Experimental demonstration of 1 Gbps POF link for GEPOF technical feasibility

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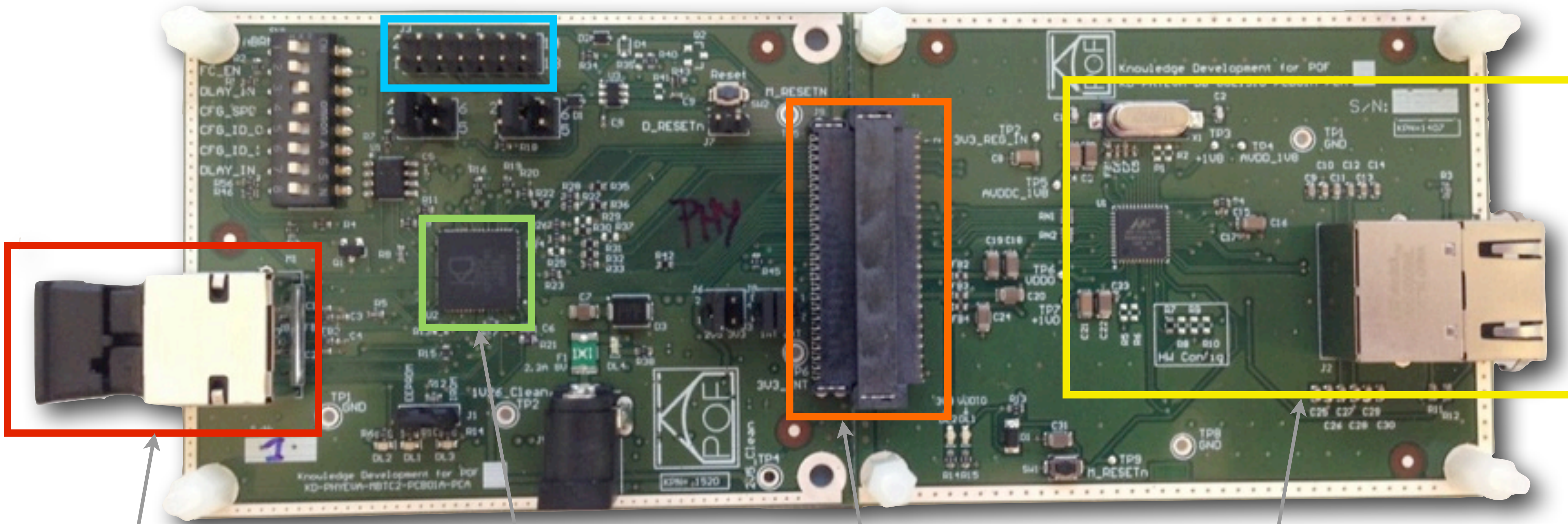
Agenda

- Objectives
- Experiments in worst case temperature - consumer grade
- Experiments in worst case temperature - automotive grade
- Experiments with bending
- How the communication system works in a real product
- Appendix: introduction to POF characteristics
- Conclusions

Experiments in worst case temperature
Commercial grade scenario

Device under test (DUT)

MDIO/MDC



KDPOF KD1001B0
1Gbps POF PHY

Avago Bare Fiber
Transceiver (linear
O/E TX and RX)

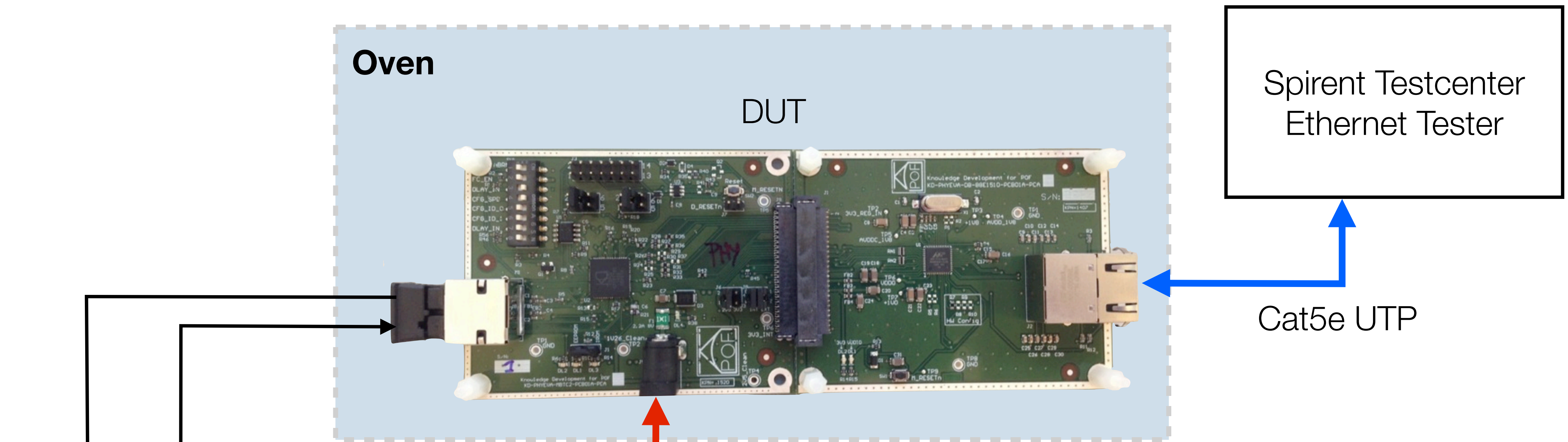
RGMII, supply,
reset, …

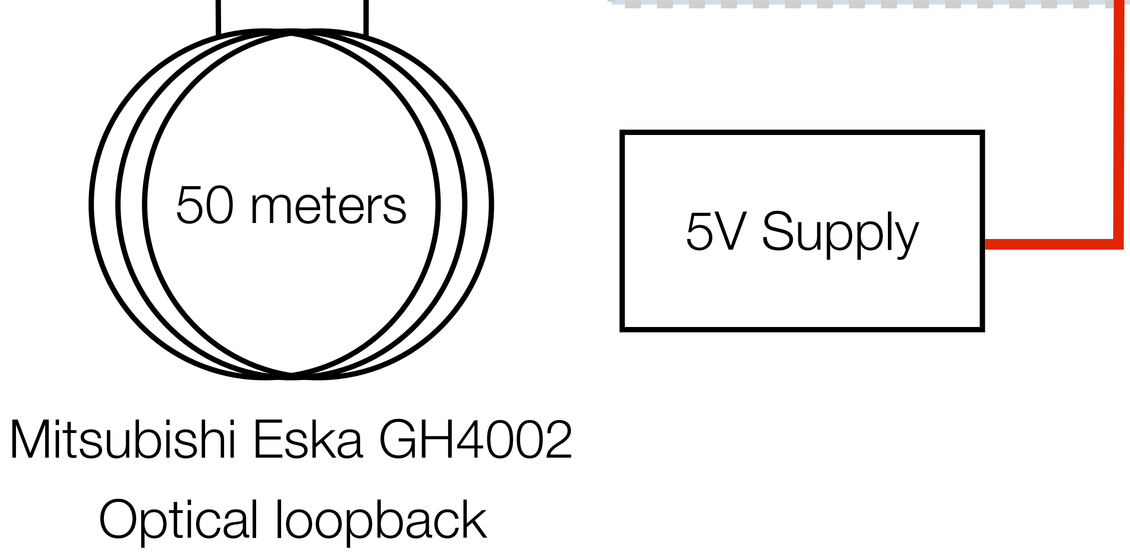
1000BASE-T PHY &
RJ45 port

Details on transmission technique

- Full duplex 1Gbps at RGMII interface
- Coded modulation based on Multi-Level Coset Code of 3 levels (see [1])
- 16-PAM baseband modulation built on 7bits/2D RZ^2 QAM modulation (see [1])
- Symbol rate = 312.5 MSps (see [1])
- Spectral efficiency = 3.3145 bits/s/Hz/dim (see [1])
- Component codes of 1st and 2nd MLCC levels based on shortened BCH codes over Galois field of $GF(2^{11})$ (see [1])
- MLCC net coding gain = 6.7 dB at BER = 10^{-12} (see [1])
- Linearizer based on low cost adaptive Volterra filtering implemented in the receiver (see [2])
- Channel equalization based on adaptive Tomlinson-Harashima Precoding for ISI compensation plus noise whitening (see [3])
- PCS and PMA as presented at [4] and [5]

