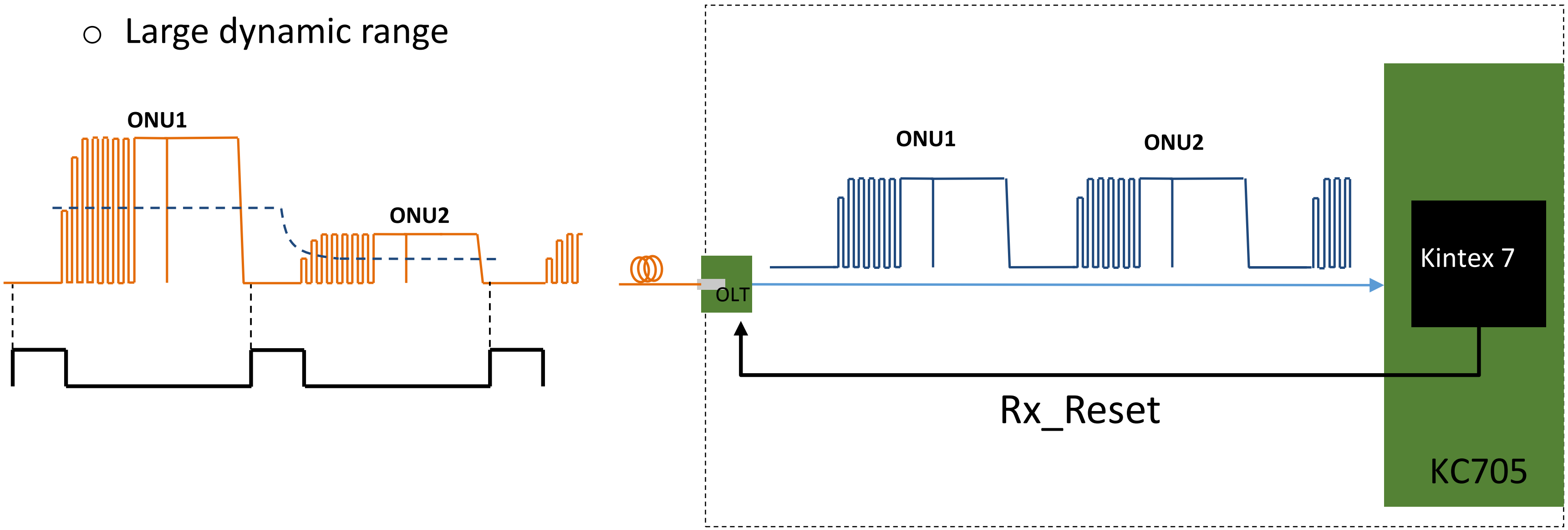


Waiting time= (Number ONU's) x (Time slot ONU)

Upstream data transmission scheme

TTC PON

- Major difficulties in burst-mode receivers
  - Short settling time
  - Large dynamic range

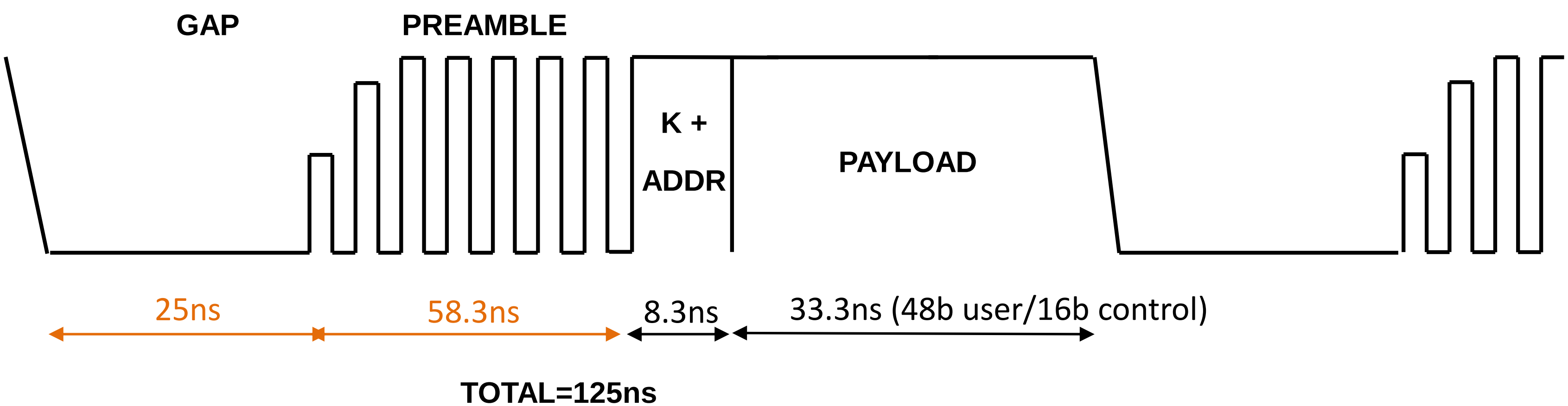


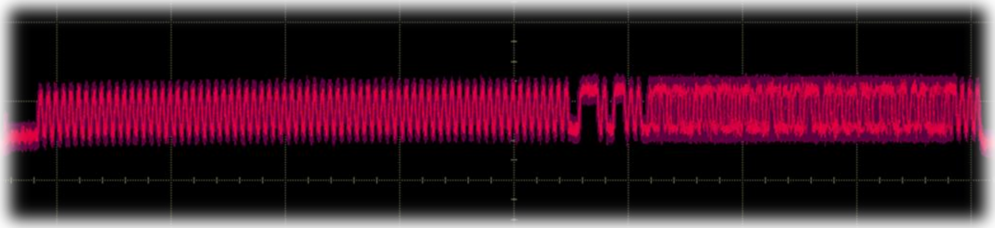
- Reset between bursts to start threshold extraction (feature XGPON)

Upstream data transmission scheme

TTC PON

- Burst composition:





- XGPON specs:
  - Minimum Gap: 25ns
  - Minimum Reset Pulse Width: 25ns
  - Maximum Settling time: 52ns (=min. preamble length)

Upstream Challenges & Performance

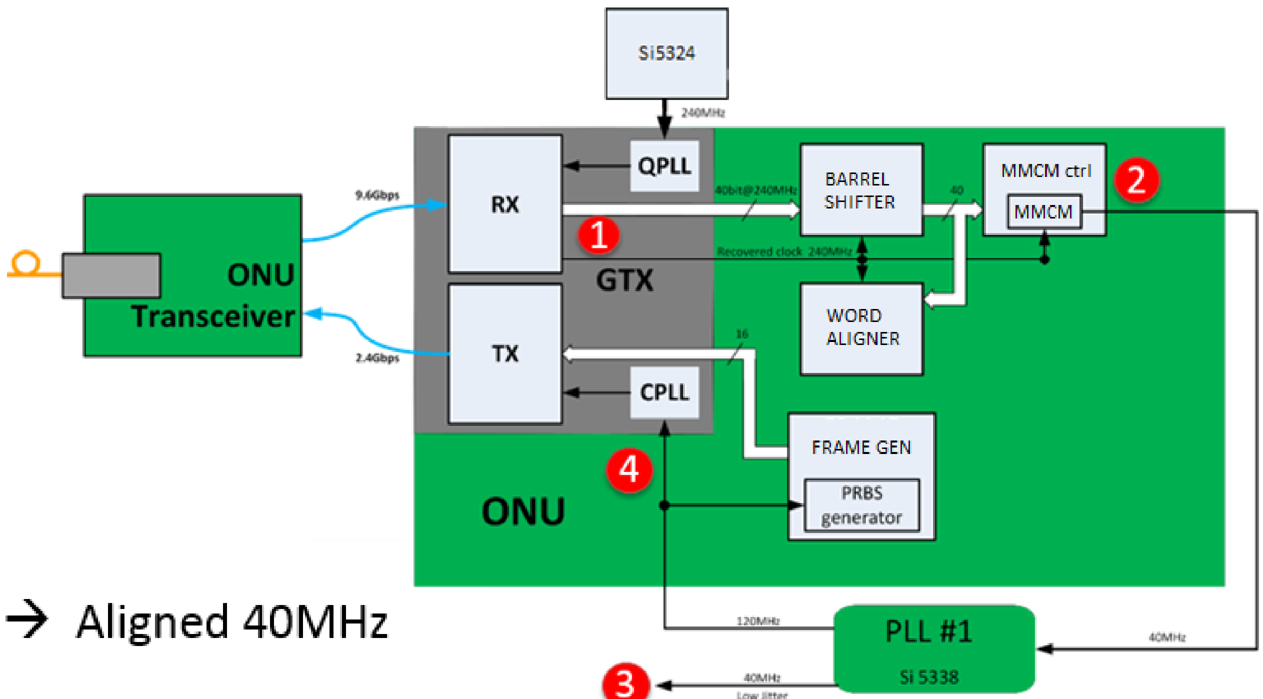
TTC PON

- Challenges of short bursts:
  - Link synchronization
  - ⇒ Clock recovery and re-use for transmit path (@ONU level)
  - Phase changing between bursts → classical CDR is not an option
  - ⇒ Oversampling scheme (@ OLT RX level)
  - TDM arbitration (token is automatically passed between ONUs)
  - ⇒ Requires a calibration procedure
- Performance
  - Power Budget
  - Dynamic Range
  - Missing ONU analysis
  - Latency

Upstream Challenges

TTC PON

- Link synchronization @ ONU
    - Clock recovery and re-use for upstream transmission



1. Recovered 240MHz
2. 240MHz → 40MHz → Aligned 40MHz
3. Clean 40MHz
4. 40MHz → 120MHz aligned to 40MHz

Upstream Challenges & Performance

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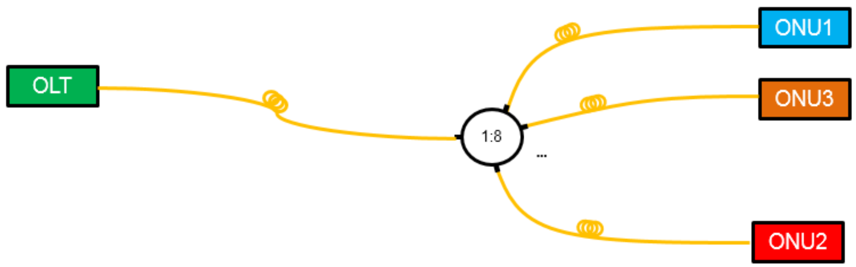
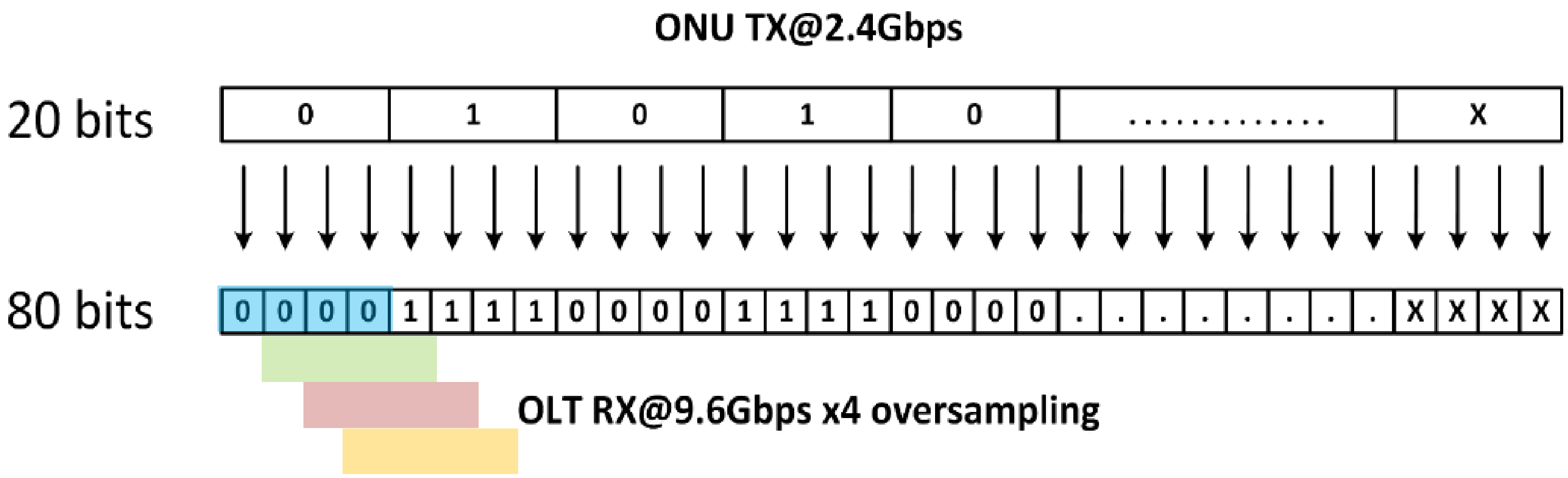
Upstream Challenges

TTC PON

- Phase changing between bursts
  - Oversampling scheme@OLT (principle x4 oversampling)

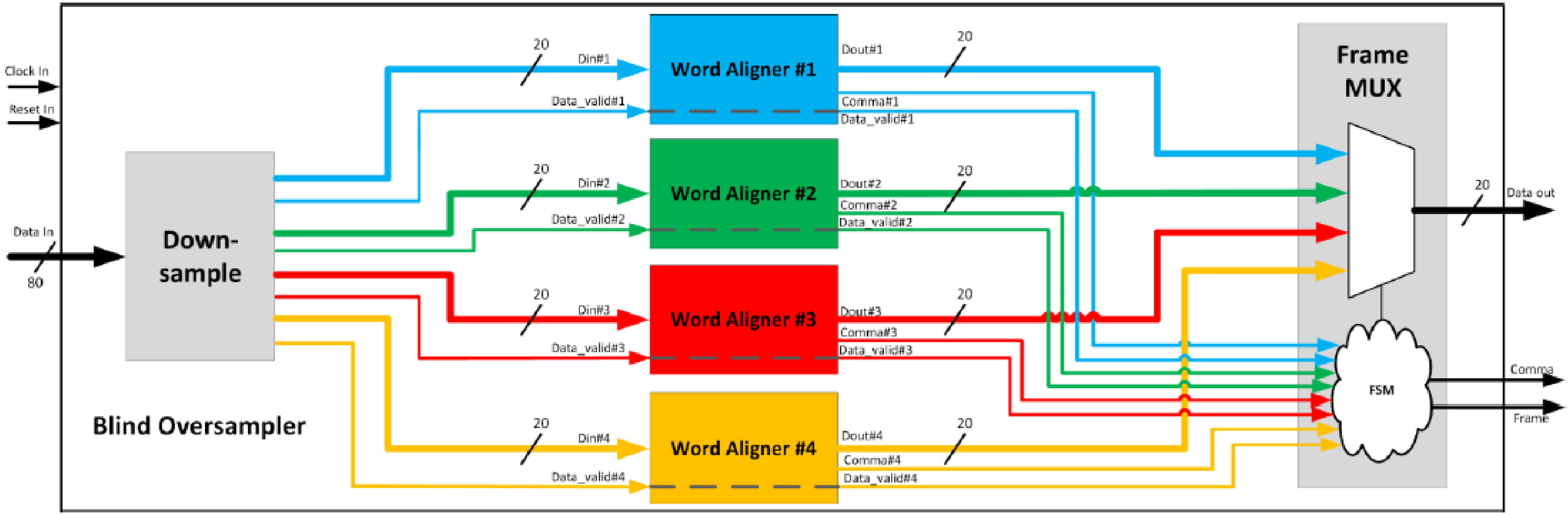




Upstream Challenges

TTC PON

- Phase changing between bursts
  - Oversampling scheme@OLT
  - Architecture BOS (BlindOverSampler)



Upstream Challenges & Performance

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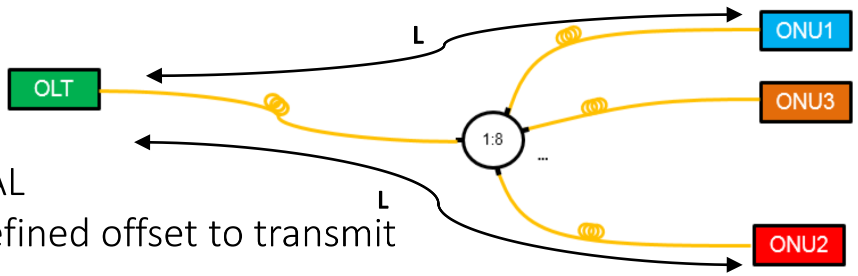
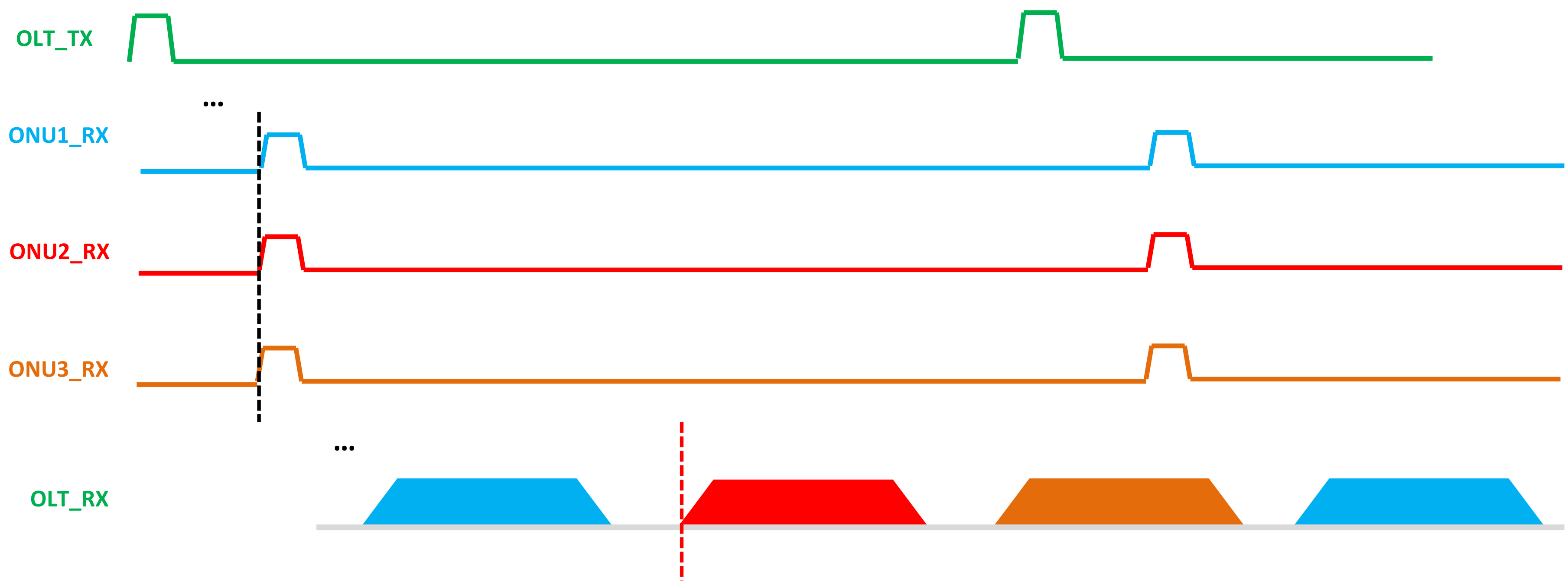
Upstream Challenges



- TDM arbitration
  - OLT broadcast TIME REFERENCE SIGNAL
  - Each ONU has an internal counter + defined offset to transmit