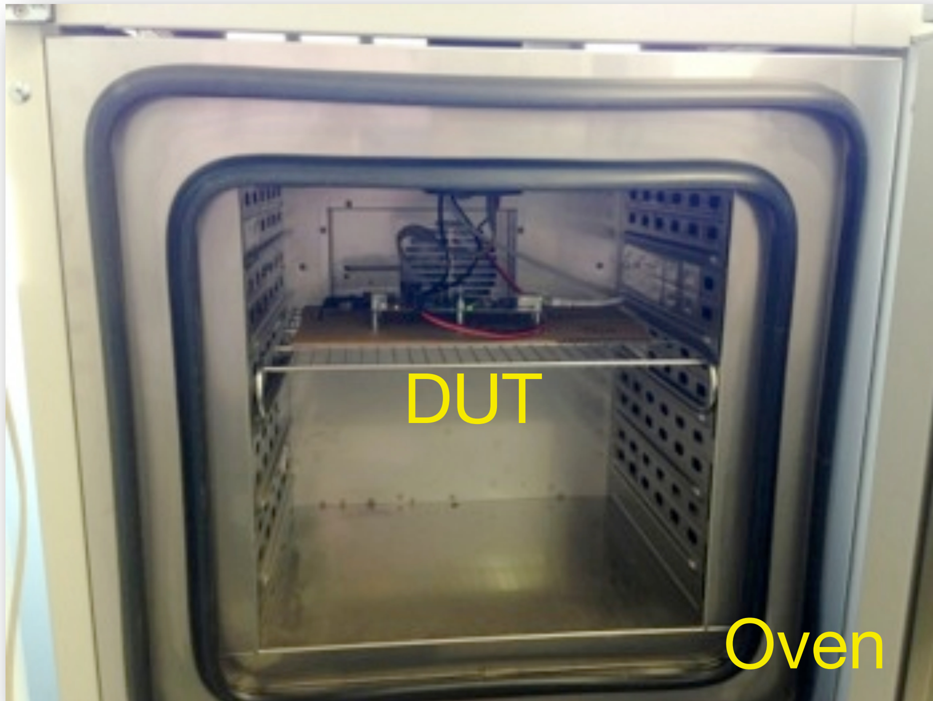
WC Temp experiments - test setup



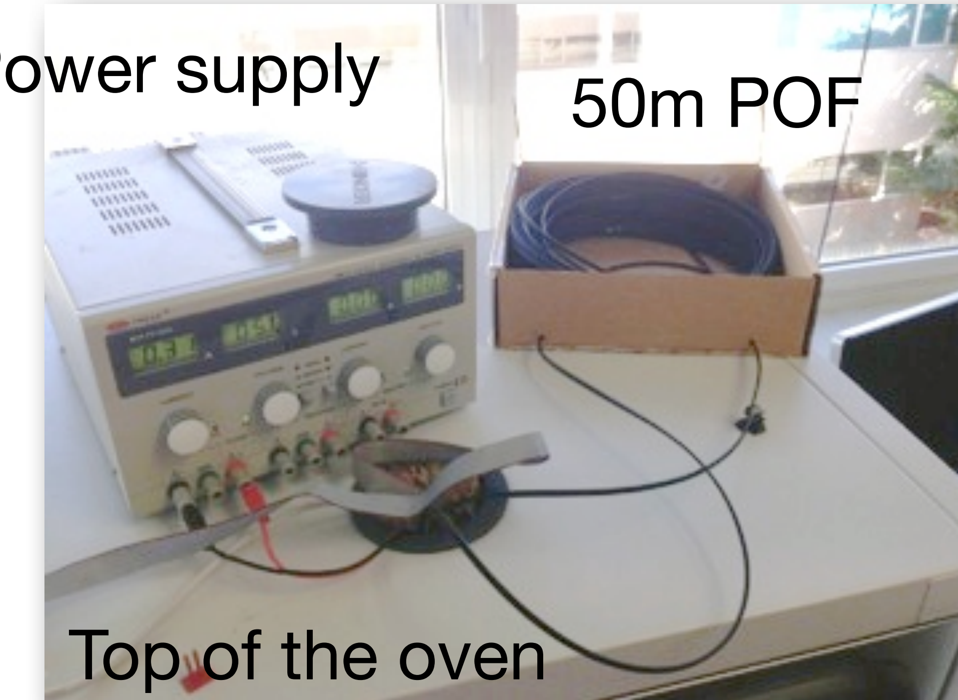


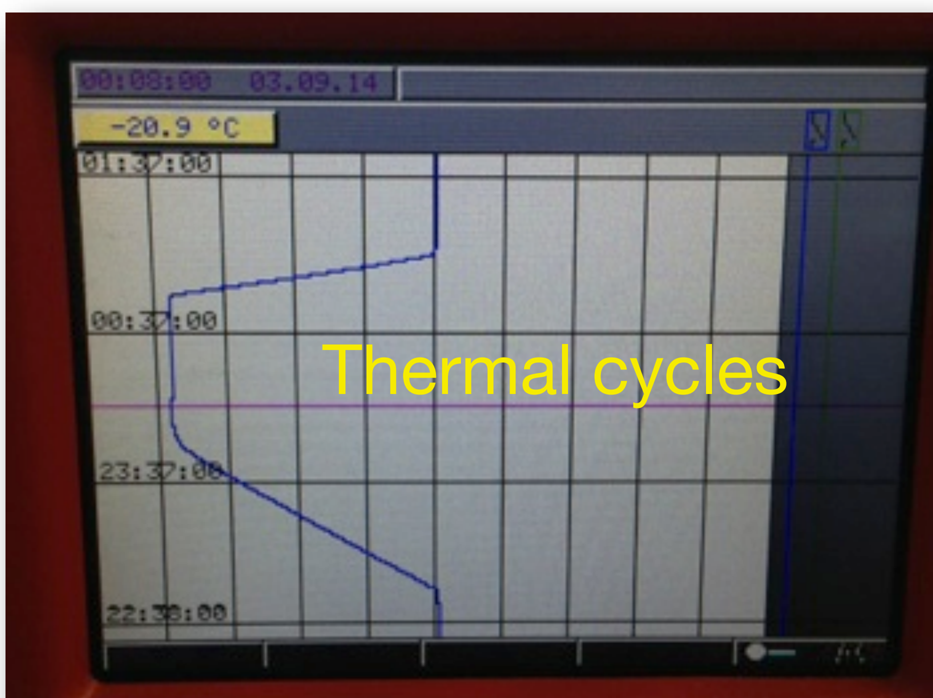
- Test conditions:
  - 5 thermal cycles of:
    - fast ramp from -20°C to 75°C
    - 1 hour at 75°C
    - fast ramp from 75°C down to -20°C
    - 1 hour at 20°C
  - 100% 1Gbps traffic load
  - Random packet size from 64 to 1518 bytes
  - Min IPG = 12 bytes
  - PRBS fill type and signatured packets

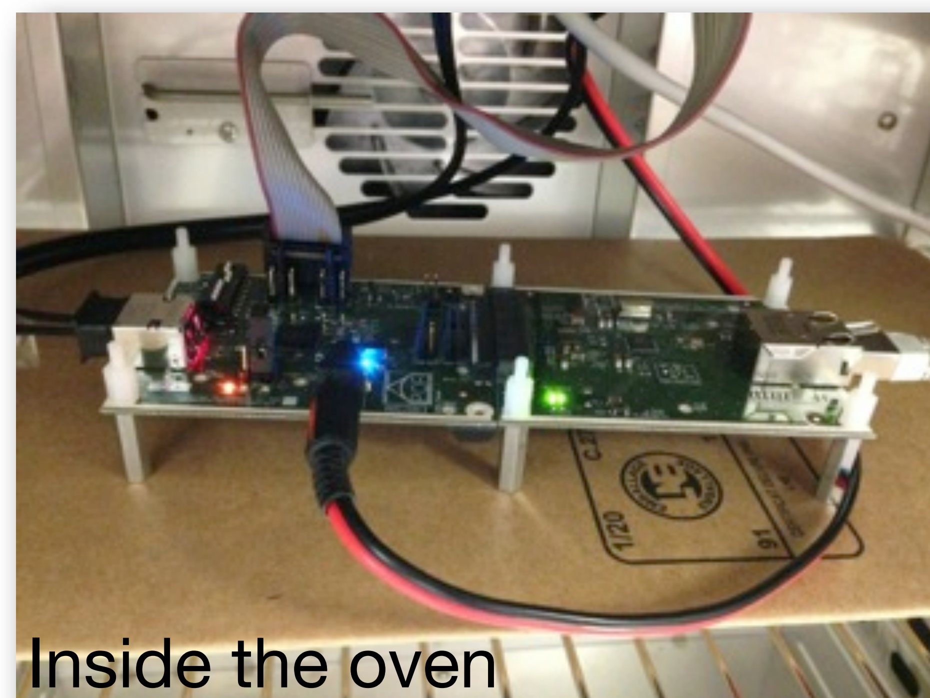
WC Temp experiments - test setup



Power supply







WC Temp experiments - test results

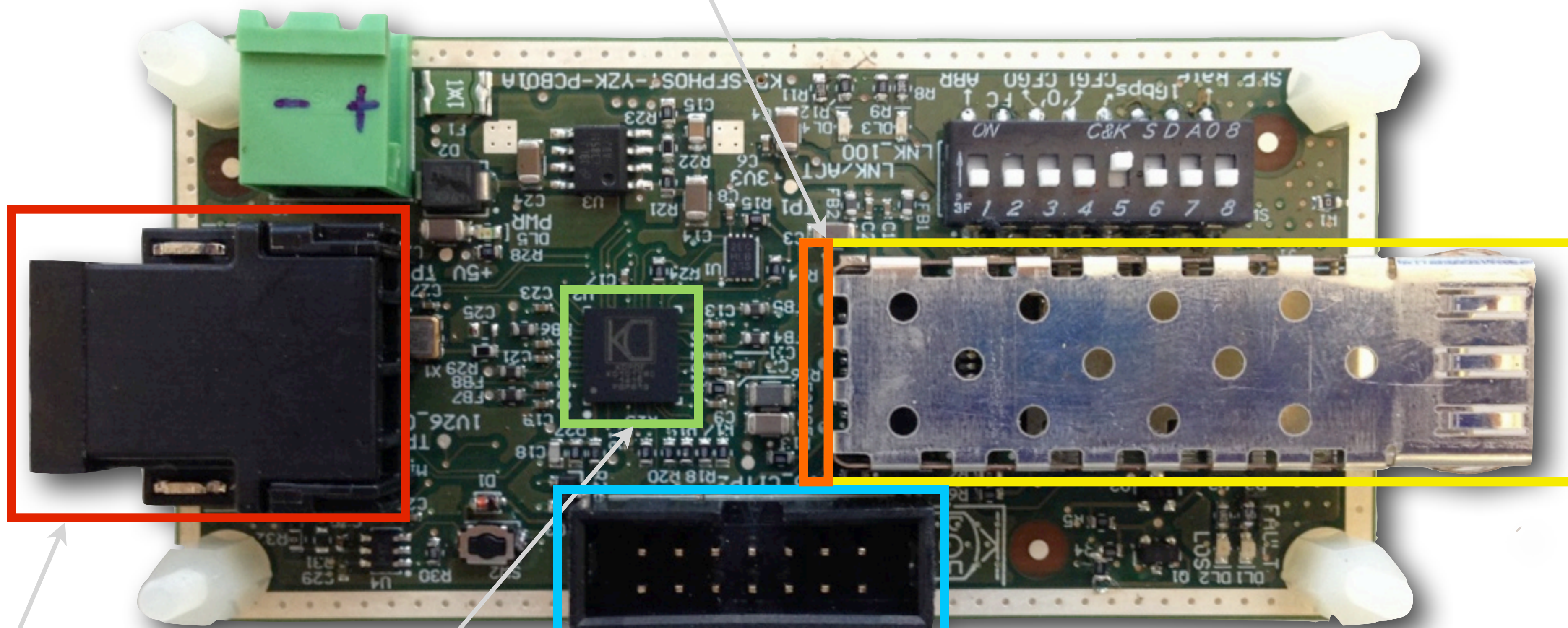
- BER = 1.2e-12 after 10 hours of test with -20 to 75ºC temperature cycles
- Dropped frames = 0
- The communication system shows its adaptability to varying non-linear channel response produced by optoelectronics under temperature changes
- 50 m POF gigabit link demonstrated under worst case commercial grade temperature conditions

- Note:
  - PRBS generator is configured in Spirent TestCenter as fill type of Eth frames (only information payload is random)
  - The experiments are also valid with constant or any fill pattern, since the communication system implements both binary and symbol level scramblers; therefore, the performance is the same regardless the content or size of ethernet frames

Experiments in worst case temperature
Automotive grade scenario

Device under test (DUT)

SGMII / 1000BASE-X



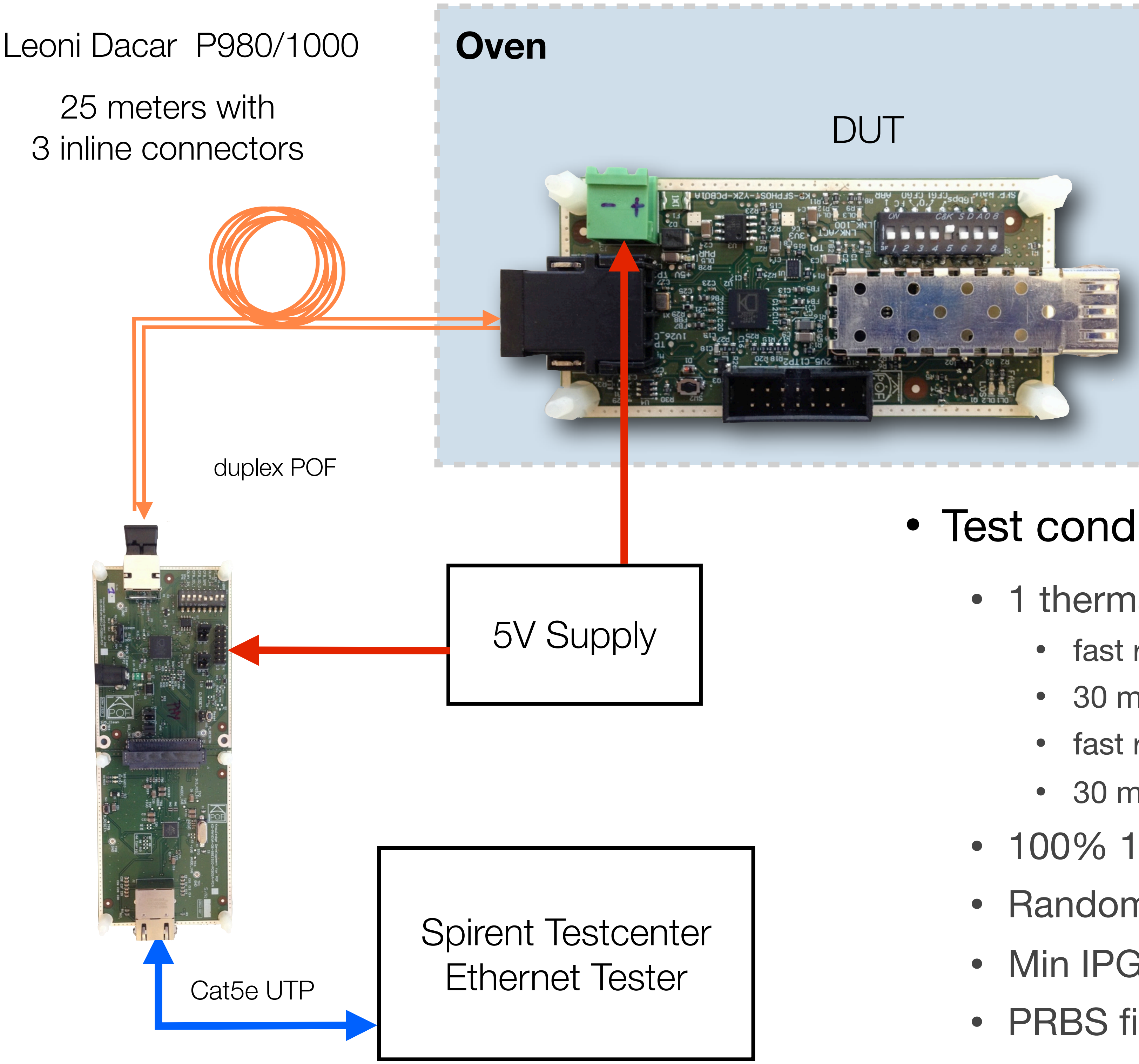
MDIO/MDC or I^2C

SFP socket

KDPOF KD1012B0
1Gbps POF PHY

Yazaki SFF MOST Connector for POF (linear O/E TX and RX inside)