Upstream Challenges

TTC PON

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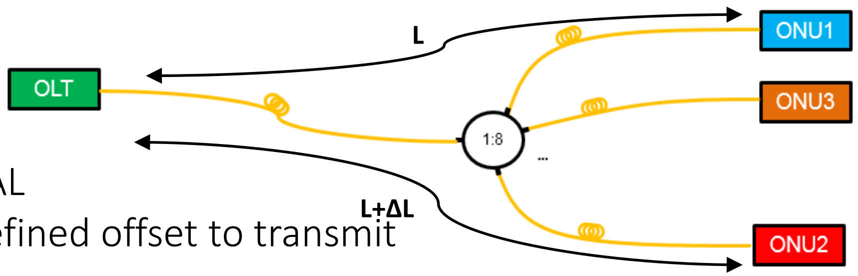
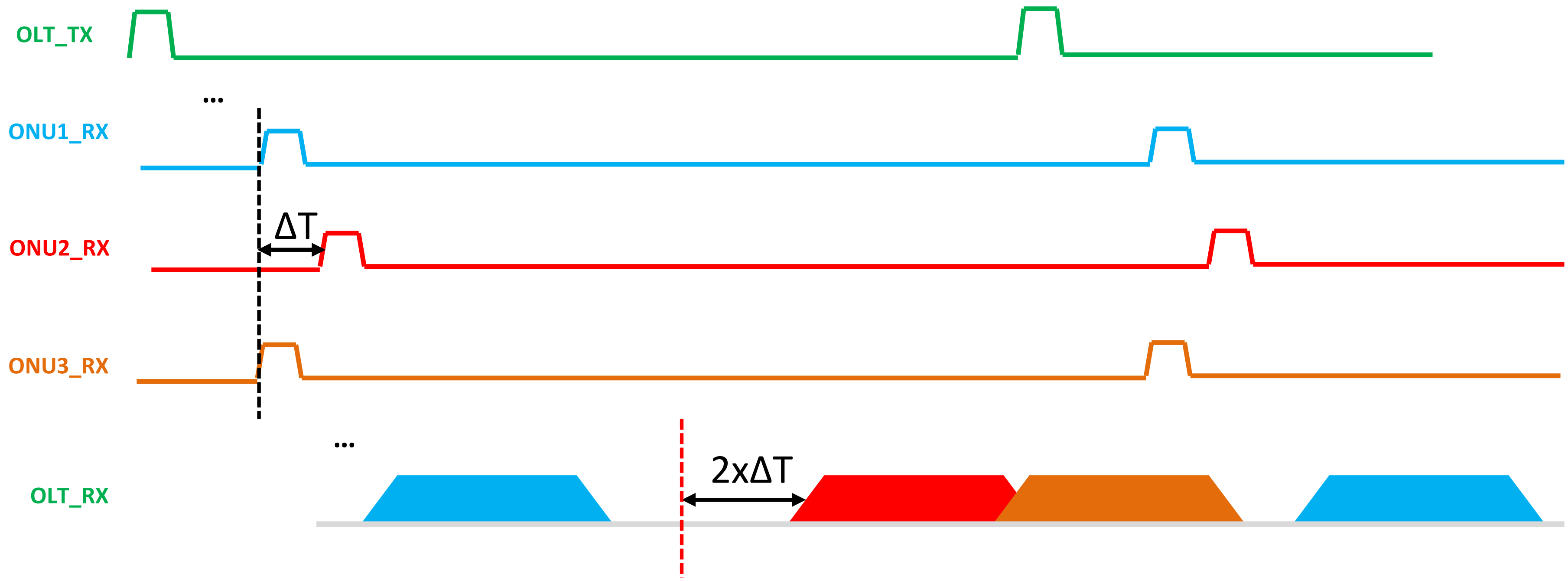
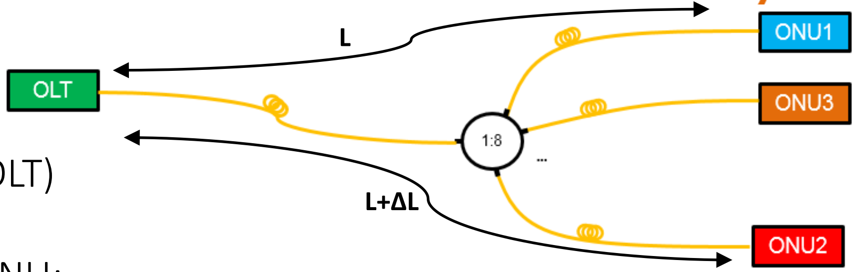


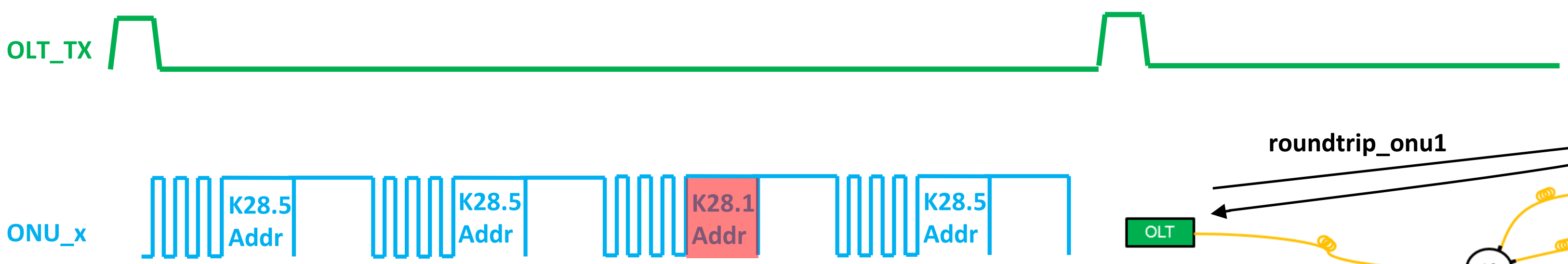


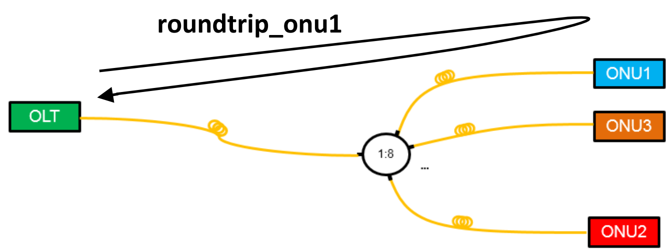
Upstream Challenges

TTC PON



- TDM arbitration – Calibration
  - The procedure is arbitrated by the master (OLT)
  - OLT measures the roundtrip time for each ONU:
    - OLT sends a command: ONU_x enters in calibration_mode / all the others disable transmission
    - When a onu is in calibration_mode, it sends data in a continuous way and acts as a comma-mirror



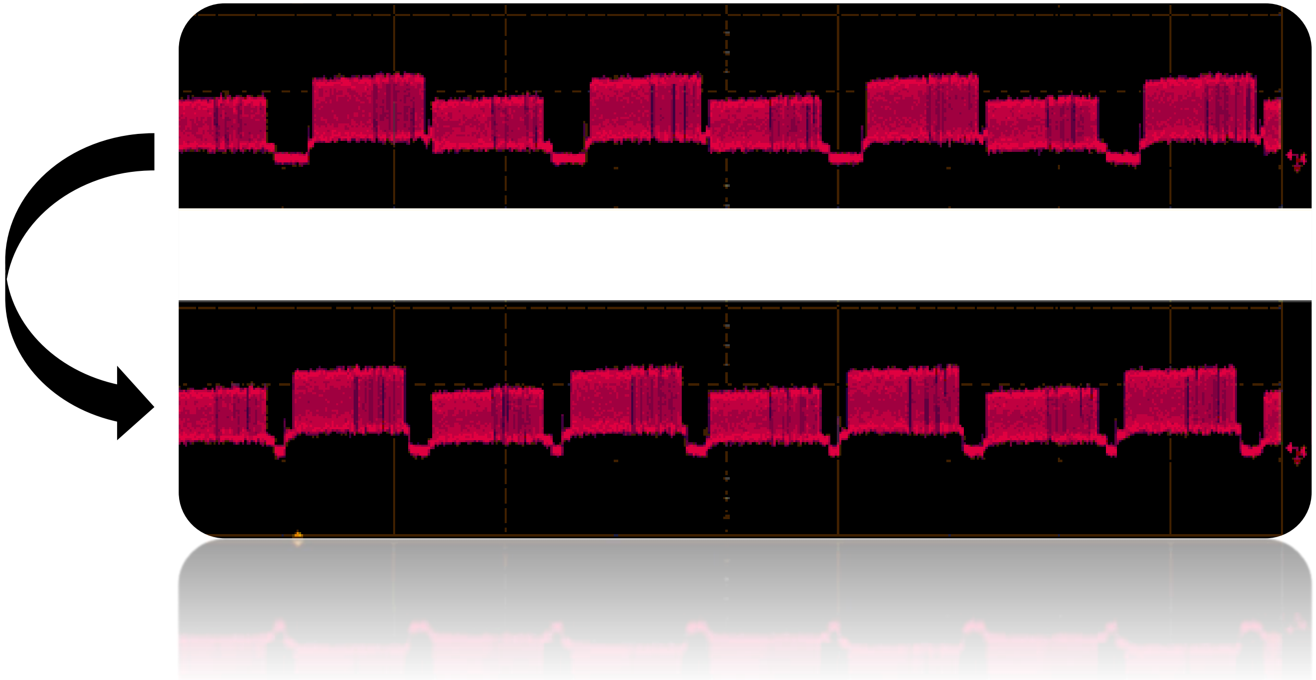


- ONU_x offset is compensated depending in the measured roundtrip

Upstream Challenges

TTC PON

- TDM arbitration – Calibration Illustration



- **More than 10.000 tests performed (also with different fiber lengths)**
- **Resolution=0.417ns* / Calibration time < 1ms (per ONU)**

Upstream Challenges & Performance

TTC PON

- Challenges of short bursts:
  - Link synchronization
  - ⇒ Clock recovery and re-use for transmit path (@ONU level)

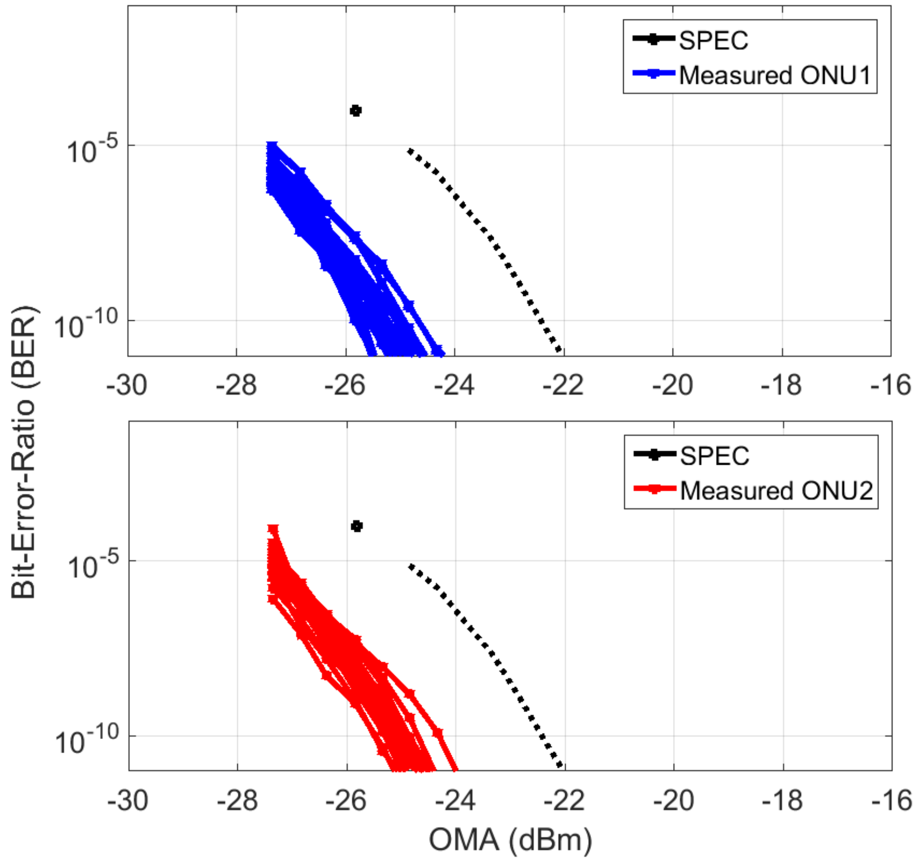
  - Phase changing between bursts → classical CDR is not an option
  - ⇒ Oversampling scheme (@ OLT RX level)

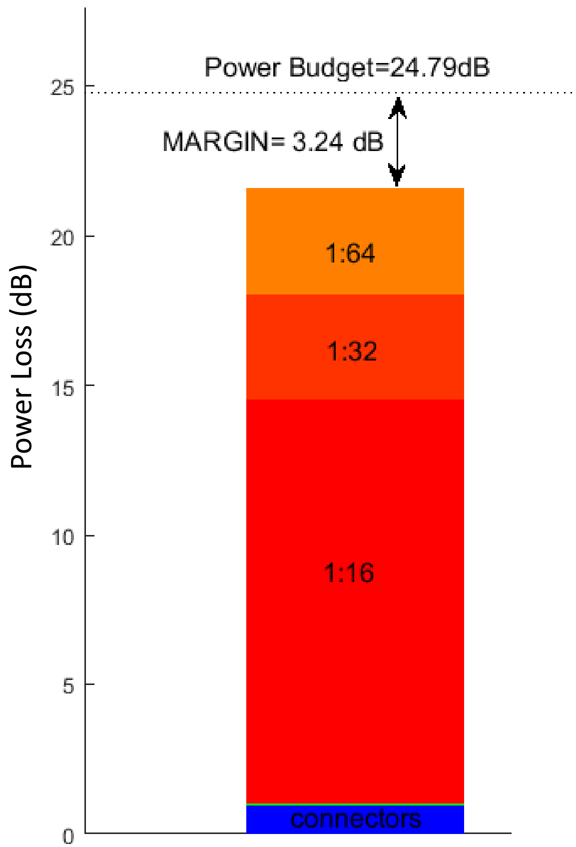
  - TDM arbitration (token is automatically passed between ONUs)
  - ⇒ Requires a calibration procedure

- Performance
  - Power Budget
  - Dynamic Range
  - Missing ONU analysis
  - Latency

Upstream Performance

Power Budget





For 100m fiber

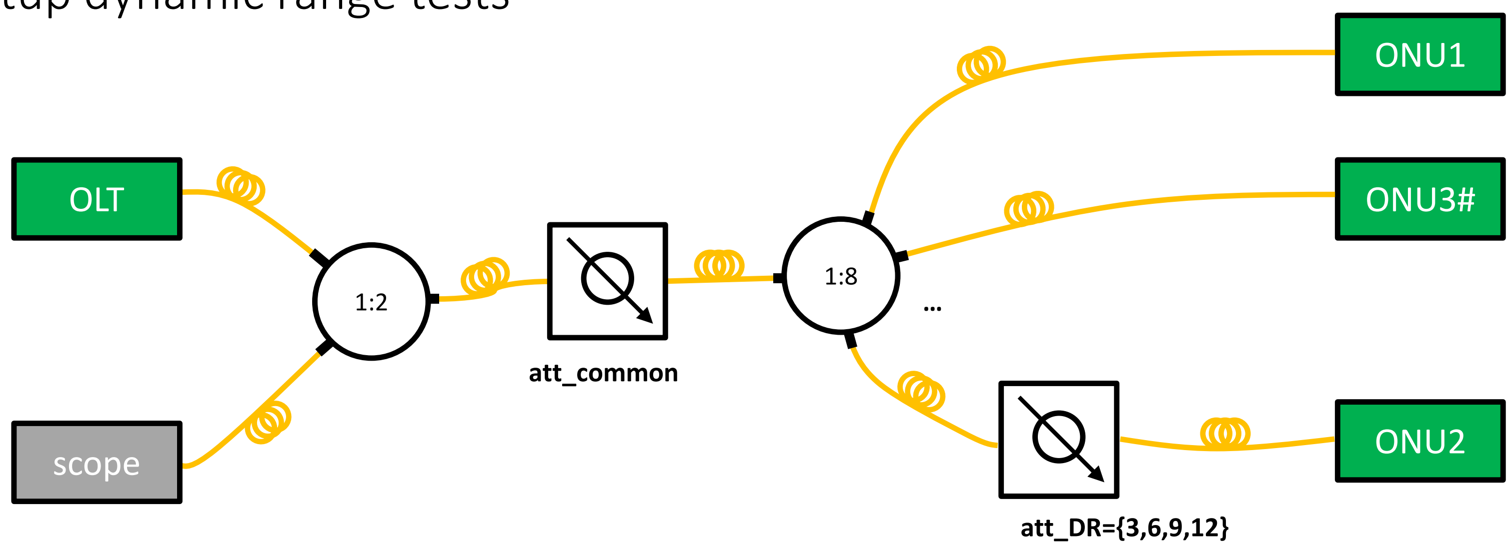
- Target BER : 10^{-11} - CL: 0.95 – ≈10 days measurement