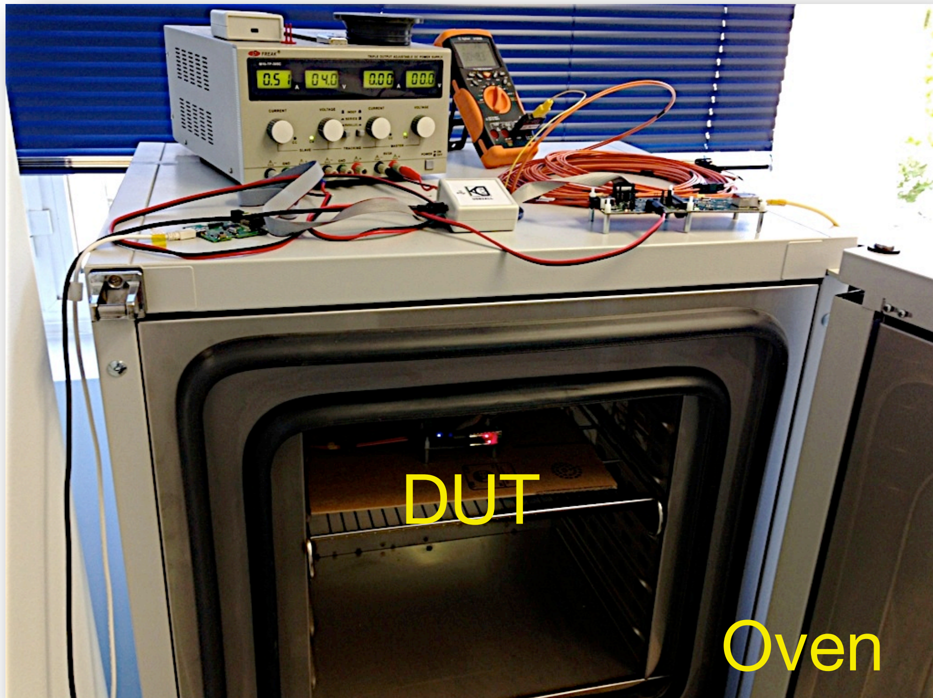
WC Temp experiments - test setup

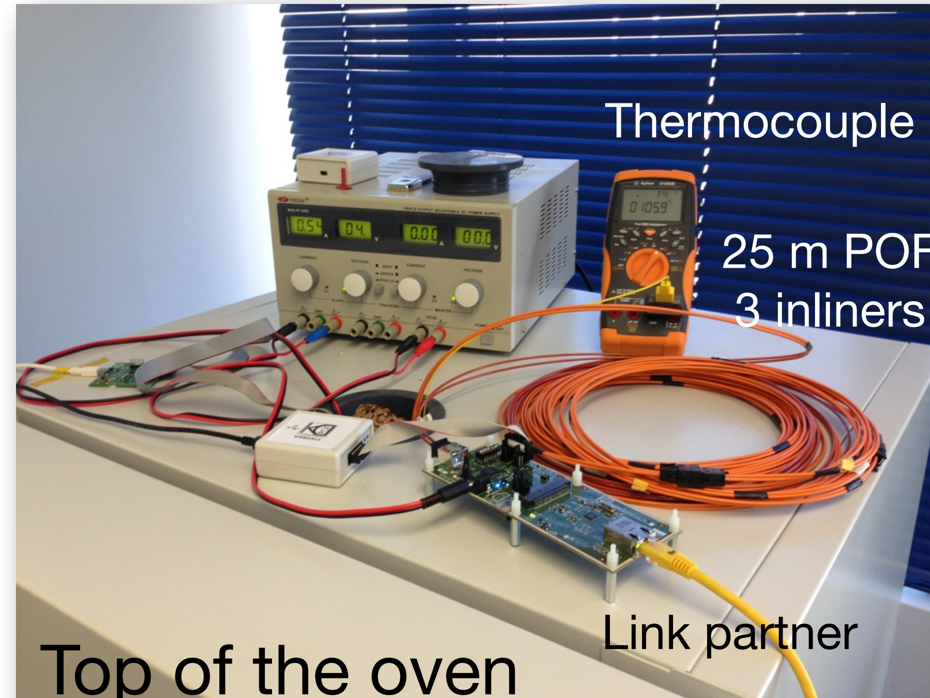


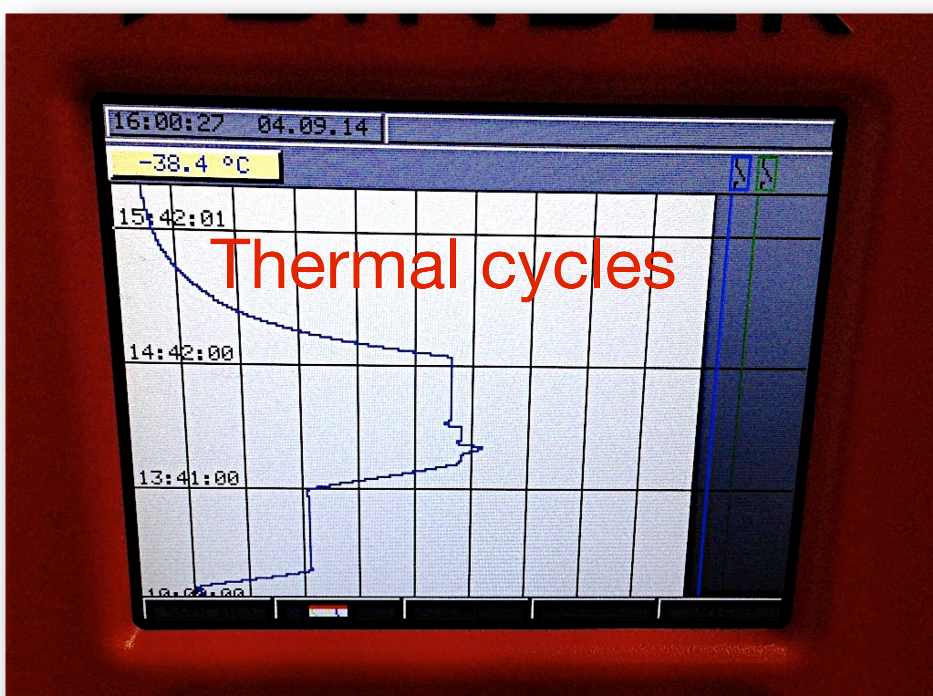
Line loopback is configured in POF PHY (received Eth frames are looped back at GMII and retransmitted to PCS TX for verification by Spirent connected to link partner)

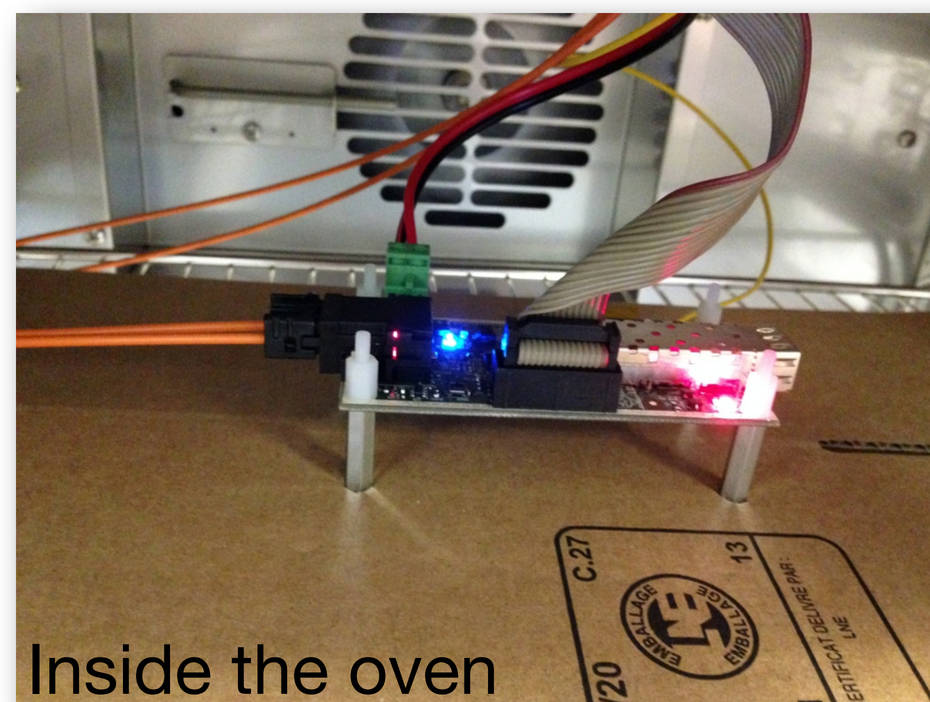
- Test conditions:
  - 1 thermal cycle of:
    - fast ramp from 25ºC to 90ºC
    - 30 min at 90ºC
    - fast ramp from 90ºC down to -40ºC
    - 30 min at -40ºC
  - 100% 1Gbps traffic load
  - Random packet size from 64 to 1518 bytes
  - Min IPG = 12 bytes
  - PRBS fill type and signatured packets

WC Temp experiments - test setup









WC Temp experiments - test results

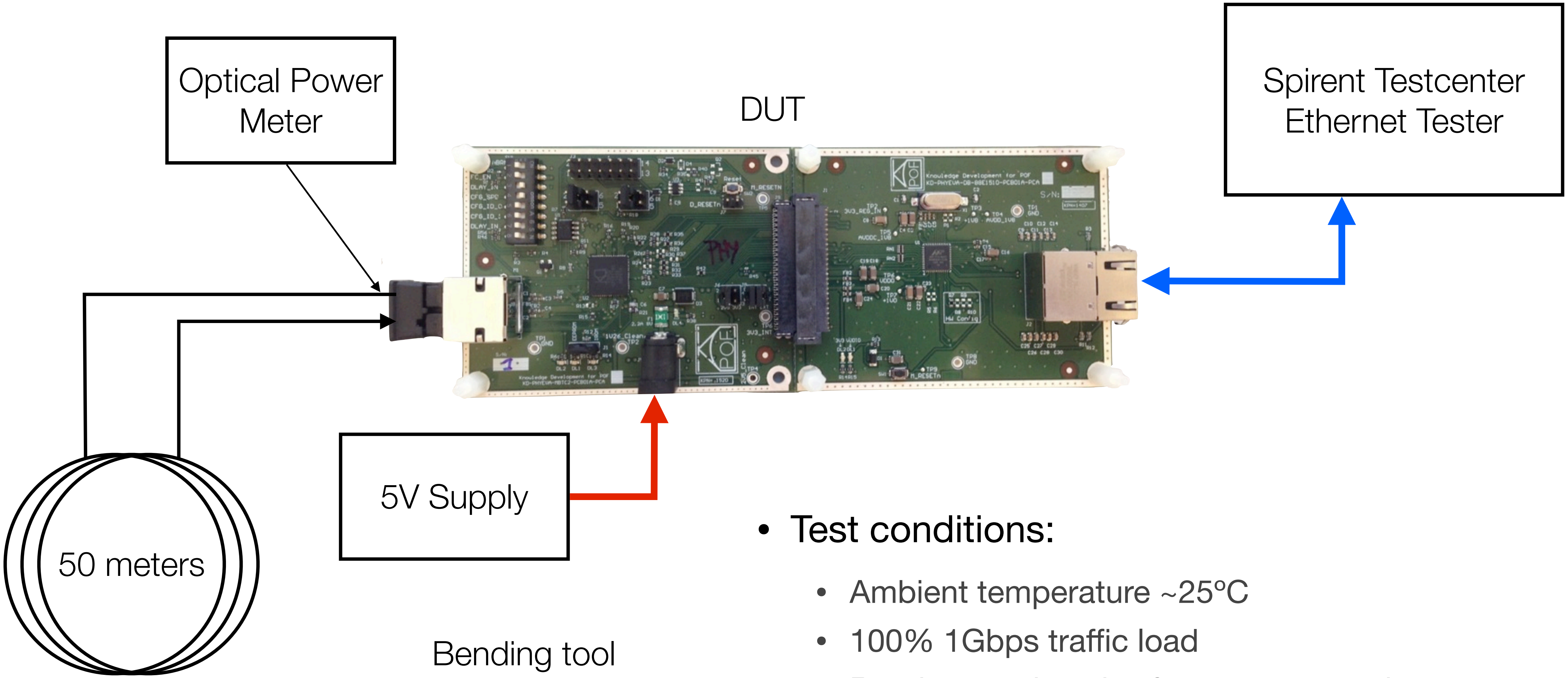
- BER = 1.4e-12 after 3 hours of test with varying temperature between -40 ºC and 90 ºC
- Dropped frames = 0
- 1 Gbps POF link demonstrated in automotive grade conditions

- Test limits:
  - Max temperature limit of test was imposed by the power management circuitry of PCB used inside the oven
  - More tests will be run and reported next meeting with new board setup for up to 105ºC

- Note:
  - PRBS generator is configured in Spirent TestCenter as fill type of Eth frames (only information payload is random)
  - The experiments are also valid with constant or any fill pattern, since the communication system implements both binary and symbol level scramblers; therefore, the performance is the same regardless the content or size of ethernet frames

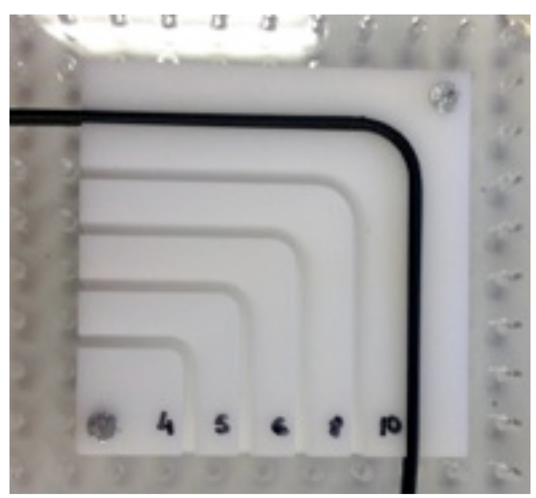
Experiments with bending

Bending experiments - test setup



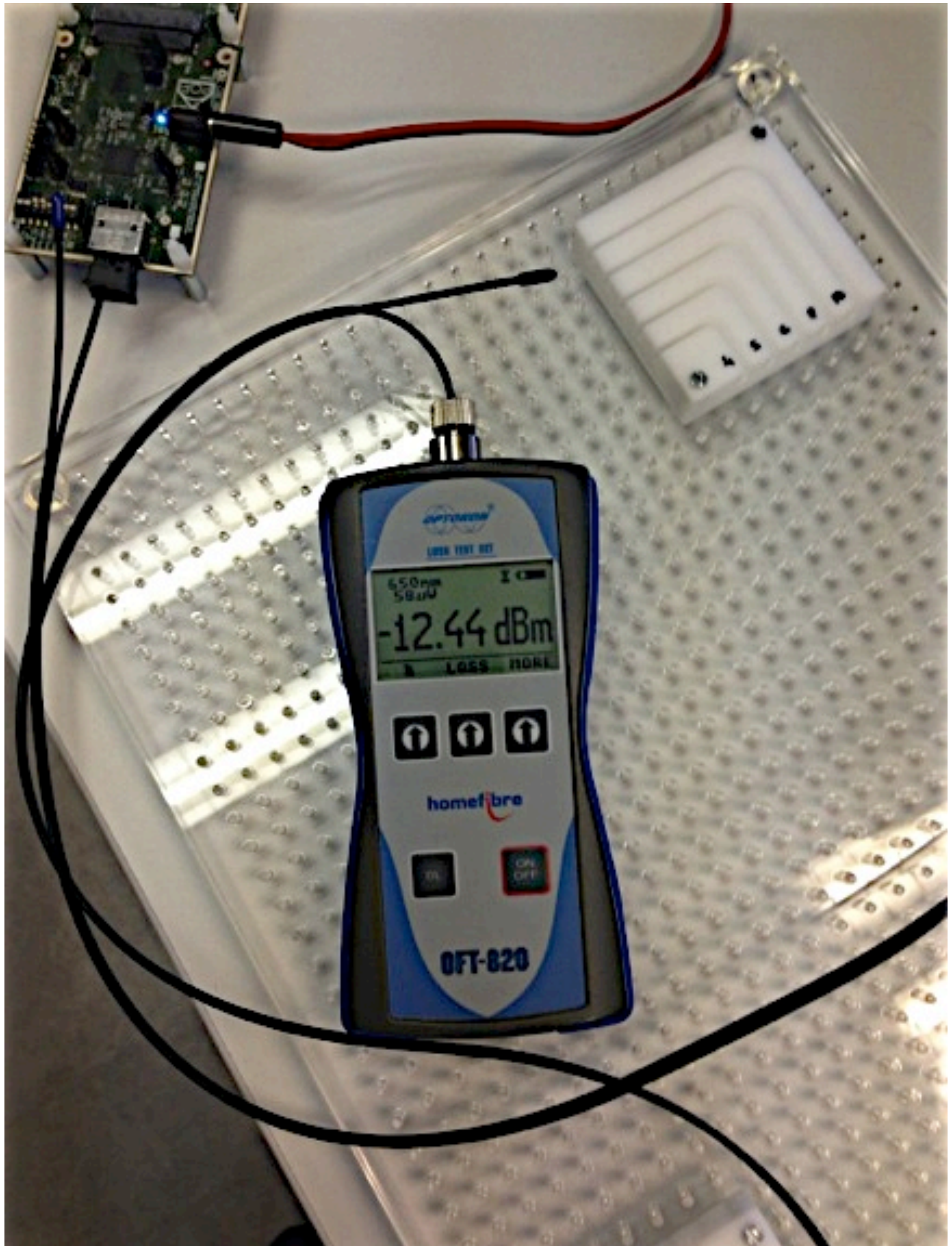
Mitsubishi Eska GH4002
Optical loopback

Bending tool



- Test conditions:
  - Ambient temperature ~25°C
  - 100% 1Gbps traffic load
  - Random packet size from 64 to 1518 bytes
  - Min IPG = 12 bytes
  - PRBS fill type and signatured packets
  - Bends in different locations of fiber and different bending radius

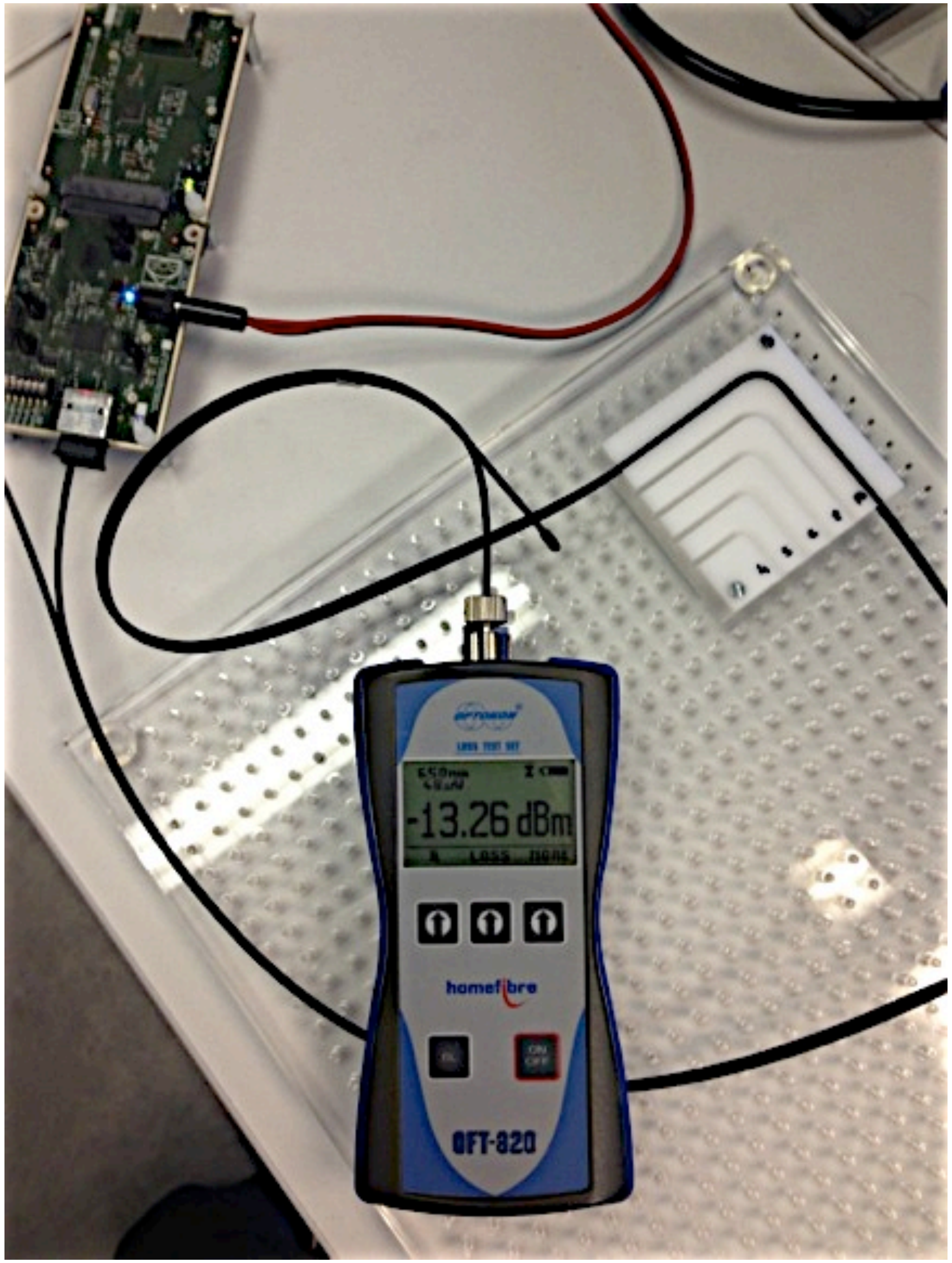
Bending experiments



- 50 meters of POF Mitsubishi Eska GH4002
    - 1 mm single-core SI-POF fiber
    - 980um core diameter
    - 20 um cladding
    - 2.2 mm jacket diameter
    - Att. 0.19 dB/m with red LED, hence 9.5 dB attenuation at 50 m
    - NA 0.5
    - Compatible with IEC 60793-2-40, category A4a.2