➡ Reasonable margin

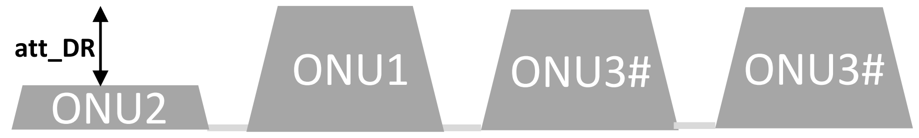
Upstream Performance

Dynamic Range

- Setup dynamic range tests



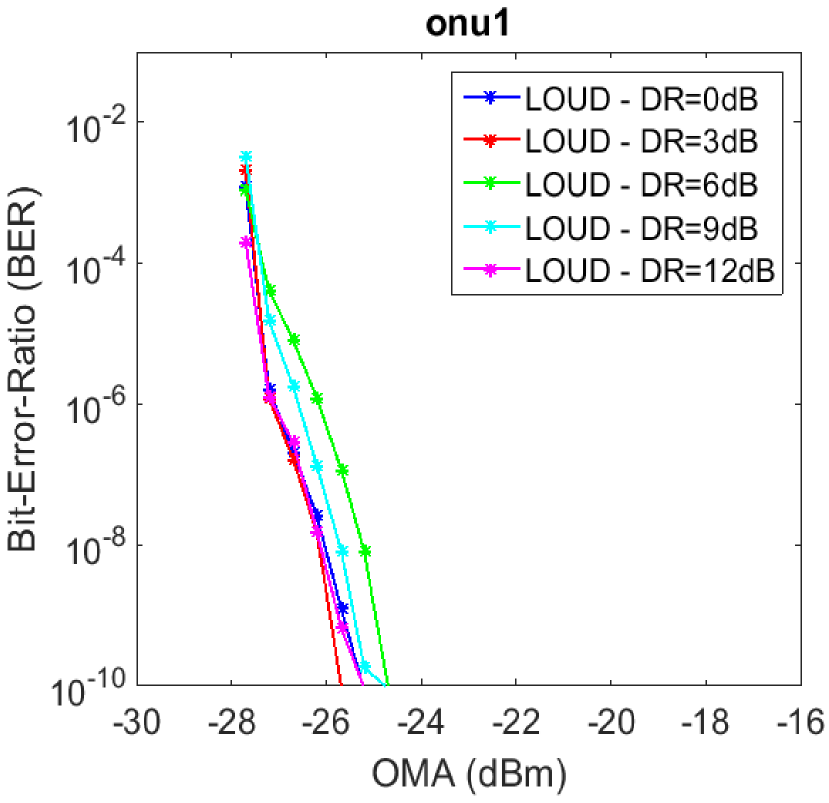
ONU3# is used for emulation purposes

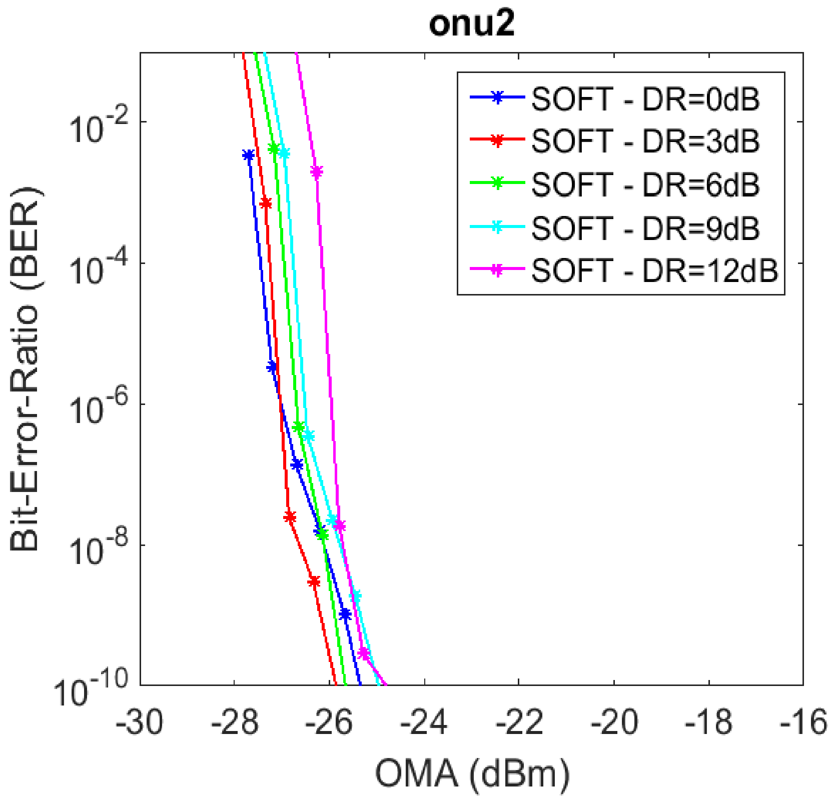


Upstream Performance

Dynamic Range

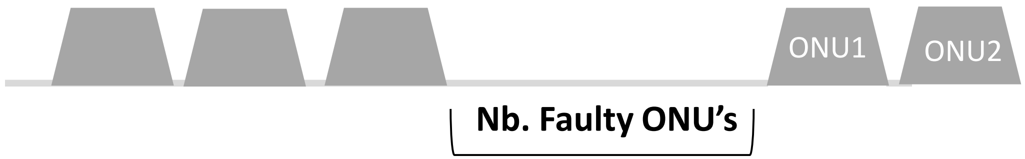
- No penalty up to 12 dB



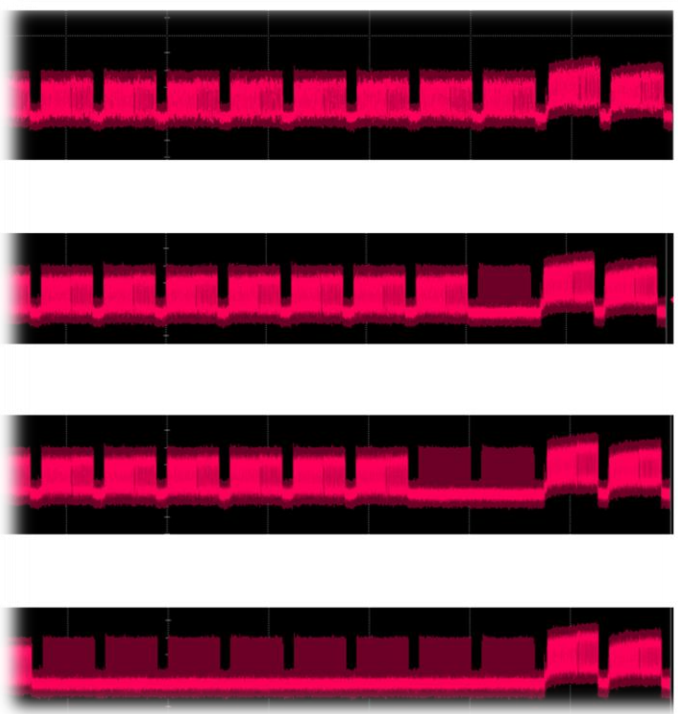


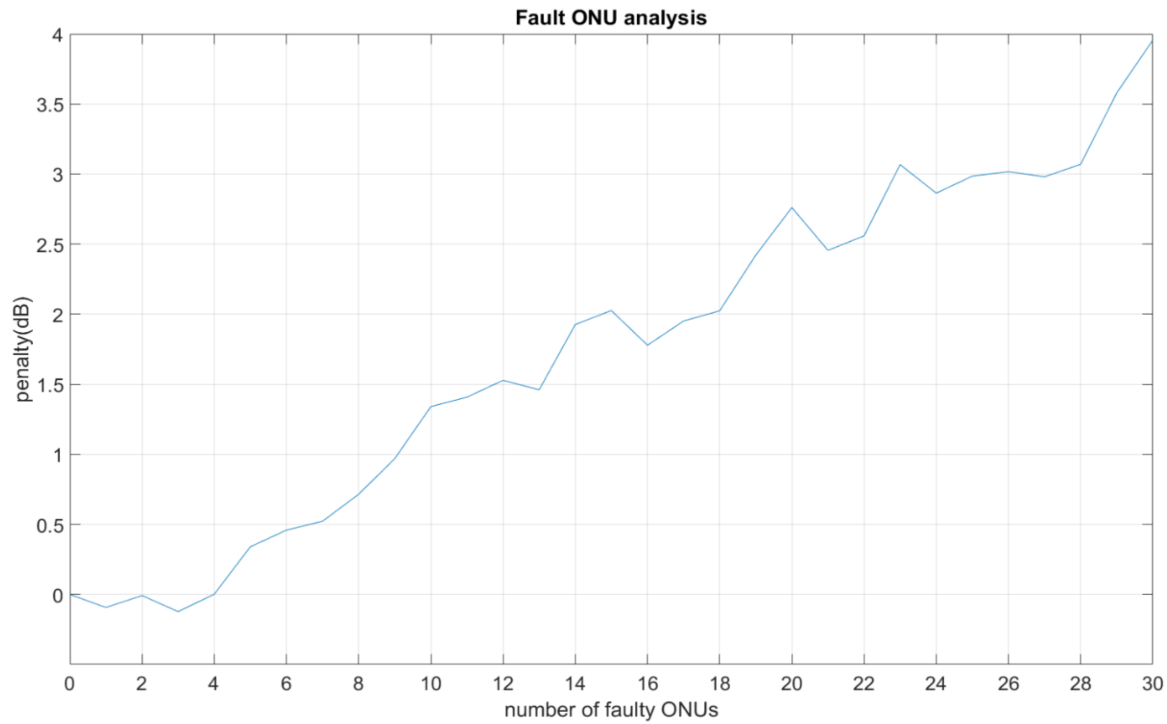
Upstream Performance

Missing ONU analysis



*ONU3 emulates 64 ONU's





Outline

- Introduction to FTTx & PON
- From TTC to TTC-PON(s)
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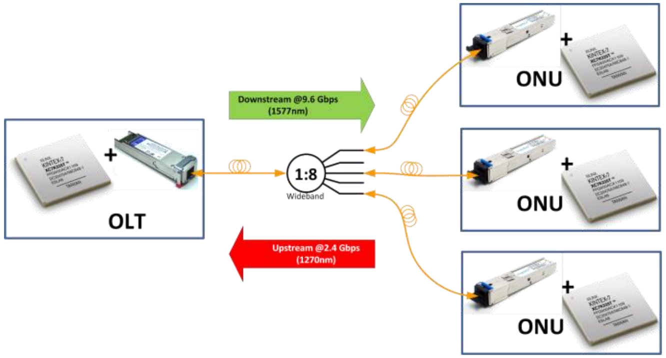
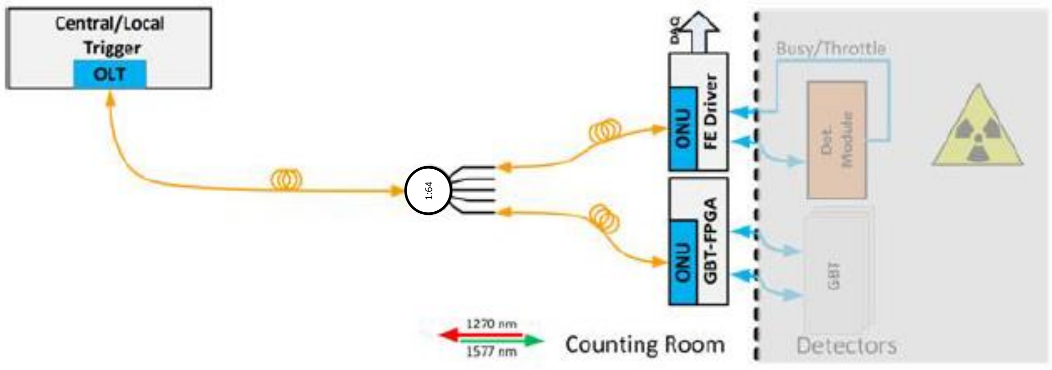


System Performance

TTC PON

System
Bidirectional
Fully scalable and flexible
Split ratio: 1:64 maximum
*Immune to temperature variations



Downstream	
Bunch clock synchronous	
Data-Rate	9.6Gbps (6.4Gbps user)
Payload user	160b (per BC)
Latency	~86ns

Upstream	
Data-Rate	2.4 Gbps - linerate 8Mbps (64 ONU's)
Payload user	48b (each N_ONUx125ns)
Waiting time per ONU	N_ONUx125ns 8us – 64 ONUs 4us – 32 ONUs
Dynamic range	12 dB (!)

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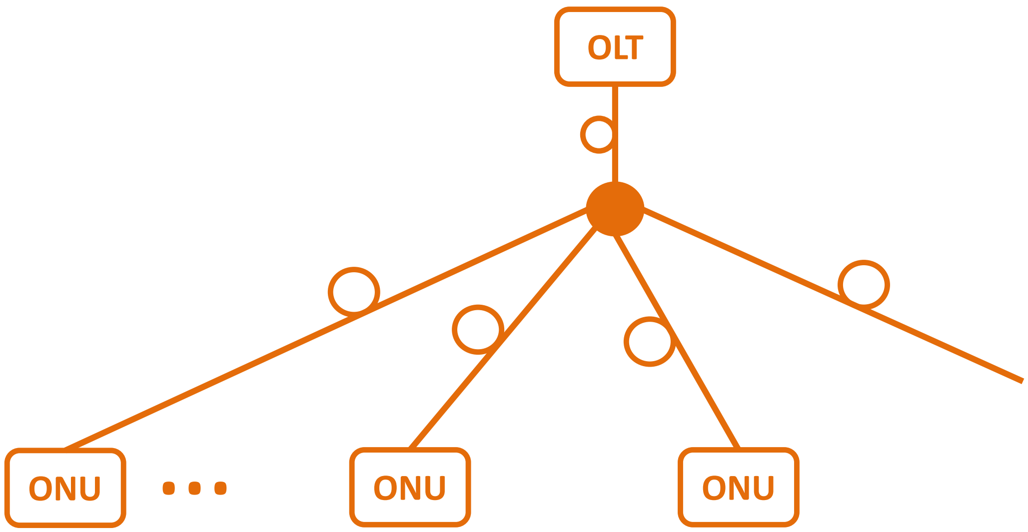
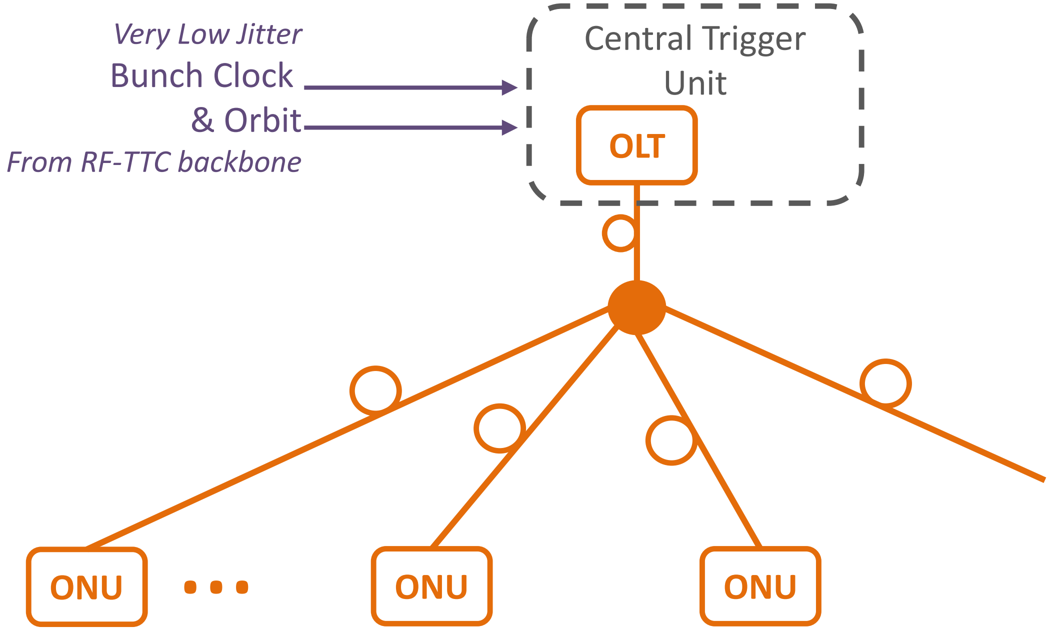
Integration with GBT & legacy TTC