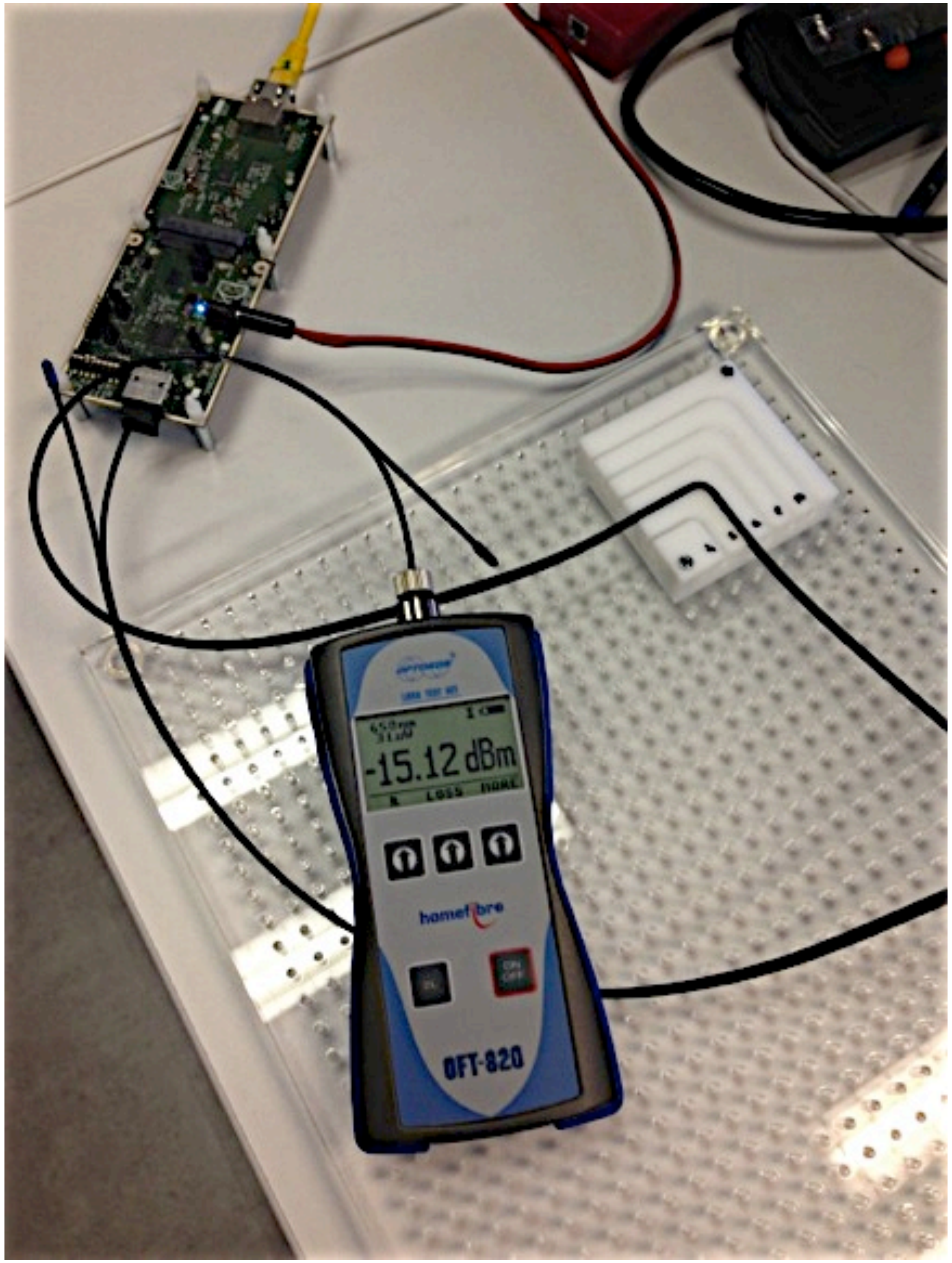
- No bending
- Average Optical Power (AOP) at SP3 = -12.44 dBm

Bending experiments



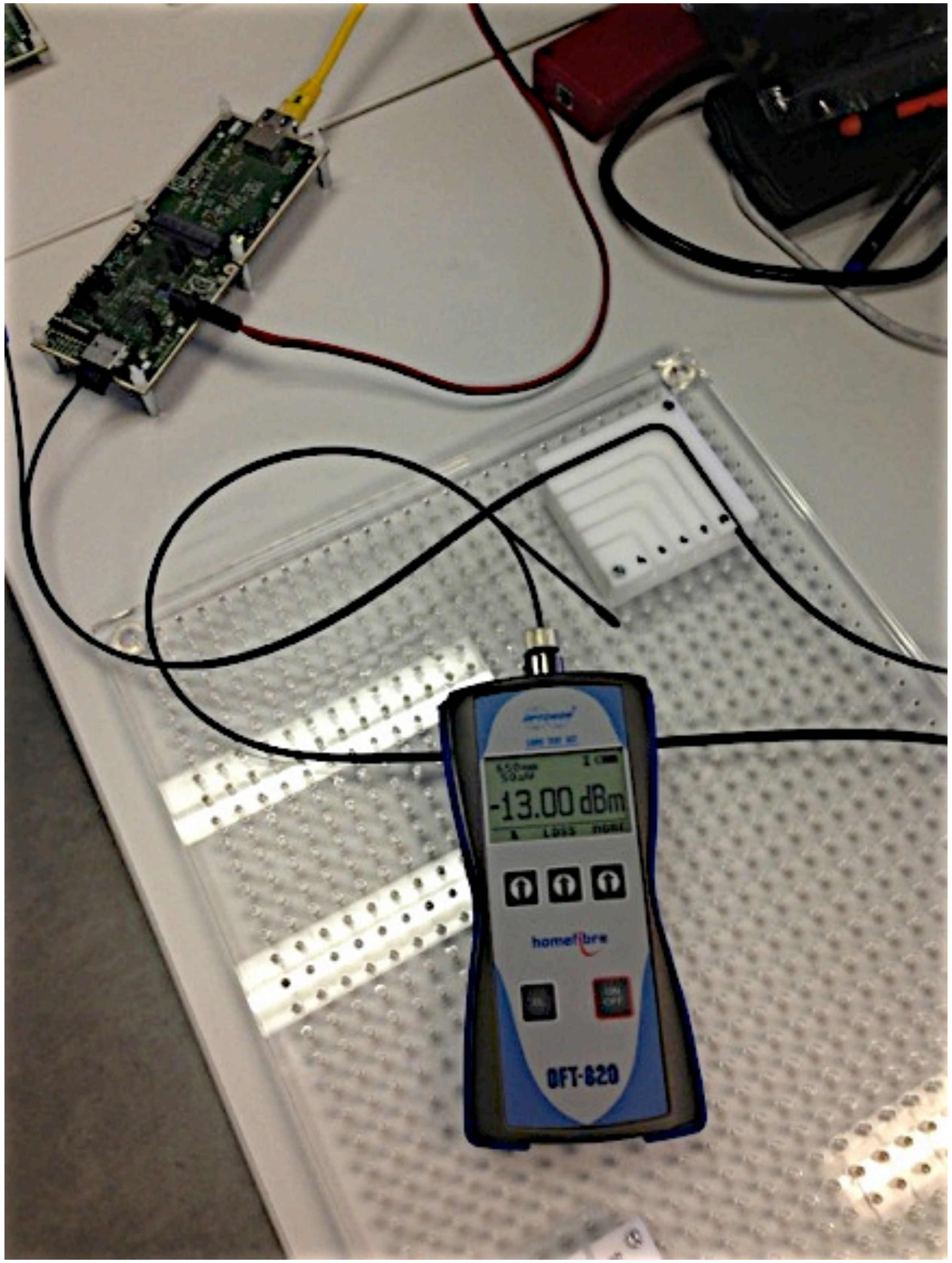
- 50 meters of POF Mitsubishi Eska GH4002
- 90º bend, r = 10 mm close to RX
- AOP at SP3 = -13.26 dBm
- Bending attenuation = 0.82 dB
- 1Gbps link works fine

Bending experiments



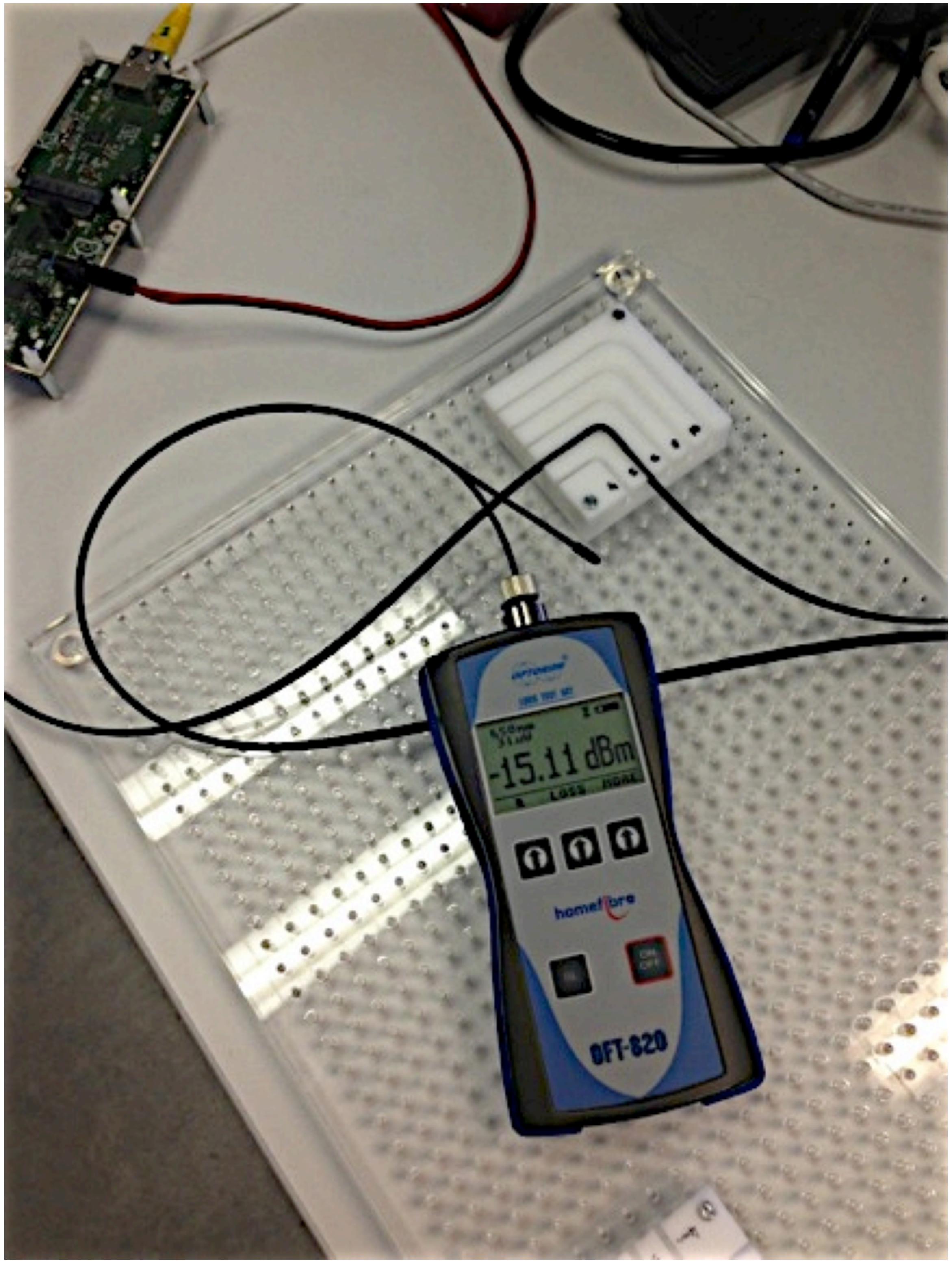
- 50 meters of POF Mitsubishi Eska GH4002
- 90º bend, r = 5 mm close to RX
- AOP at SP3 = -15.12 dBm
- Bending attenuation = 2.68 dB
- 1Gbps link works fine

Bending experiments



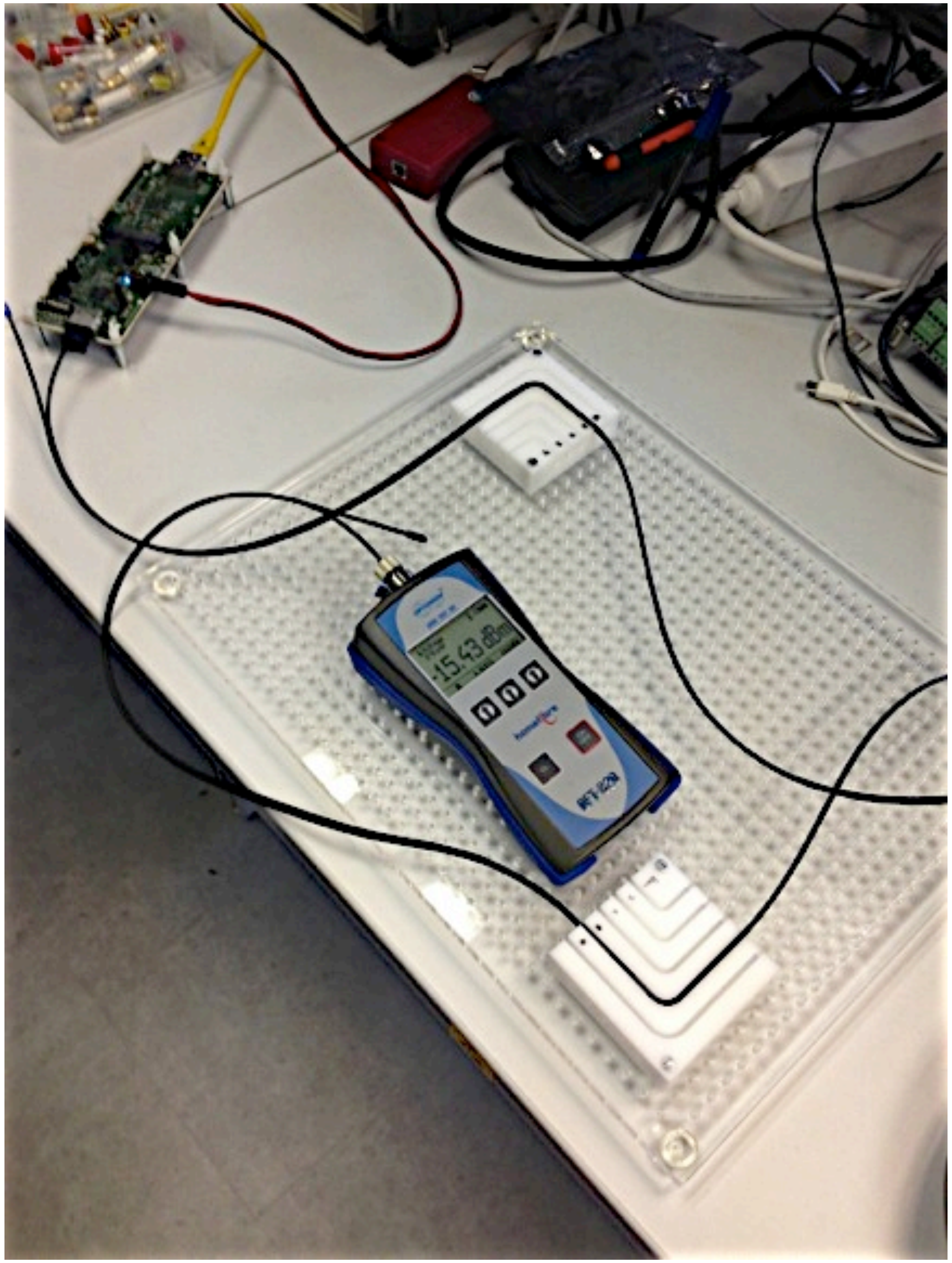
- 50 meters of POF Mitsubishi Eska GH4002
- 90º bend, r = 10 mm close to TX
- AOP at SP3 = -13.00 dBm
- Bending attenuation = 0.56 dB
- 1Gbps link works fine

Bending experiments



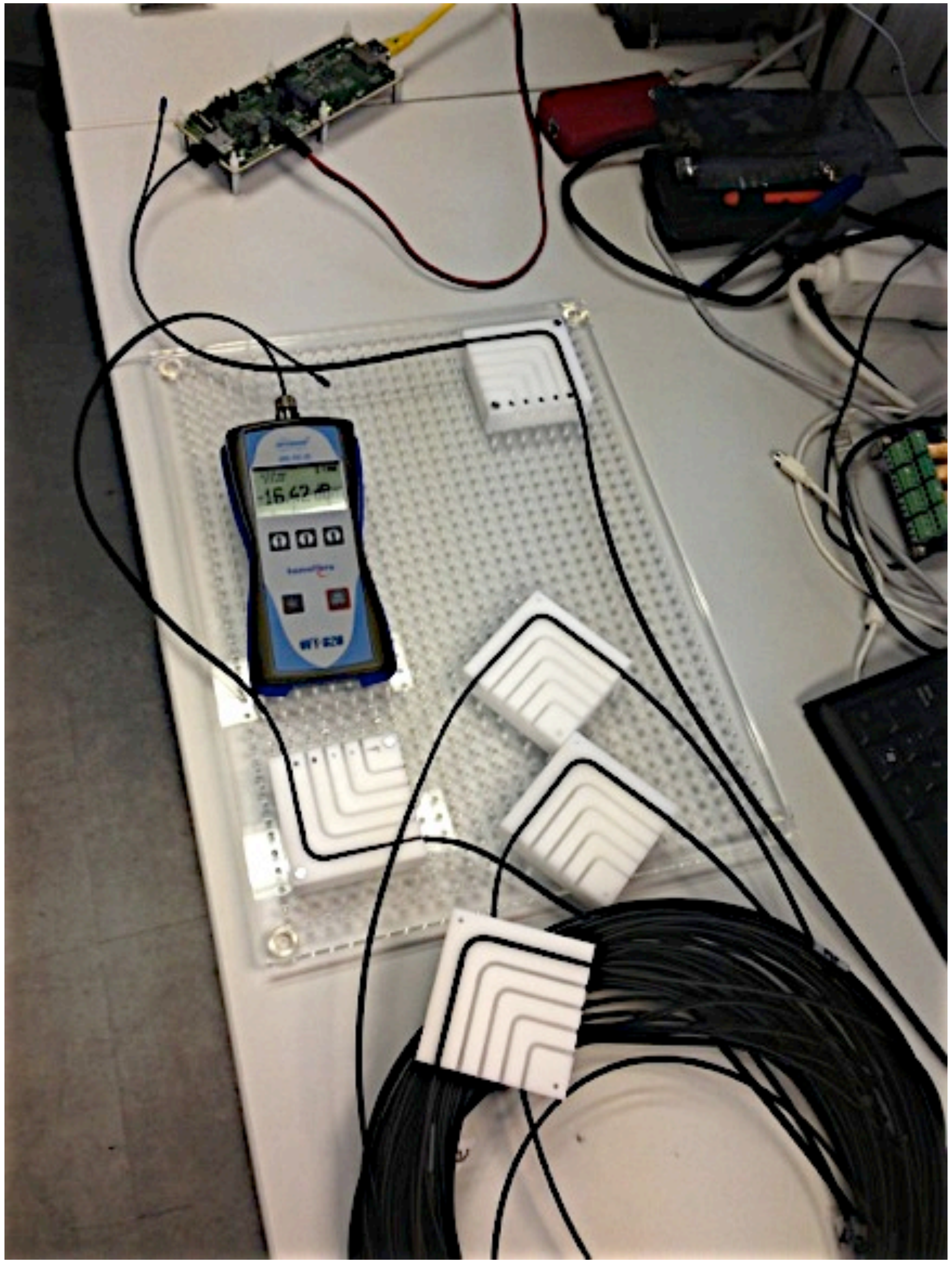
- 50 meters of POF Mitsubishi Eska GH4002
- 90º bend, r = 5 mm close to TX
- AOP at SP3 = -15.11 dBm
- Bending attenuation = 2.67 dB
- 1Gbps link works fine