TTC PON



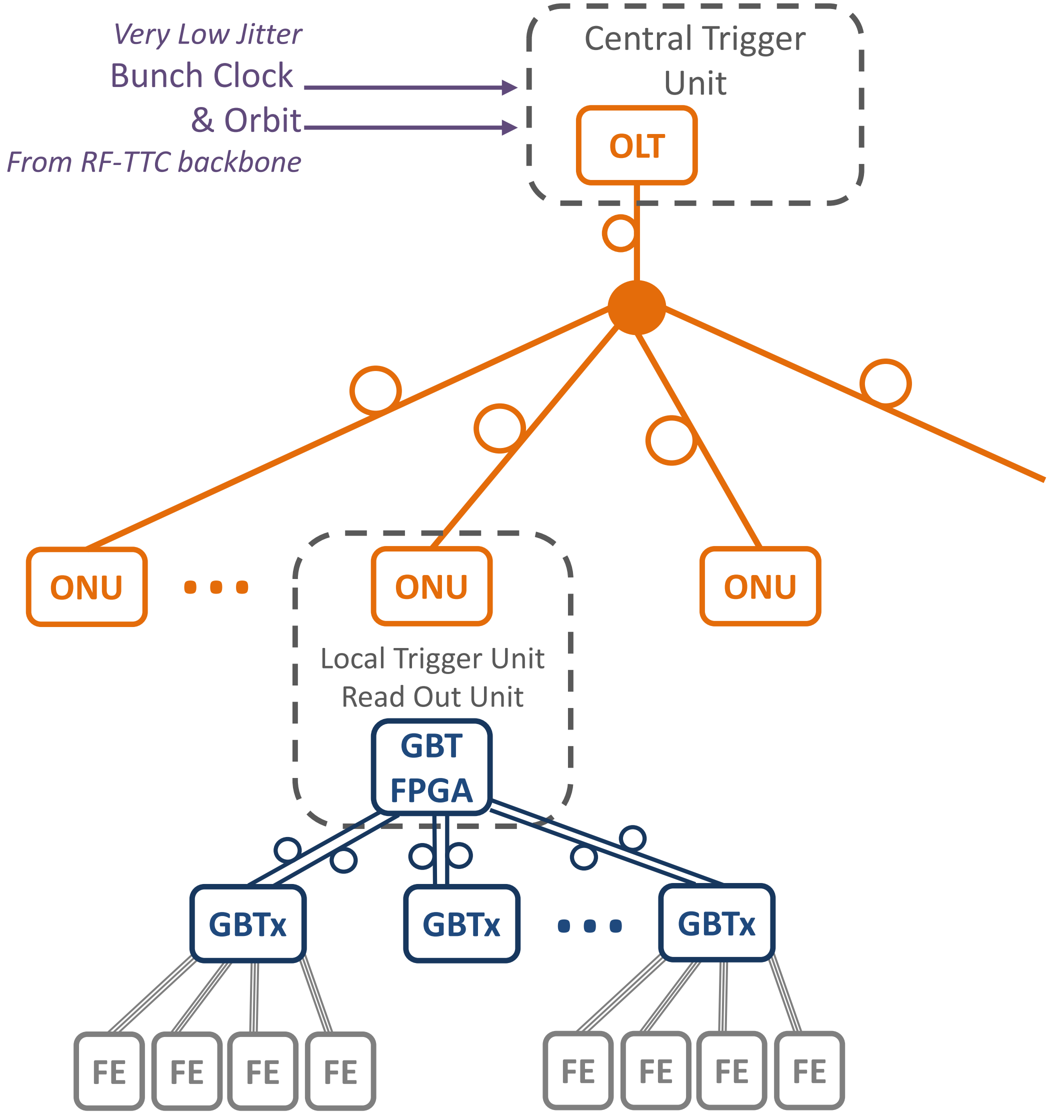
Integration with GBT & legacy TTC

TTC PON

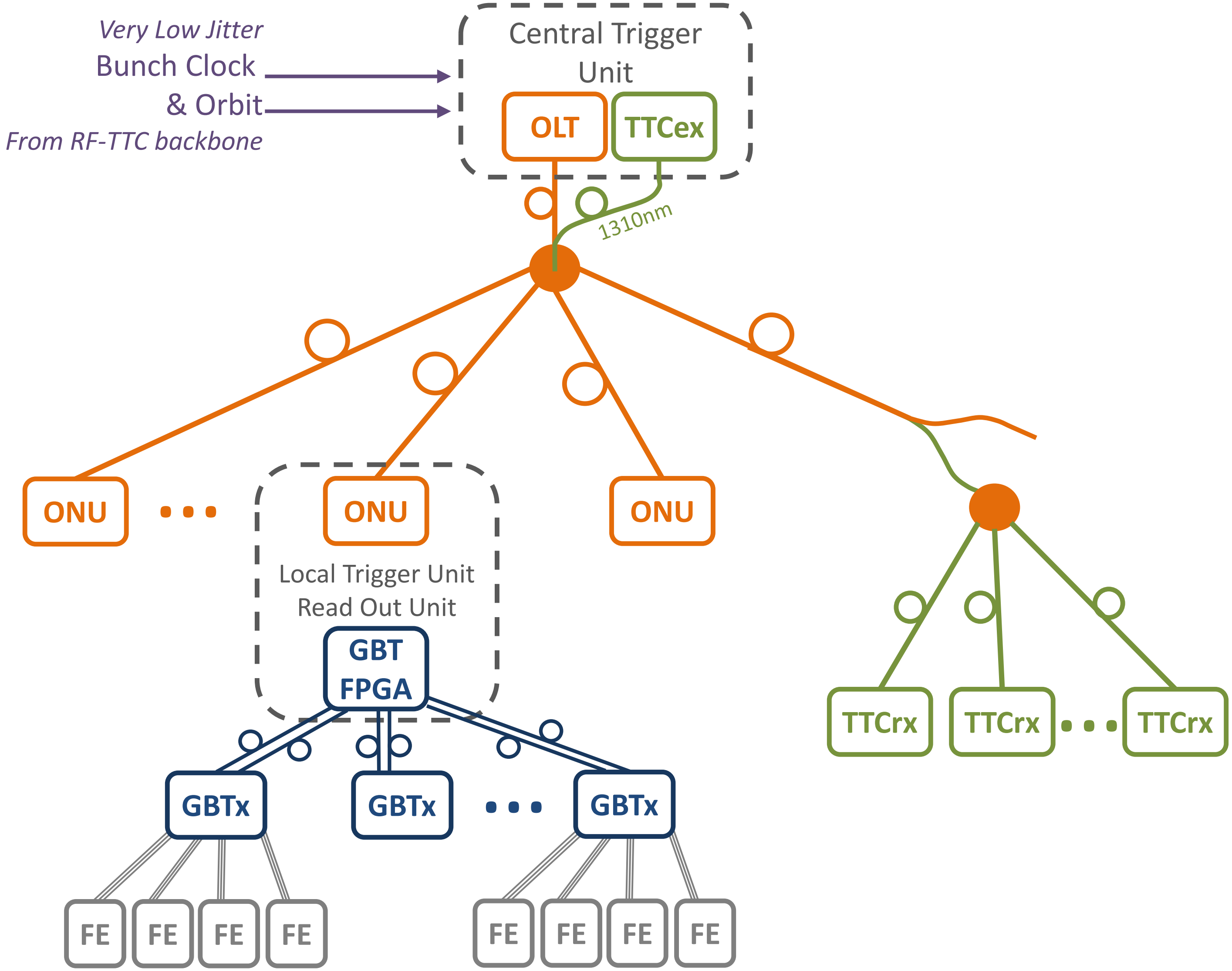


Integration with GBT & legacy TTC

TTC PON



Integration with GBT & legacy TTC



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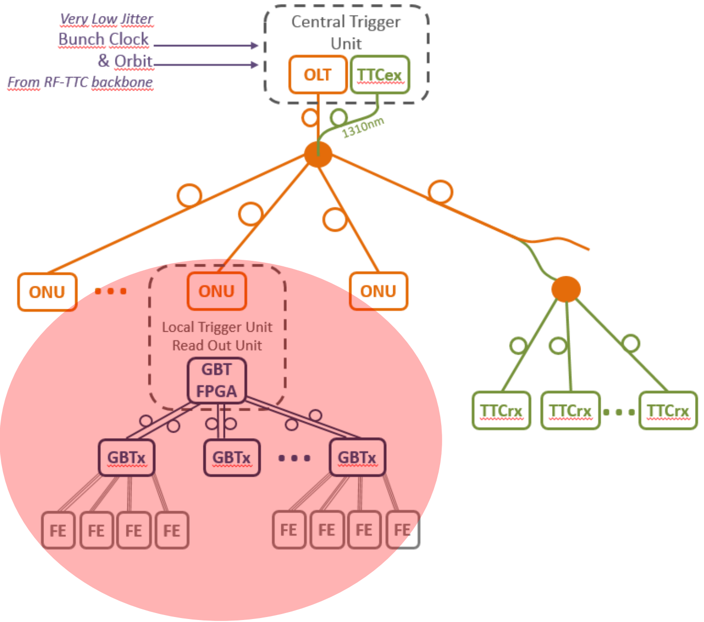
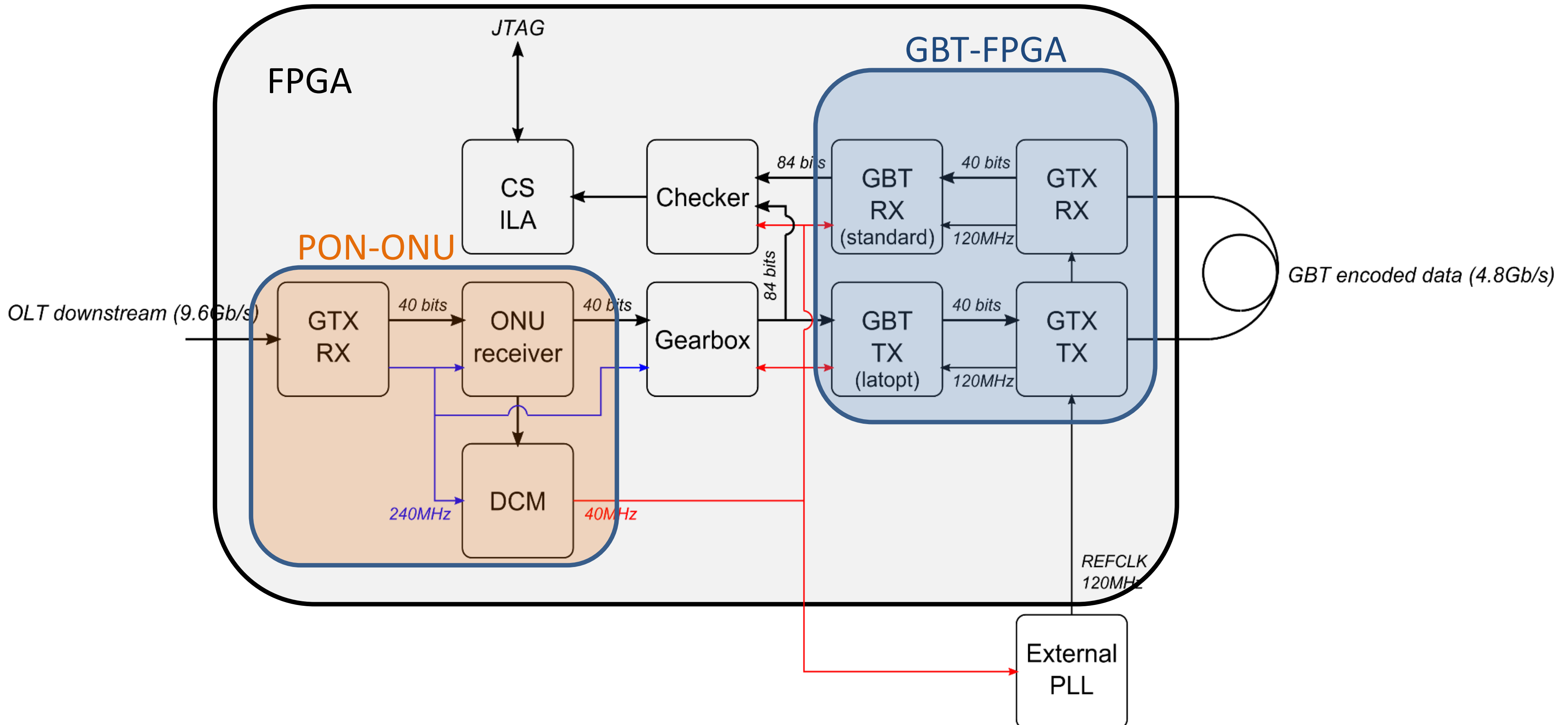


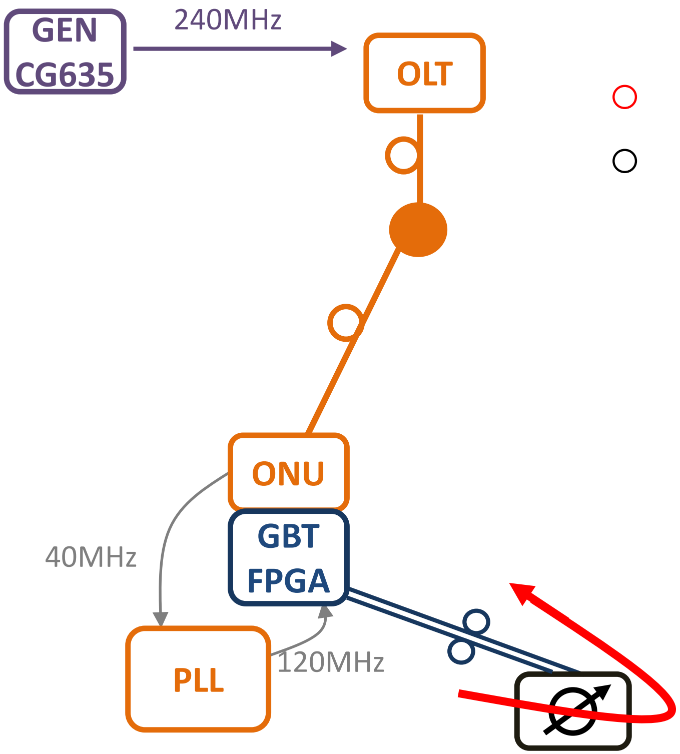
GBT link / PON-GBT bridge

TTC PON

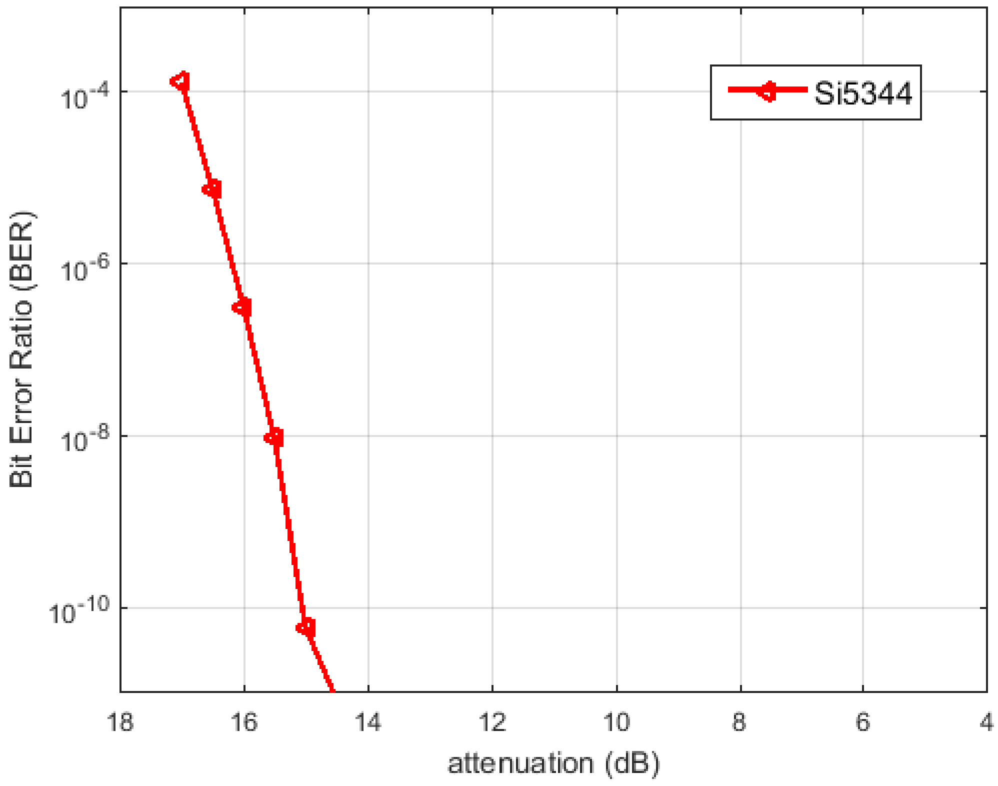


- External PLL=Si5344 / Si5338

GBT link / Loopback

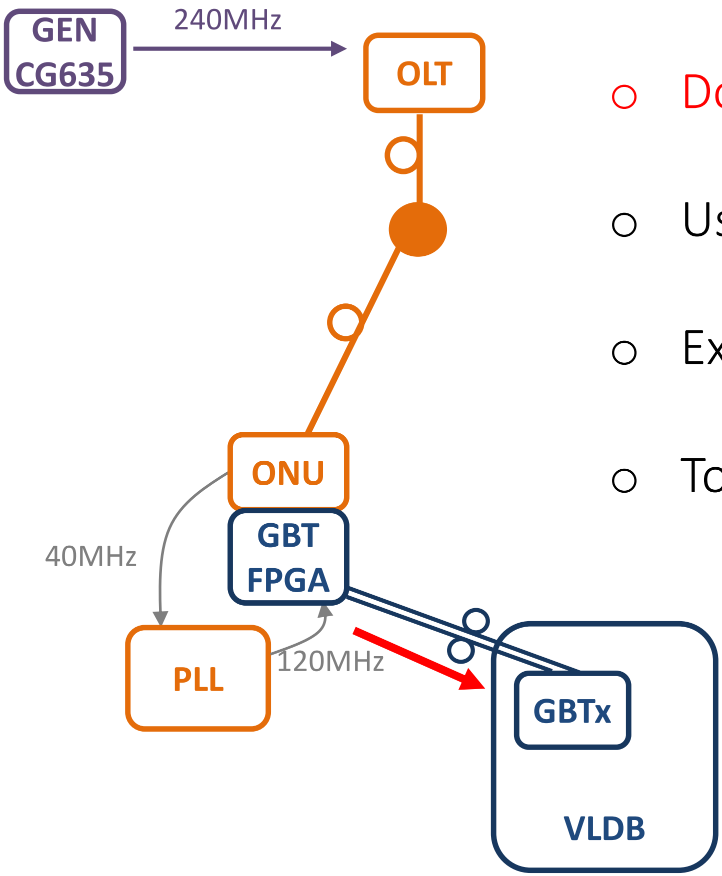


- Loopback test (prbs from OLT)
- External PLL=Si5344 / Si5338 (on-going)



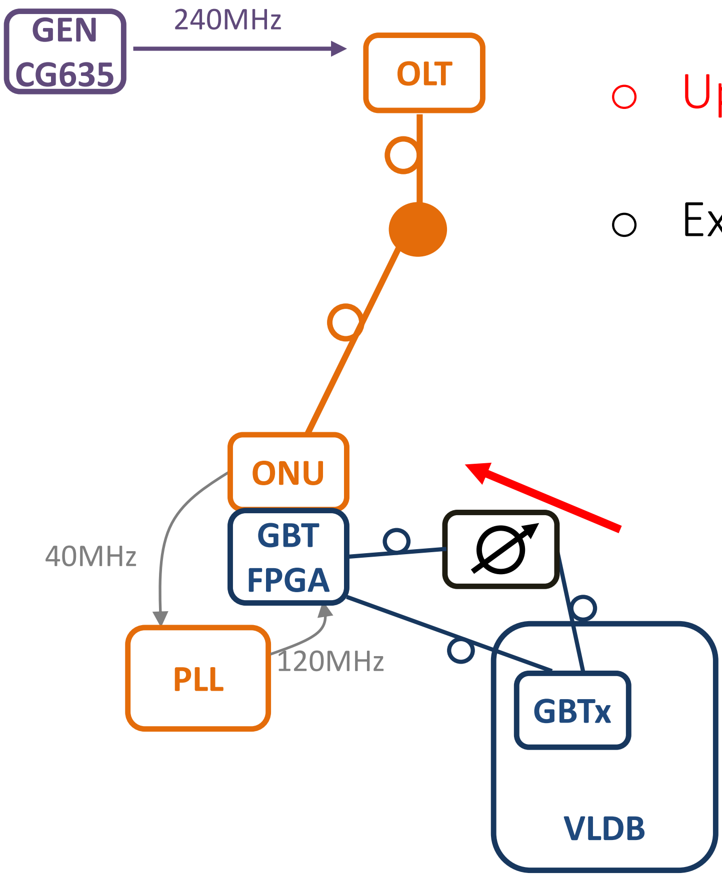
GBT link / Downlink

TTC PON

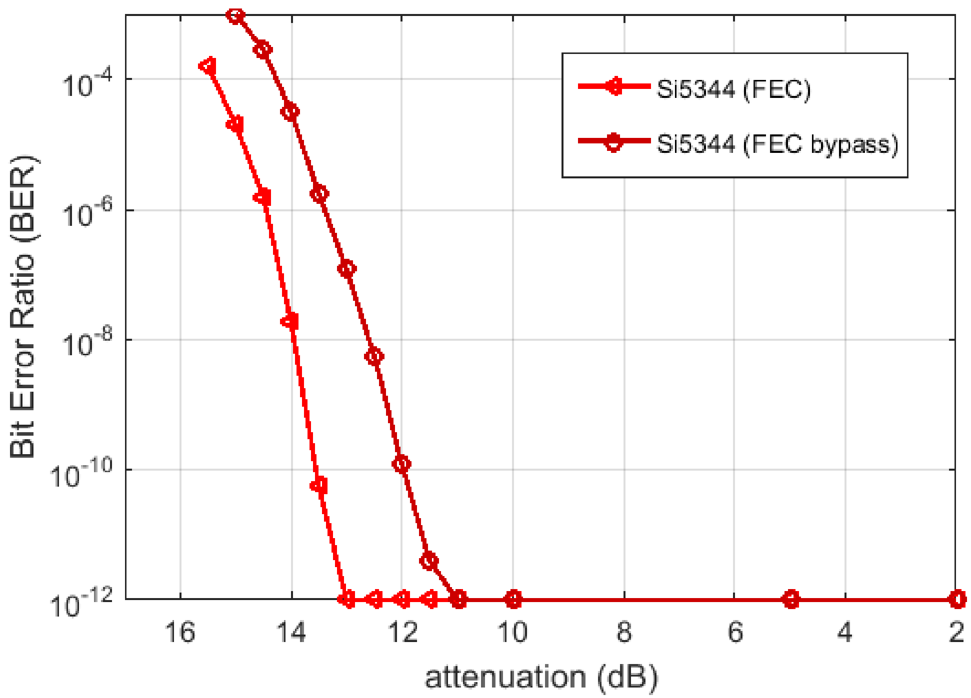


- Downlink sending constant pattern (scrambling)
- Using GBTx internal BERT – no errors found (~2h)
- External PLL=Si5344 / Si5338 (on-going)
- To be done: BERT using e-link

GBT link / Uplink



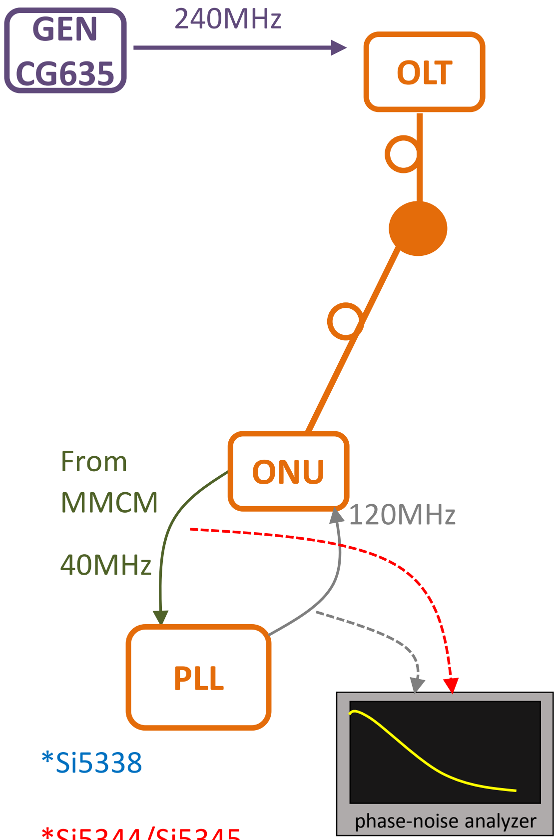
- Uplink sending constant pattern (scrambling)
- External PLL=Si5344 / Si5338 (on-going)



***GBTx in transceiver mode**

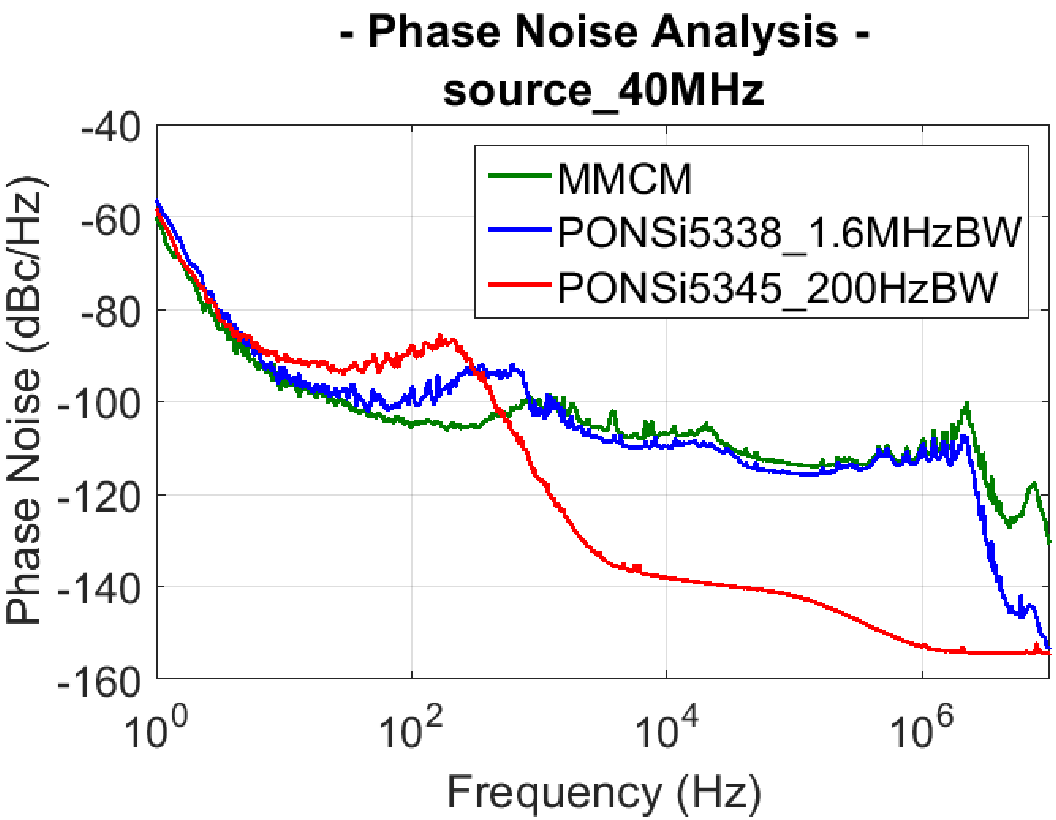
(recovered clock used for transmission)

GBT link / Jitter map



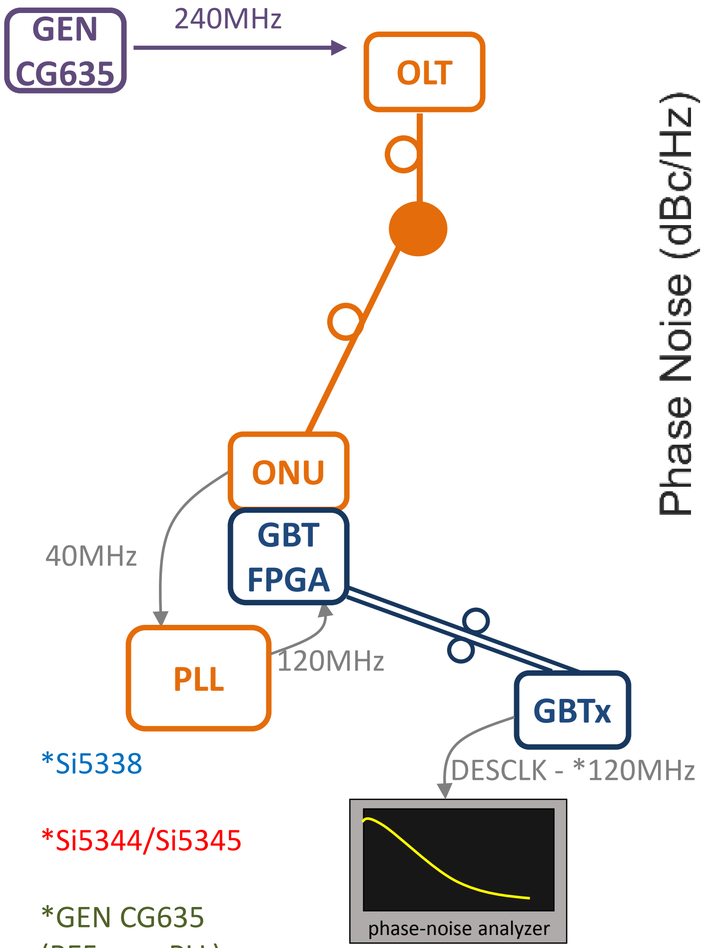
*Si5338

*Si5344/Si5345



	MMCM	Si5338	Si5344
RMS jitter (1Hz-10MHz)	43.39ps	24.99ps	4.95ps

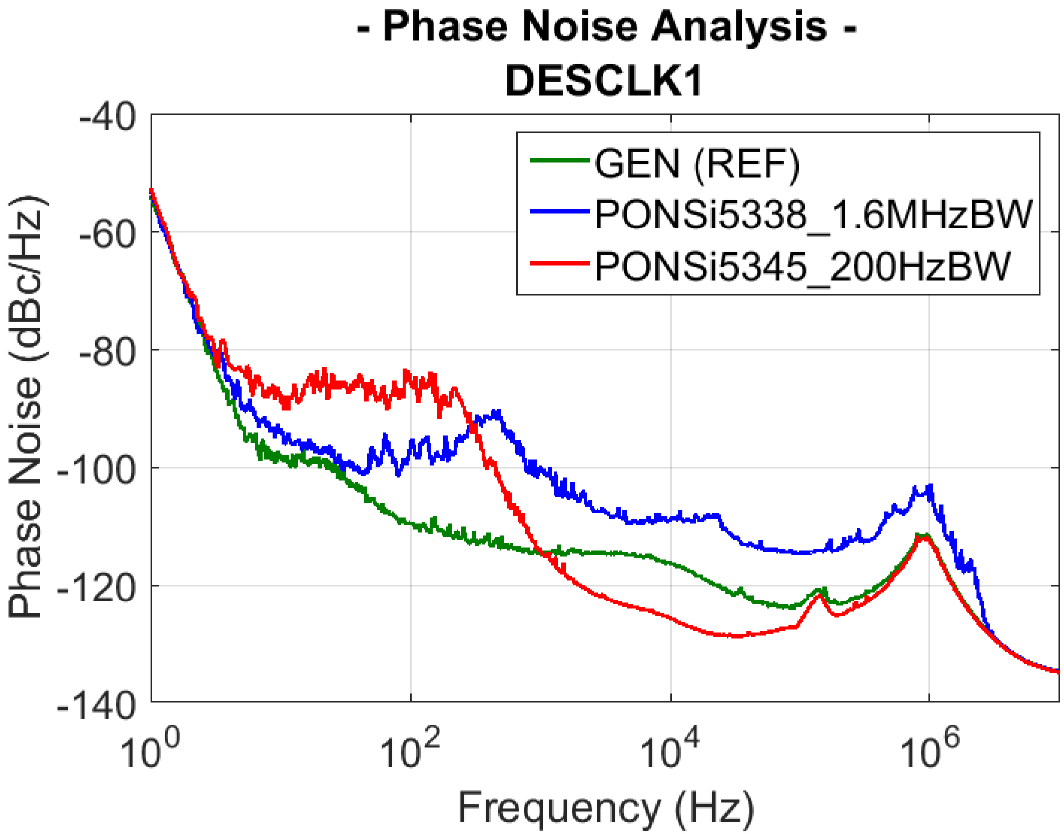
GBT link / Jitter map



*Si5338

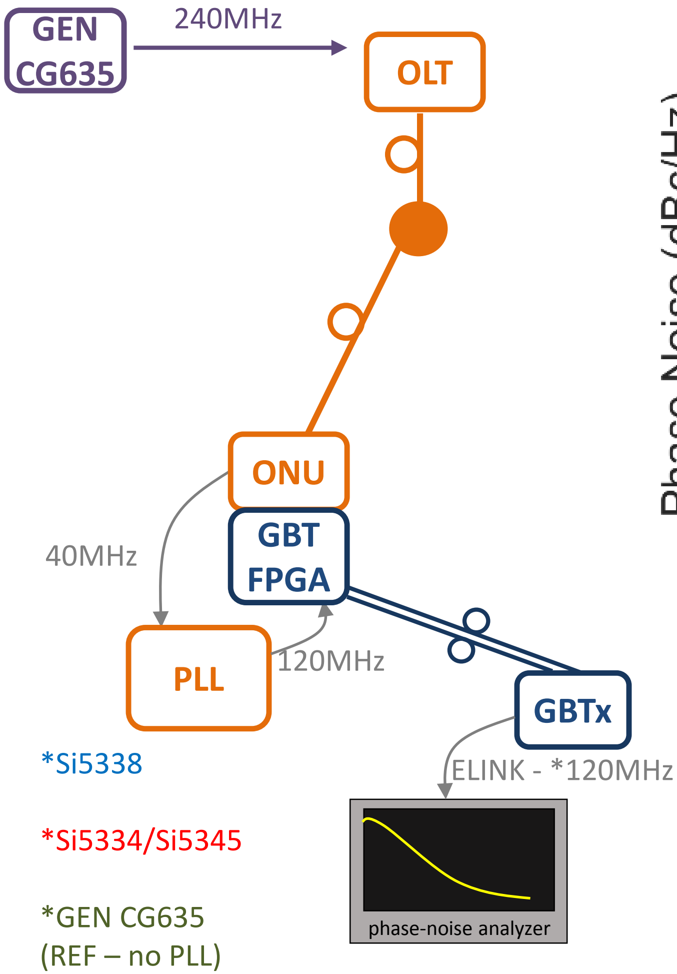
*Si5344/Si5345

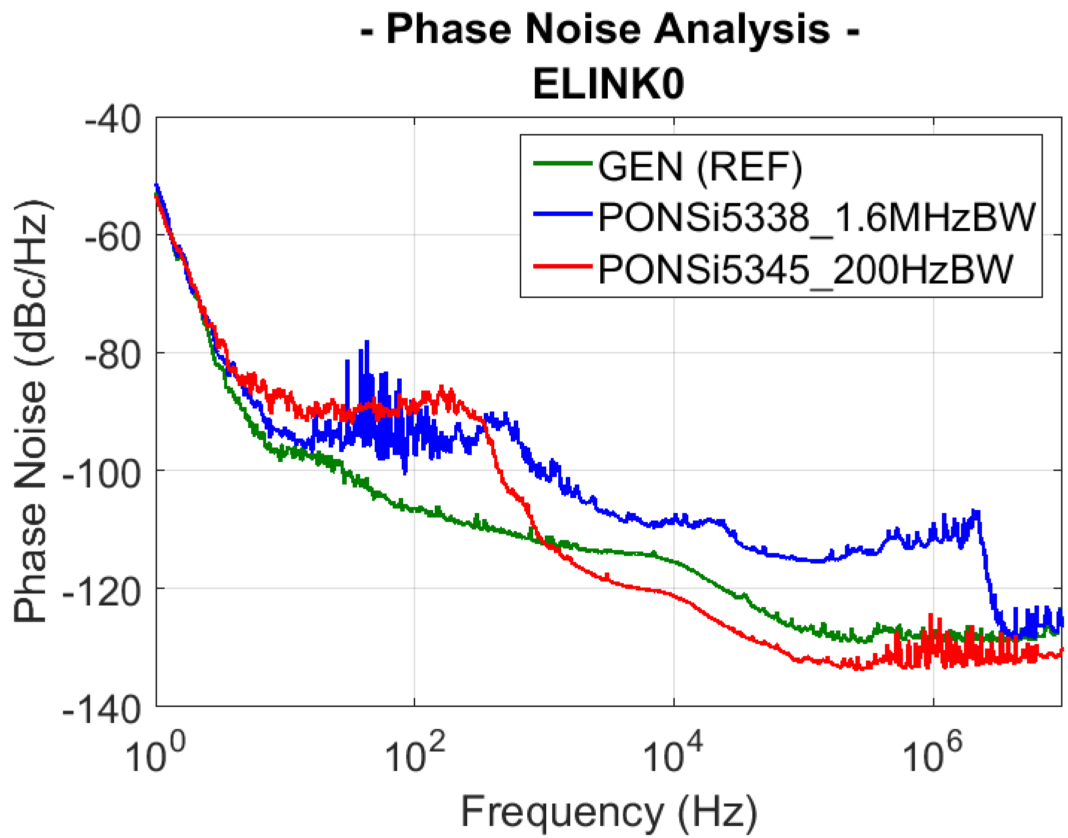
*GEN CG635
(REF – no PLL)



DESCLK1	GEN (REF.)	Si5338	Si5344
RMS jitter (1Hz-10MHz)	13.74ps	29.94ps	13.85ps

GBT link / Jitter map





ELINK0	GEN (REF.)	Si5338	Si5344
RMS jitter (1Hz-10MHz)	9.79ps	28.31ps	8.49ps

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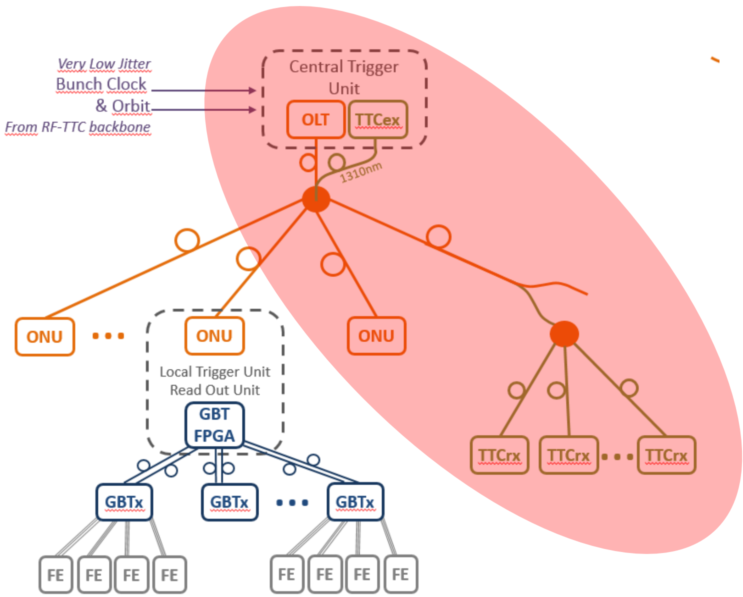
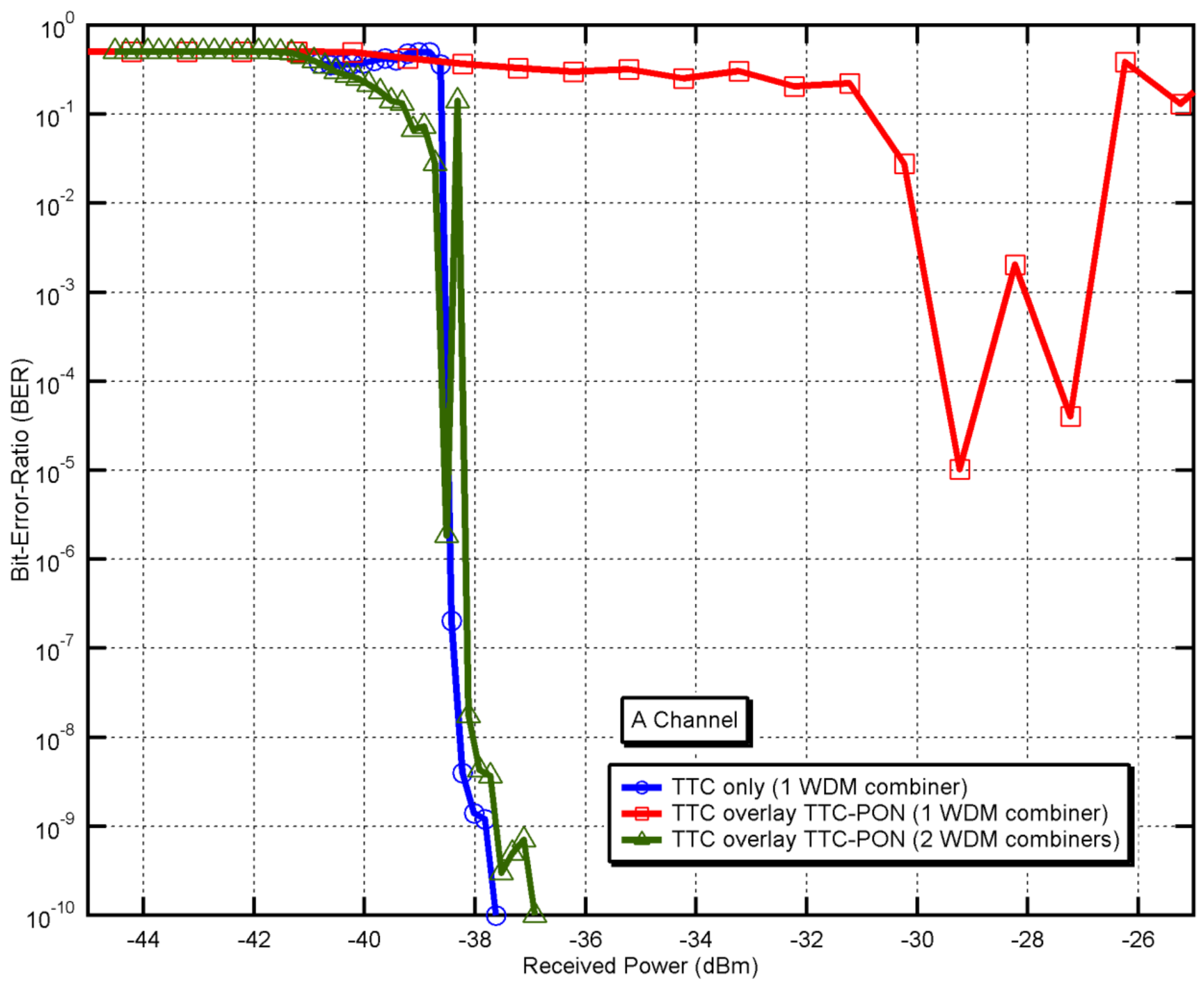


TTC Legacy

TTC PON

- TTC and TTC-PON not directly compatible
  - No effect on TTC-PON
  - Error floor on TTC
- Solution:
  - 1 WDM filter per TTC tree (100$)



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On-going developments

TTC PON

- System Consolidation
  - Finalise **extensive tests with GBTx & Si5338**
  - Implement **FEC** (see Eduardo's slides 23-24)
  - Long **BER** tests with high split ratio
    - Focusing on repetitive upstream BER plots (target: 10^{-11} with a split ratio of 1:64)
    - Downstream target: 10^{-14}
  - **Temperature tests** from 10 to 60°C (jitter, phase, fixed latency)
    - OLT
    - ONU + PLL (Si5344)
  - **Ageing** of PON-devices (several months required)

- ALICE and LHCb potentially interested in this solution for Phase-1 upgrades
  - Several tests are currently being performed by experiments to validate PON

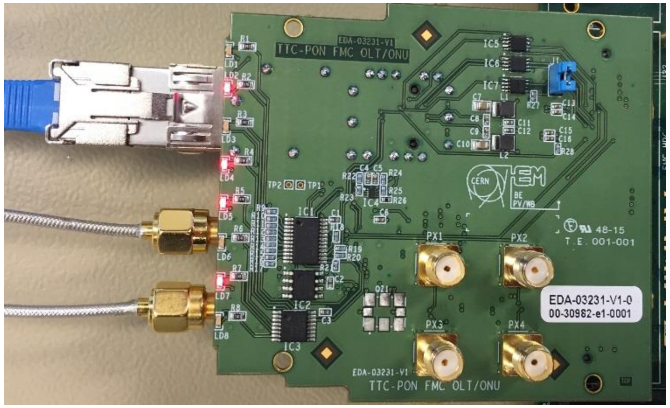
On-going developments

TTC PON

- Preparing distribution 1/2
  - Firmware:
    - IP Blocks reshaping
      - Low level block wrapped with AXI + signal busses
      - Control core (configuration and calibration) software or firmware based
    - Expected resources usage of these IP blocks (Kintex7 XC7K325T)
      - OLT =~ 1% Slices LUT
      - ONU =~0.5% Slices LUT
    - Targeted FPGAs
      - Kintex7 (current design platform)
      - Kintex Ultrascale (ALICE OLT)
      - Arria10 (LHCb OLT/ONUs, ALICE ONUs)

On-going developments

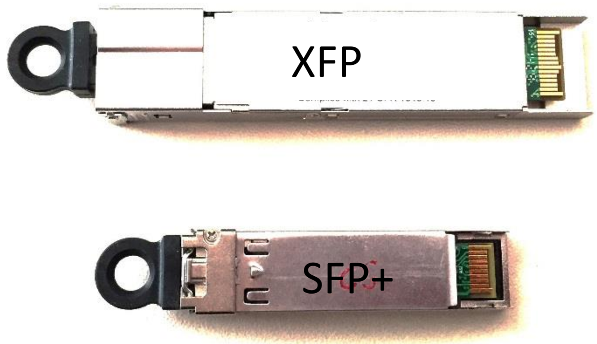
- Preparing distribution 2/2
  - Hardware:
    - Prepare **full specifications** & recommendations based on characterization + experience with PON FMC
    - Reference design for future developments
      - PON-FMC:
        - Version 1 equipped with Si5338 (ONU, OLT, SFP+) - available
        - Version 2 equipped with Si5344 (ONU, OLT, SFP+ plug and play) – on-going
        - Version 3 equipped with Si5344 (XFP OLT) – to be done



On-going developments

TTC PON

- Devices procurement
  - Form Factor
    - SFP+ favoured for OLT and ONU
  - Market survey being prepared



- Delays & Quantities.
  - OLTs: ~100 à 200 pieces (SFP+)
  - ONUs: ~1000 à 1500 pieces
  - Order Q3 2016 -> ok for delivery in 2017 (by batches)
- Prices (examples for small quantities)
  - SFP+ XGPON1 **OLT: 965 USD**
  - SFP+ XGPON **ONU: 258 USD**
  - XFP+ XGPON1 OLT: 1075 USD

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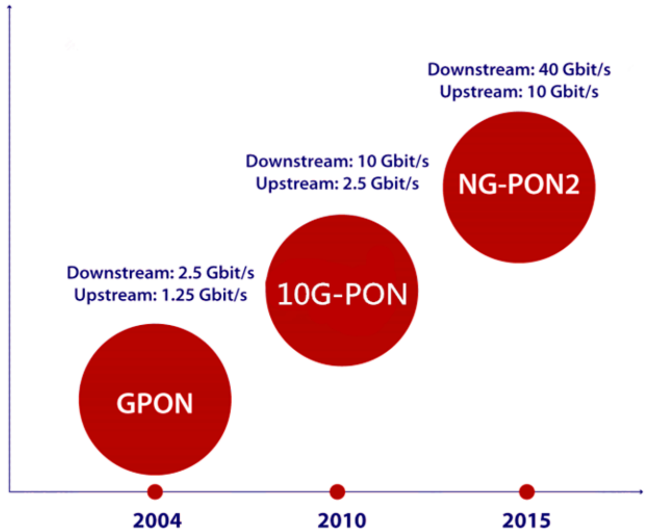
Potential developments for Phase-2

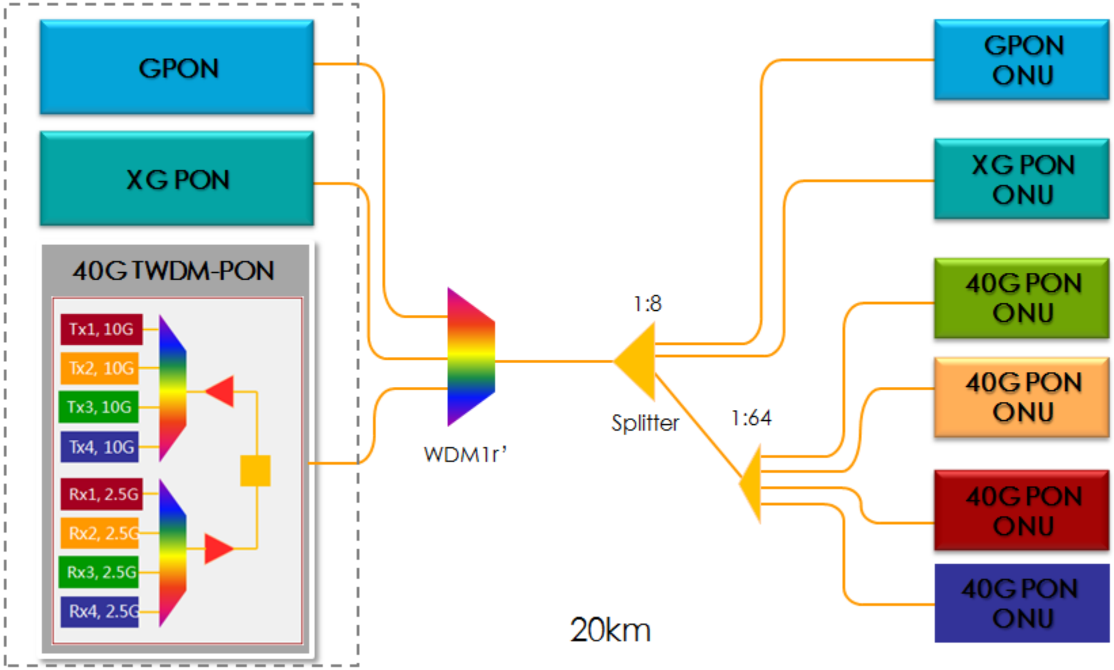
- FPGA Manufacturers finally come into play
  - Altera 2012 - StratixV– White Paper: Implementing Next-Generation Passive Optical Network Designs with FPGAs
  - Xilinx Serie7 - 2014: Fractional Burst Clock Data Recovery for XG-PON Applications
  - Xilinx Ultrascale: Burst-Mode Clock Data Recovery with GTH and GTY Transceivers

Potential developments for Phase-2

TTC PON

- New PON standards are coming
  - NGPON2 (2015)
    - WDM and colored ONUs
    - Higher power budget
    - Amended in 2016 to 8 symmetrical 10G PONs on the same fiber





Power budget : 38dB
Split : 1:512@20km,
1:128@40km,
1:32@60km
(maybe a bit optimistic)

Potential developments for Phase-2

TTC PON

- XGS PON
  - **Brand New** Standard: approved by ITU-T in Feb 2016
  - **Symmetric** 10G PON, based on XG-PON1 and 10G-EPON
  - **Intermediate step** between GPON and NG-PON2 at a lower cost (fixed wavelength optical transceivers)
  - Higher power OLTs – target split ratio of **1:128 for 20km**

- Towards even higher transmission capacities
  - ITU-T looks at 25Gbps transceivers
  - IEEE works on the 100G-EPON

Potential developments for Phase-2

TTC PON

Future of TTC-PON

- higher split ratio,
- higher upstream bandwidth,
- lower busy delay,
- available burst-mode CDR embedded in FPGAs…

…A lot of place for creativity!

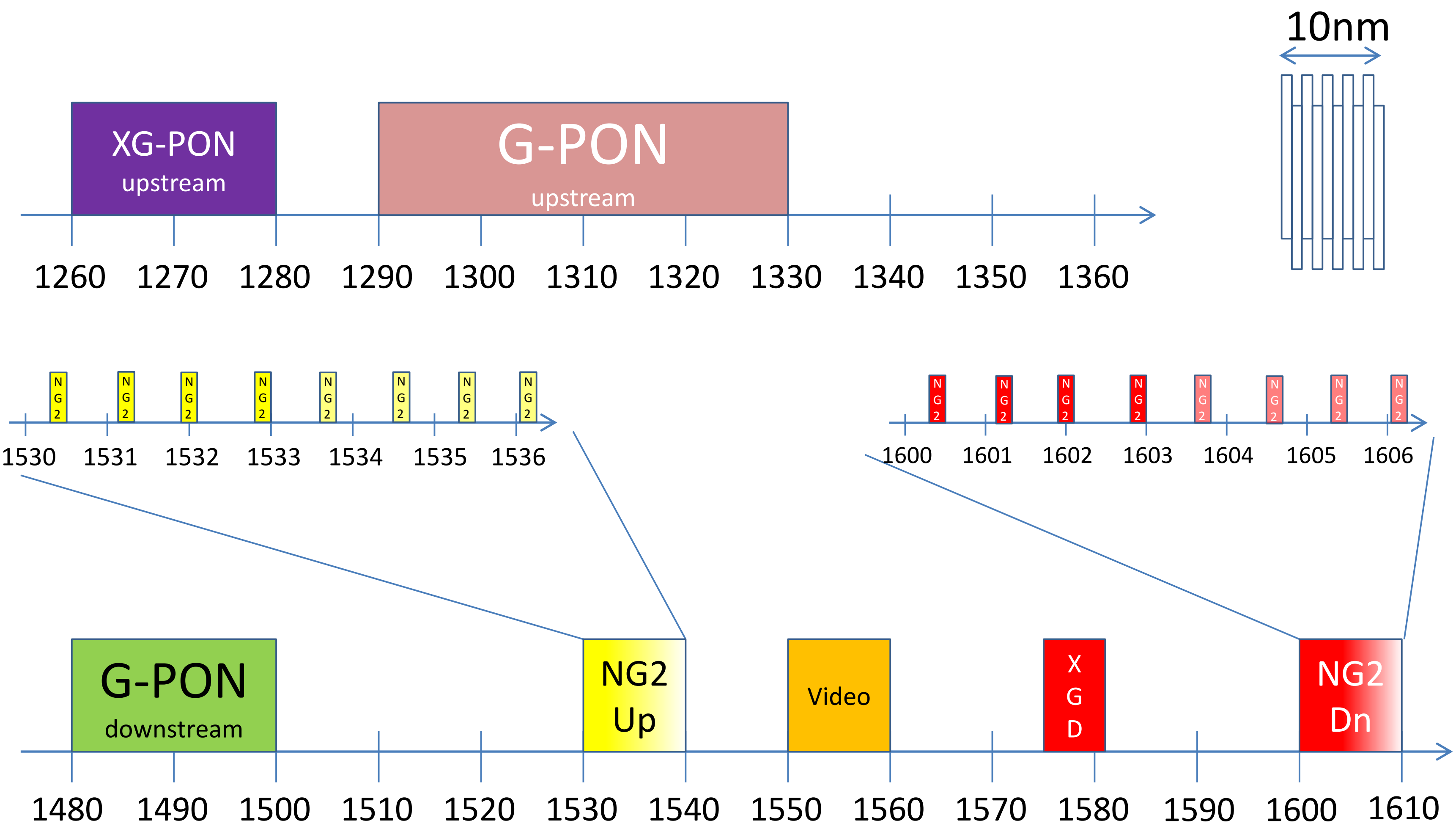
Thank You !

https://espace.cern.ch/Project-TTC-PON/SitePages/Home.aspx

TTC PON

Spare Slides

PON wavelength plan



PON families of technology

TTC PON

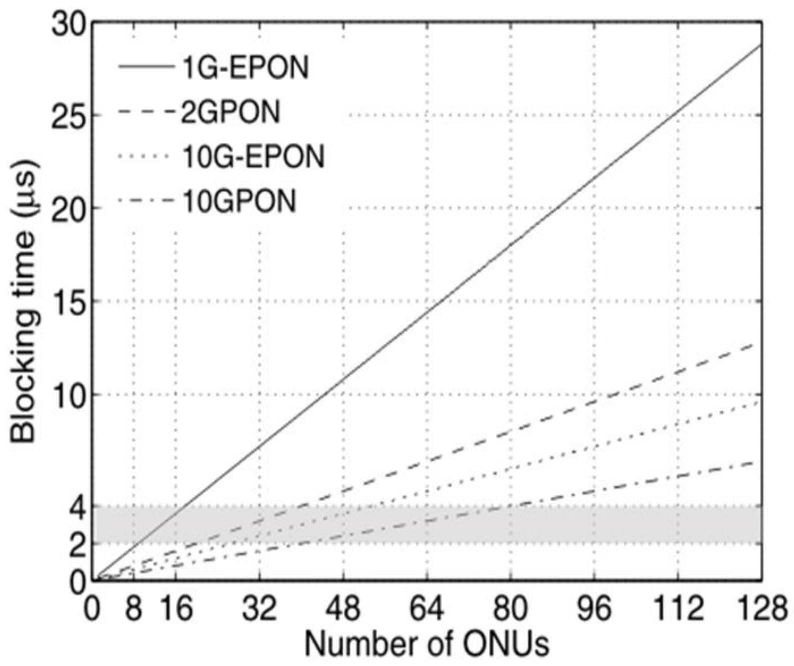
	GPON	1G-EPON	XGPON1	10G/1G-EPON	NG-PON2	10G/10G-EPON	
Specs	ITU-T G.984	**IEEE 802.3bk-2013**	**ITU-T G.987**	IEEE 802.3bk-2013	ITU-T G.989	**IEEE 802.3bk-2013**	units
PON Rate	2.488G/ 1.244G	**1.25G/1.25G**	**9.953G/2.488G**	10.3125G/1.25 G	9.953G/9.953G	**10.3125G/10.3125G**	Gbps
Downstream λ	1490	**1490**	**1577**	1577	1600	**1577**	nm
Upstream λ	1310	**1310**	**1270**	1310	1530	**1270**	nm
Split Ratio	1:128	**1:64**	**1:128**	1:64	1:256	**1:64**	
Max Reach	60 (C+)	**20 (PX40)**	**40**	20 (PRX40)	40	**20 (PR40)**	km
OLT Form factor	SFP	**SFP**	**XFP, SFP+**	XFP,	XFP	**XFP**	
ONU Form factor	SFP	**SFP**	**SFP+**	SFP+	SFP+	**SFP+**	

1 (1G-EPON) 3 (XGPON1) 2 (10G/10G-EPON)

Source - COMPARING IEEE EPON & FSAN/ITU-T GPON FAMILY OF TECHNOLOGIES – Arris 2014

Standard Features

Field	1G-EPON	10G-EPON	10GPON
Inter Frame Gap (ns)	50	50	16
Training (ns)	125	12.5	12.5
Payload (ns)	40	4	4
Total per frame (ns)	215	66.5	32.5
No. of bunch-cycles between transmissions	9	3	2



From TTC to TTC-PON 2016

TTC PON

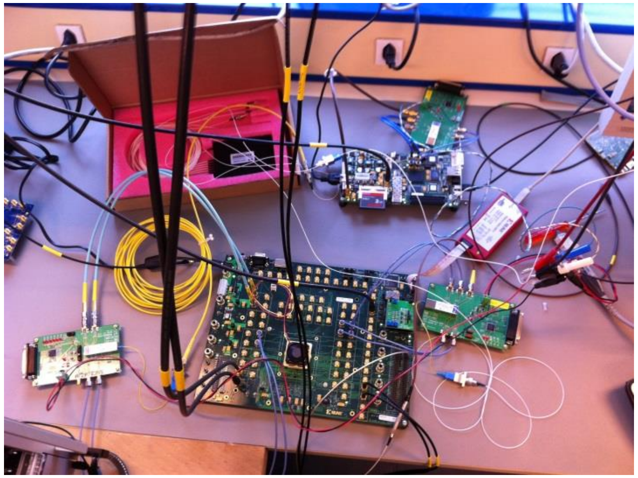
GENERAL FEATURES					
	TTC system	TTC-PON (2011)	TTC-PON (2014)	TTC-PON (2015)	TTC-PON (2016)
Technology	SONET/SDH OC-3	1G-EPON	10G-EPON	XGPON1	XGPON1
Line Rate (D/U)	80Mbps	1.6/0.8Gbps	11.2/2.8Gbps	9.6/2.4Gbps	9.6/2.4Gbps
Bidirectional	NO	YES	YES	YES	YES
Fiber length	10-300m	10-1000m	10-1000m	10-1000m	10-1000m
Split Ratio	1:32	1:64	1:64	1:64	1:64
BC synchronous	YES	YES	YES	YES	YES
Error detection	CH. B ONLY	YES	YES	YES	YES +FEC downstream
OLT Form Factor	SFP	SFP	XFP	XFP, SFP+*	SFP+*
ONU Form Factor	SFP	SFP	SFP+	SFP+	SFP+

DOWNSTREAM FEATURES					
Optical Power Margin with 1:64	x	1dB	1dB	1dB	3dB
Wavelength	1310nm	1490nm	1577nm	1577nm	1577nm
Encoding	BPM, Hamming	8b/10b	8b/10b	8b/10b	Scrambling, FEC
Payload	~80Mbps(1)	~590Mbps	~8.64Gbps	~8.68Gbps	~8.68Gbps
Payload/BC	2 bits(1)/BC	32 bits/BC	216 bits/BC	192 bits/BC	192 bits/BC
Trigger Rate	<40MHz	40MHz	40MHz	40MHz	40MHz
Synchronous Trigger Type	NO	YES (16 bits)	YES (>32bits)	YES (>32bits)	YES (>32bits)
Trigger latency	~100ns	~250ns	~80ns	~100ns	~100ns
Following Techno standard	YES	NO	NO	YES	YES
Immune to temperature	~	Not tested	Not tested	YES	YES

UPSTREAM FEATURES					
Optical Power Margin with 1:64	x	2dB	2dB	2dB	2dB
Dynamic Range	x	x	1dB	1dB	12dB
Wavelength	x	1310nm	1270nm	1270nm	1270nm
Encoding	x	8b/10b	8b/10b	8b/10b	8b/10b
Total Payload (All ONUs)	x	2.2Mbps	640Mbps	480Mbps	384Mbps
ONU Burst length	x	~1.6us	25ns (16 bits)	25ns (16 bits) + 8ns gap	100ns (48 bits) + 25ns gap
Max Latency for 1:64	x	14us	1.6us	2.1us	8us
Max Latency for 1:128	x	x	3.2us	4.2us	16us
Following Techno standard	x	NO	NO	NO*	YES
Immune to temperature	x	Not tested	Not tested	NO	YES

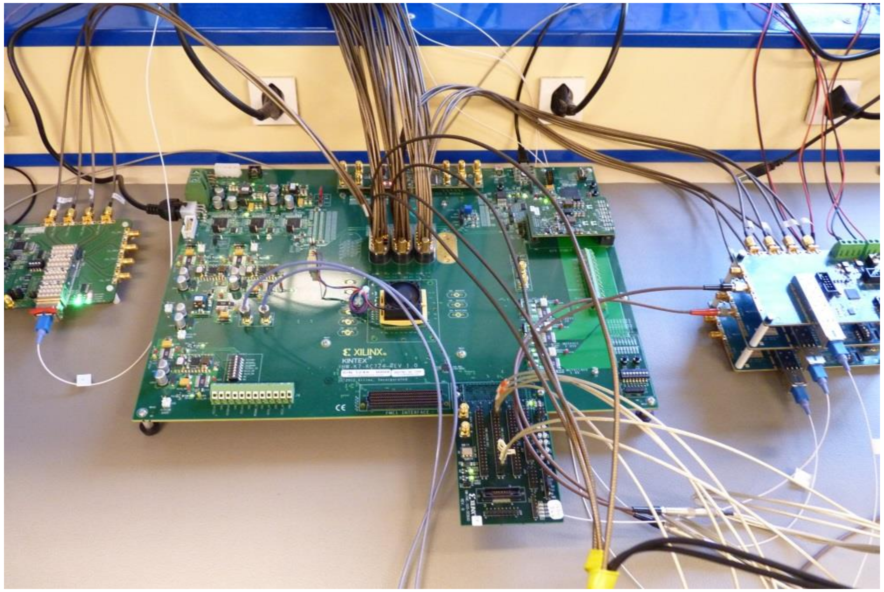
*modules customization required to take over control of the APC of the ONUs

TTC-PON Setups

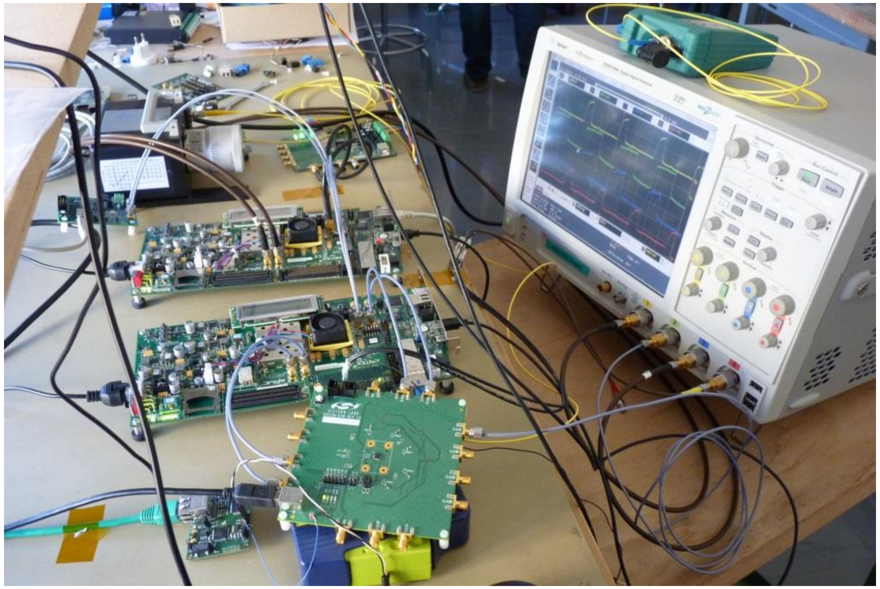


Optical: 1G EPON – OE solution
Board: ML605
PLL: CDCE62000

Optical: 10G EPON – OE solution
Board: KC724
PLL: CDCE



Optical: 10G - XGPON – Ligent
Board: KC705
PLL: Si5338/5344



EDUARDO

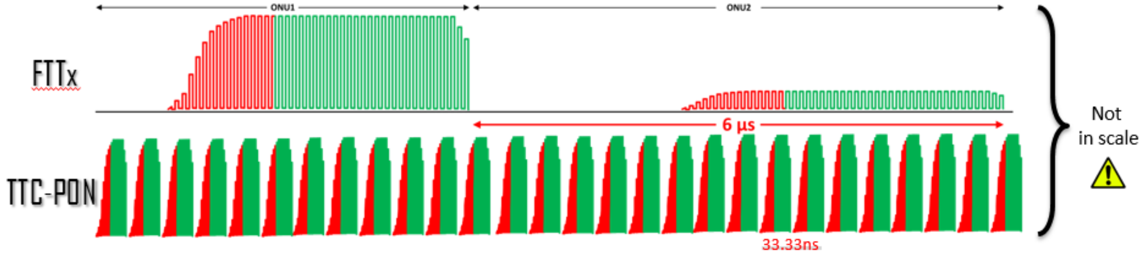
Spare slides

Limitations of CBM33

•Introduction

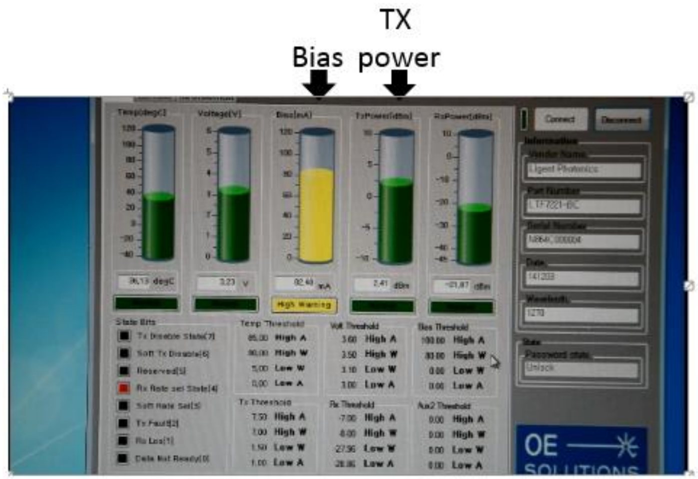
- Major motivation: fast busy transmission (latency=2.1us / 64 ONUs)
- Completely out of FTTx Standard

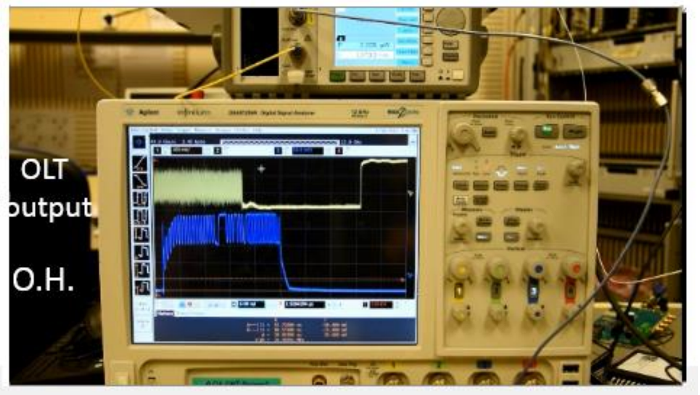
Framing:	FTTx	TTC-PON
Protocol	TDMA	TDMA
Hardware	PON Specific ASICs	FPGAs
Downstream/Upstream clocking	Asynchronous	Synchronous
Token passed by …	OLT	ONUs
Burst recovery/alignment	CDR	Oversampling
Dynamic Range	>25dB	Small (<3dB)
Guard Time	500ns	4.16ns
Training Time	500ns	12.5ns
Payload Data	3-5µs	8.33ns (2Bytes)
Waiting Time for 64ONUs (Busy)	~0,4 ms (min)	2.15 µs



Limitations of CBM33

- **Bias control through hardware patch: fixed bias**





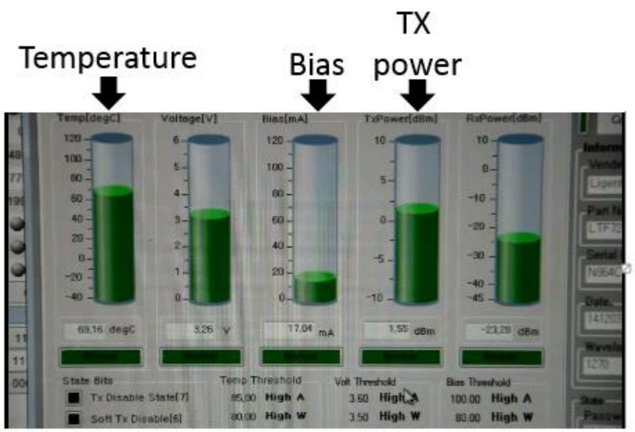
I2C control was not possible

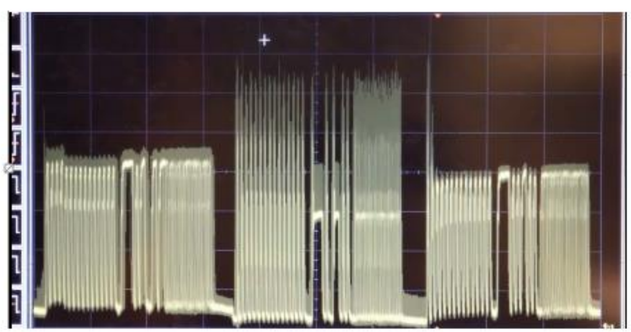
Required a hardware patch

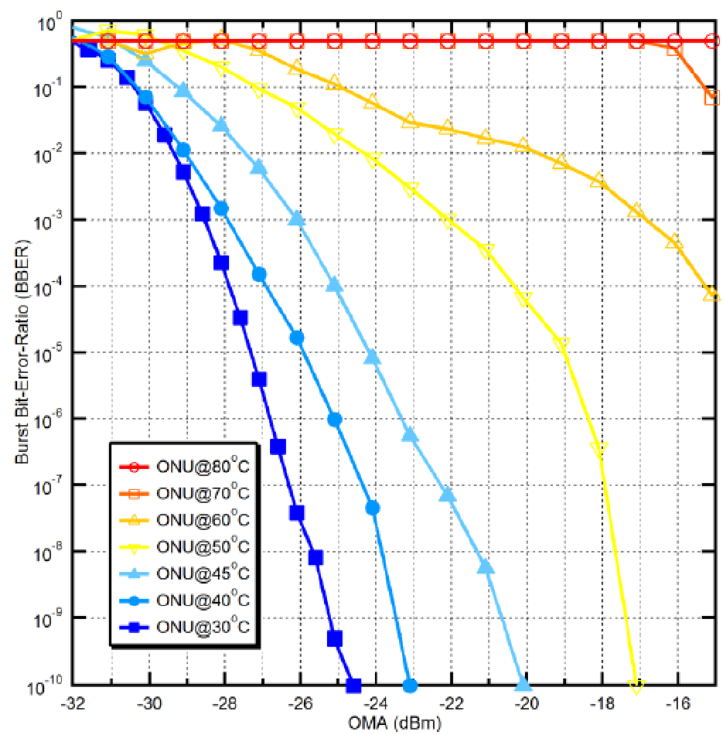
TTC PON

Limitations of CBM33

- **Upstream highly affected by temperature**
  - Likely due to fixed bias







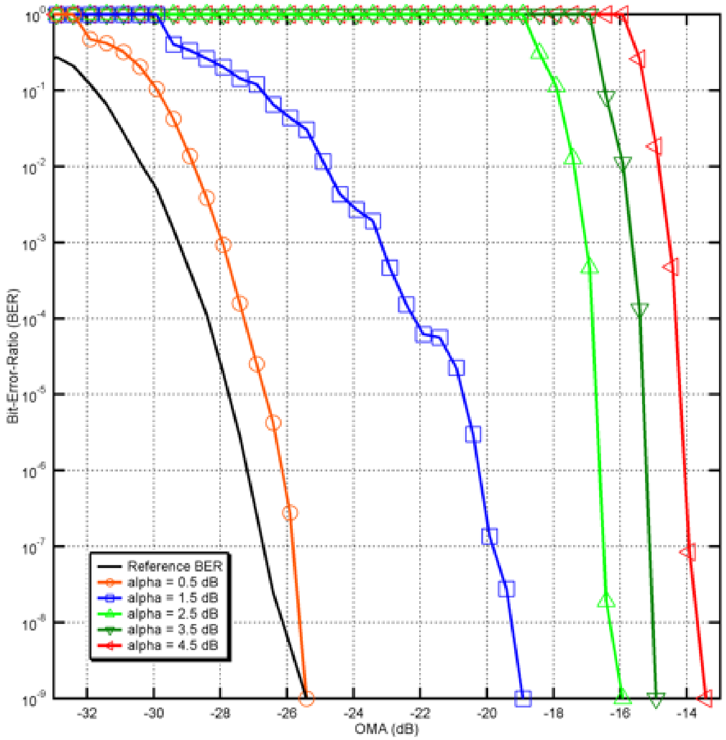
Target BER : 10^{-10}

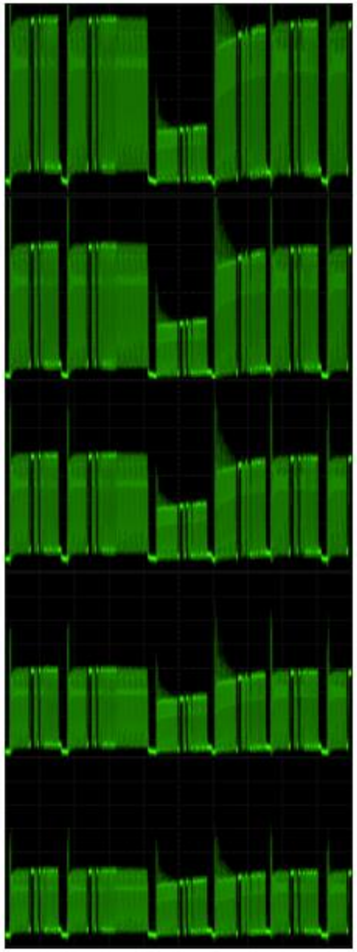
Confidence Level: -

Limitations of CBM33

- **Dynamic Range**
  - ONU1 is the soft burst

ONU1





α=4.5dB

α=3.5dB

α=2.5dB

α=1.5dB

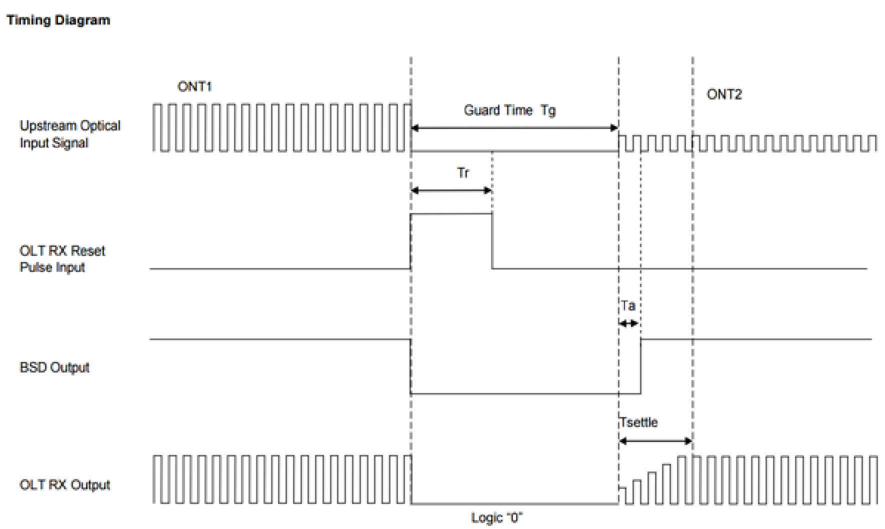
α=0.5dB

Limitations of CBM33

- **Motivation for a more “classical” PON system**
  - We had a very strict busy latency requirement from the experiments, that’s the reason why the CBM33 was heavily investigated.
  - After several discussions with ALICE and LHCb in June/2015, this requirement was relaxed.
  - We started an investigation with longer bursts trying to see what could be achieved.

The CBM125 scheme

- **Choice of protocol**
  - Minimum Burst length respecting datasheet



Receiver Timing Diagram

Parameter	Symbol	Min	Typical	Max	Units	Notes
Guard Time	T_g	25.6	-	-	ns	
Reset Pulse Width	T_r	25.6	-	-	ns	Note 1
Burst Signal Detect Assert	T_a	-	-	20	ns	Note 2
Burst Mode Receiver Setting Time	T_{settle}	-	-	52	ns	

Note 1: The RESET signal should occur in the GUARD BAND time slot and commence immediately at the end of the ONT signal.
Note 2: The Rx BURST MODE SIGNAL DETECT (BSD) asserts LOW when the RESET signal is applied; assets HIGH when an incoming burst is detected and latches HIGH until the next RESET signal.

Gap+Preamble=77.6ns

Comma/Address=8.33ns

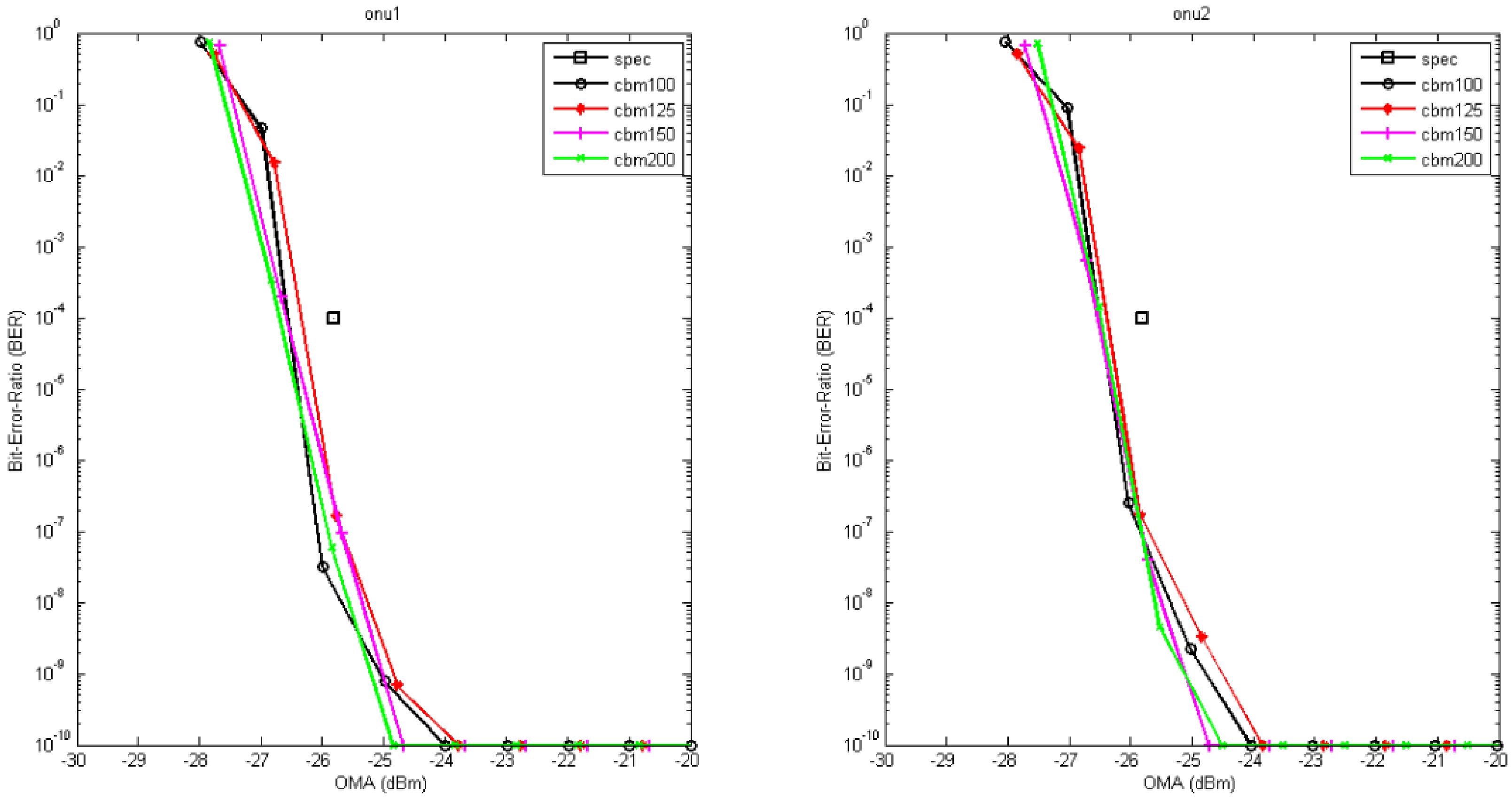
Payload=8.33ns

Total=94.26ns → CBM100

The CBM125 scheme

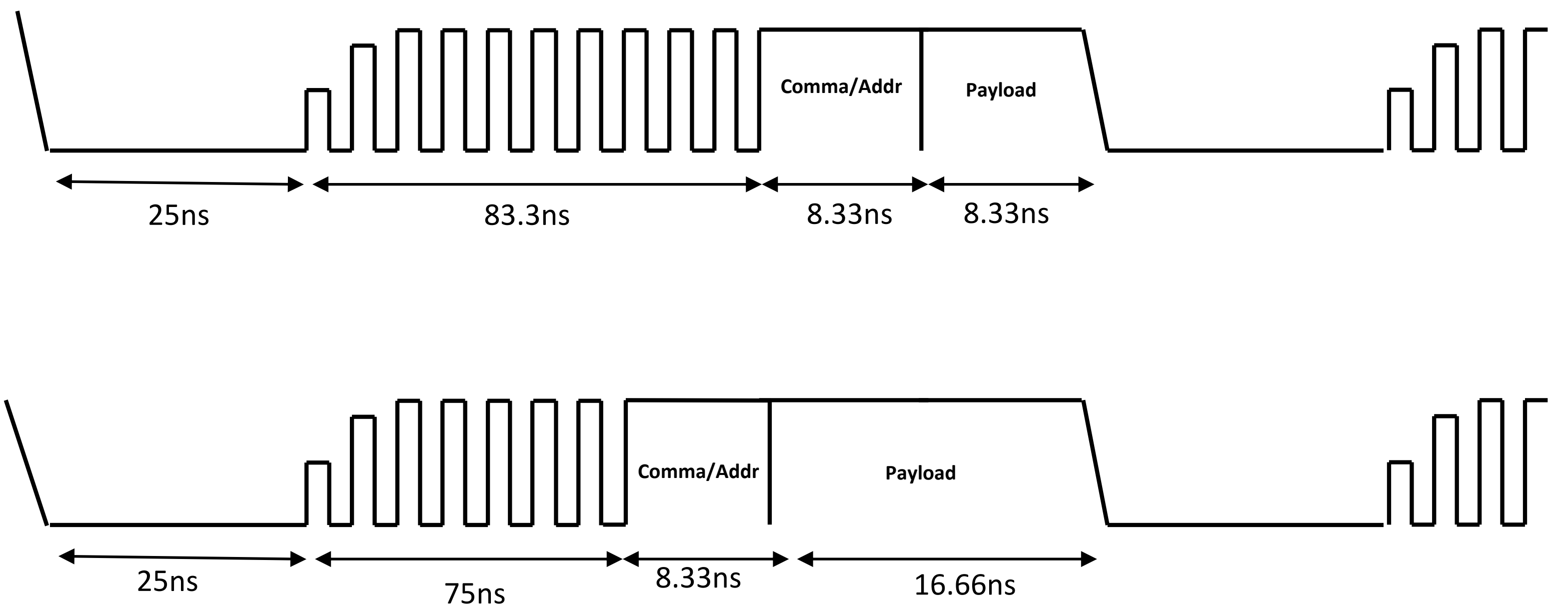
•Choice of protocol

- Burst length analysis (increasing preamble / fixed payload = 8.33ns)



The CBM125 scheme

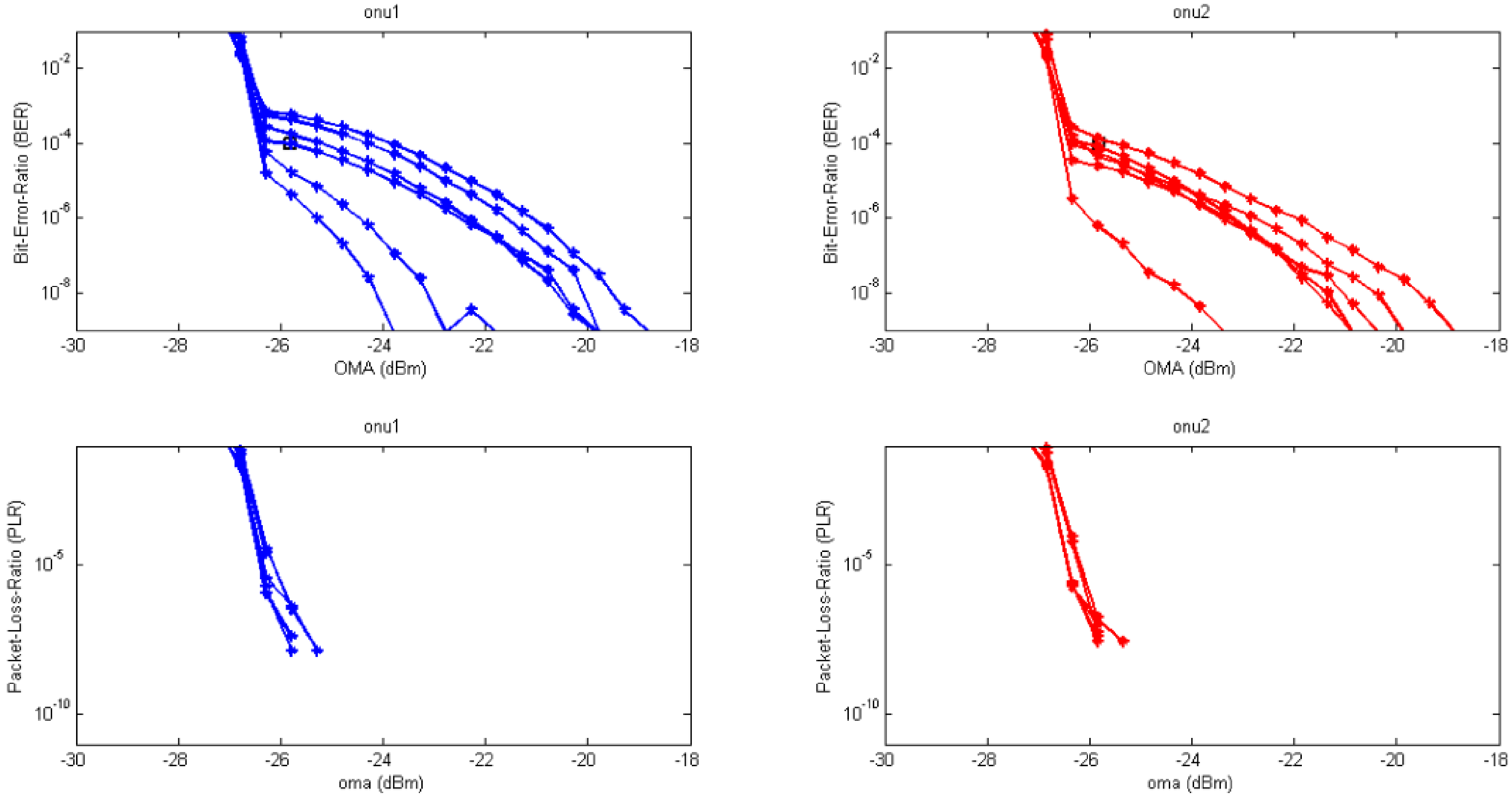
- **Choice of protocol – burst length: 125ns**
  - Payload analysis



*not in scale

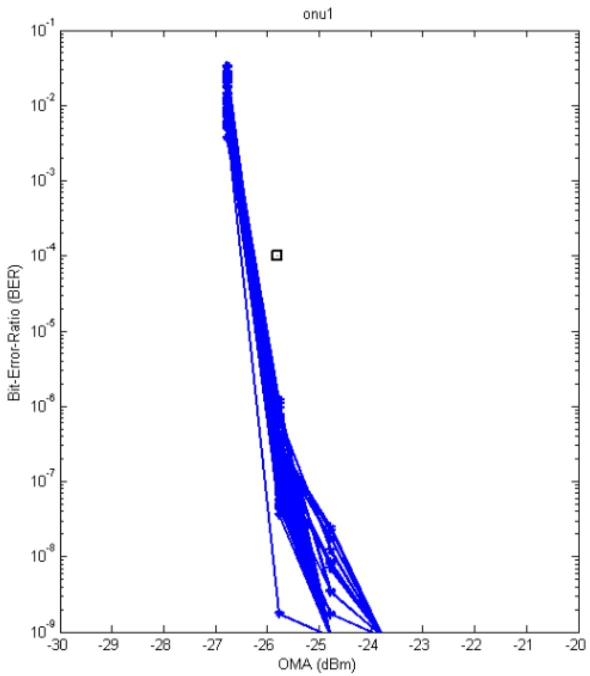
The CBM125 scheme

- **Choice of protocol**
  - Payload analysis – huge penalty when **Payload=16.66ns**

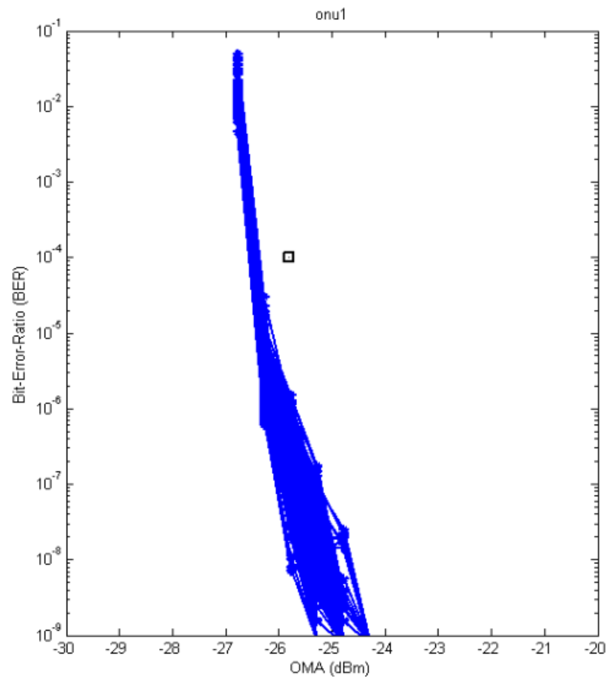


The CBM125 scheme

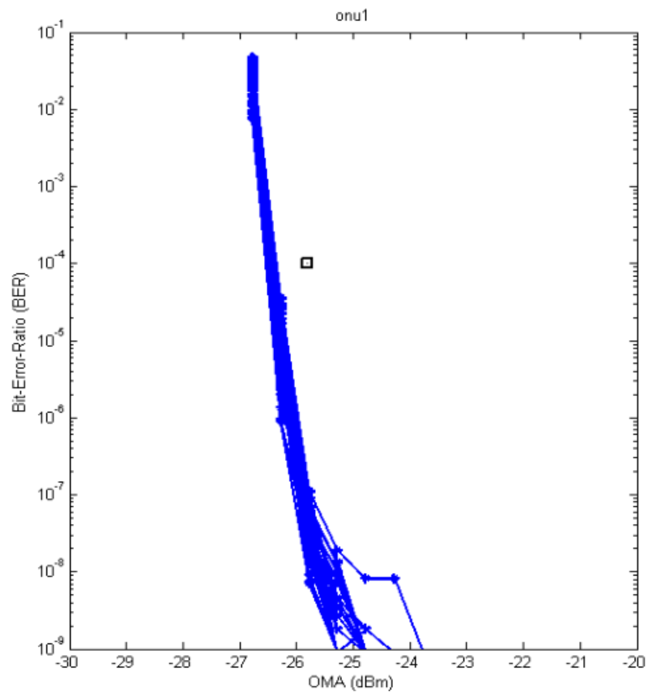
- **Choice of protocol**
  - Payload analysis - Results



PAYLOAD=16.6ns



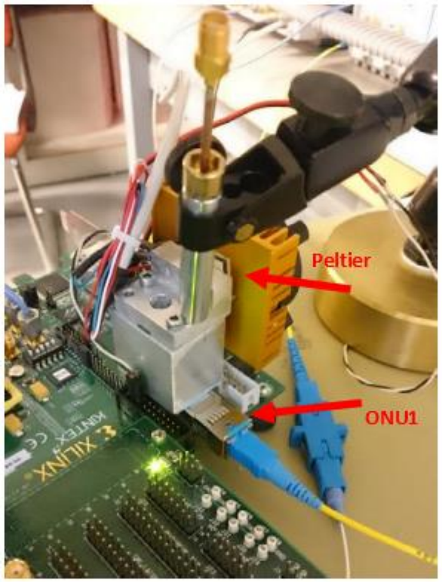
PAYLOAD=25.0ns

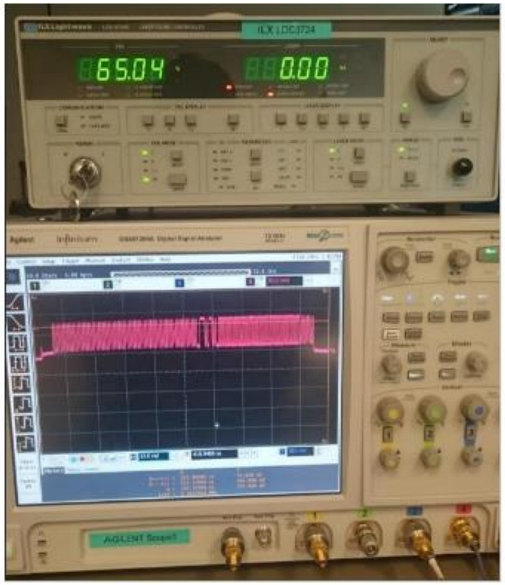


PAYLOAD=33.3ns

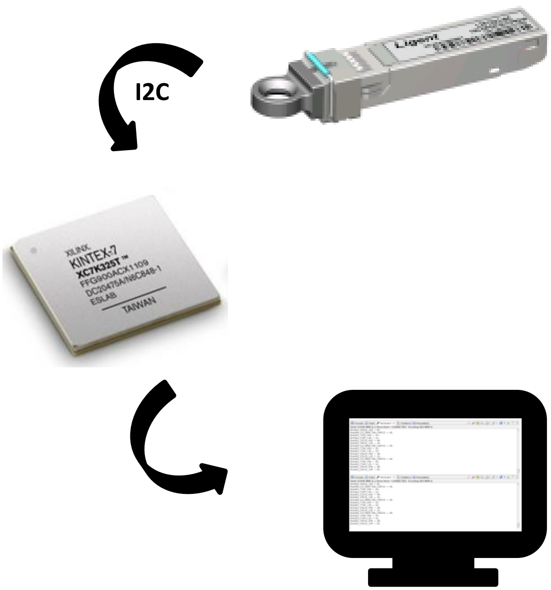
The CBM125 scheme

- **Temperature tests**





Setup (thanks Christophe)



I2C monitoring

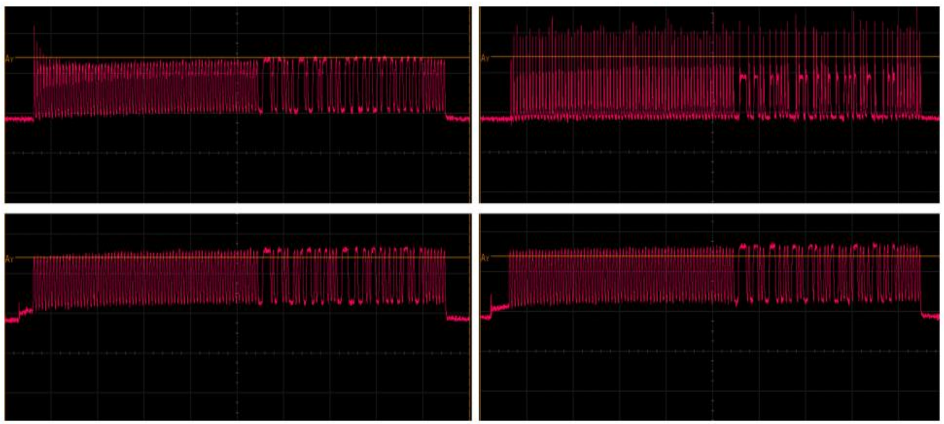
The CBM125 scheme

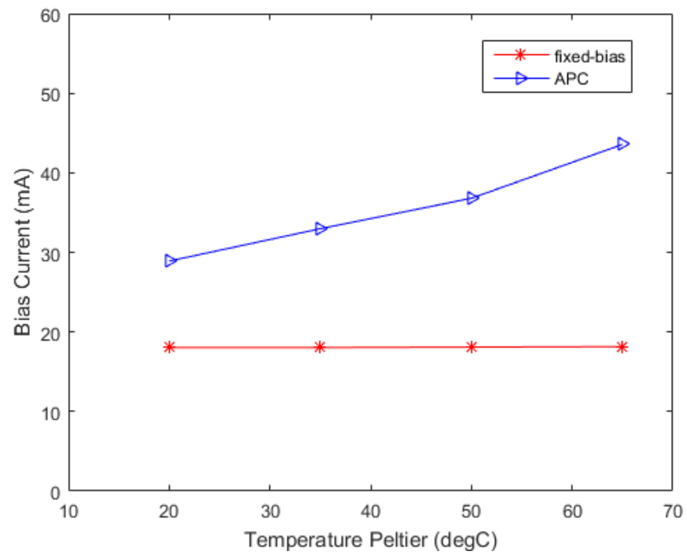
- **Temperature tests**
  - Fixed-bias ONU versus APC ONU

T=20°C　T=65°C

Fixed-Bias

APC



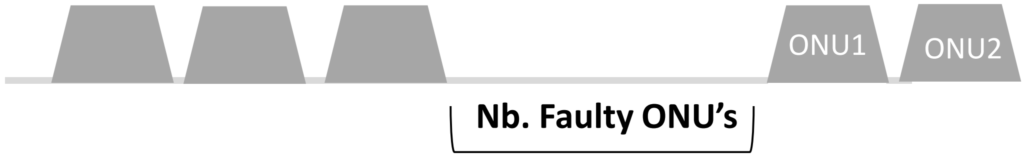


The CBM125 scheme

- **CBM33 x CBM125**

	CBM33	CBM125
Gap+Preamble	16.6ns	83.3 ns (datasheet = 77.2ns)
Comma+Addr	8.3ns	8.3ns
Payload	8.3ns (16b)	33.3ns (64b)
Latency (64 onu's)	2.1us	8us
Average data-rate	7.6Mbps (16b/2.1us)	8Mbps (64b/8us)
APC	Modified	Normal (Er≈5.4dB)
Dynamic Range	~ 1.0dB	No penalty for 6dB spec
Temperature	Huge impact from 45°C	Tested up to 55°C – no impact
Sensitivity@1e-11 (OMA)	~ -24 dBm	~ -24 dBm

Upstream Faulty ONU test



***ONU3 emulates 64 ONU's**