Bending experiments



- 50 meters of POF Mitsubishi Eska GH4002
- 90º bend, r = 8 mm close to TX
- 90º bend, r = 8 mm close to RX
- AOP at SP3 = -15.43 dBm
- Bending attenuation = 2.99 dB
- 1Gbps link works fine

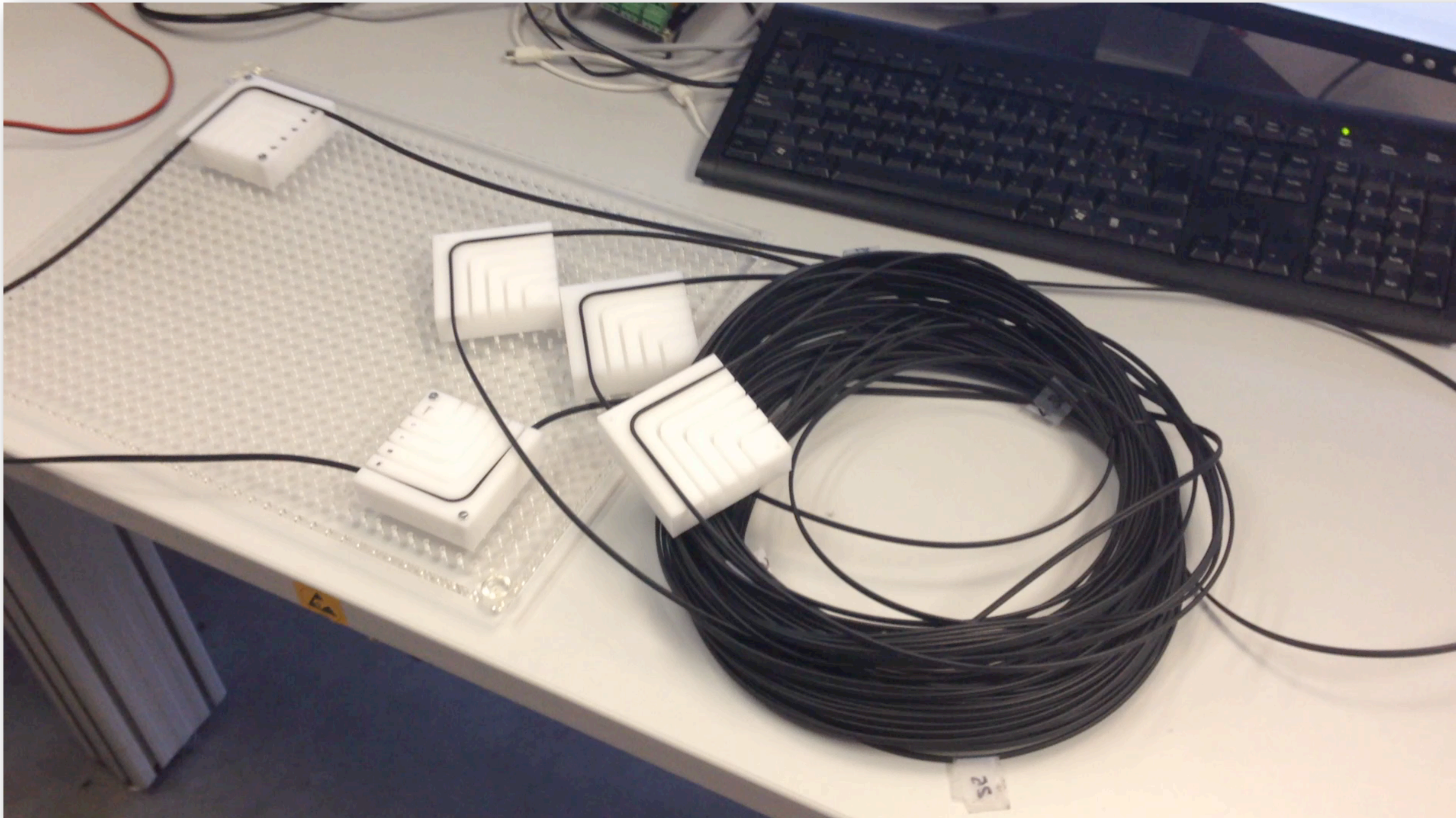
Bending experiments



- 50 meters of POF Mitsubishi Eska GH4002
- 5 x 90º bend, r = 10 mm along the fiber
- AOP at SP3 = -16.42 dBm
- Bending attenuation = 3.98 dB
- 1Gbps link works fine

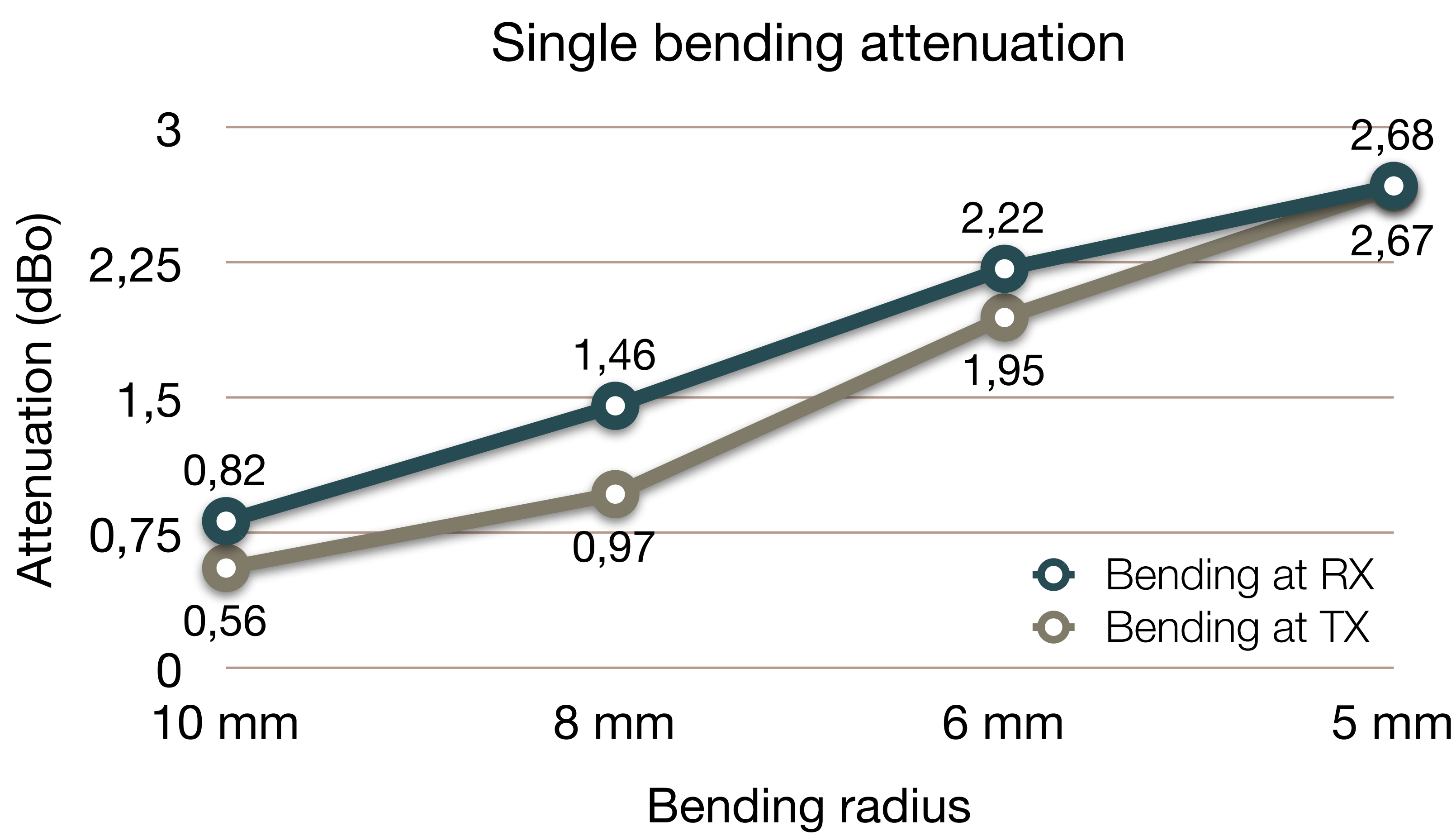
Bending experiments - demo video

Mitsubishi Eska GH4002 single-core NA 0.5 SI-POF, IEC 60793-2-40 A4a.2



50 meters link, with 5 x 10mm bends

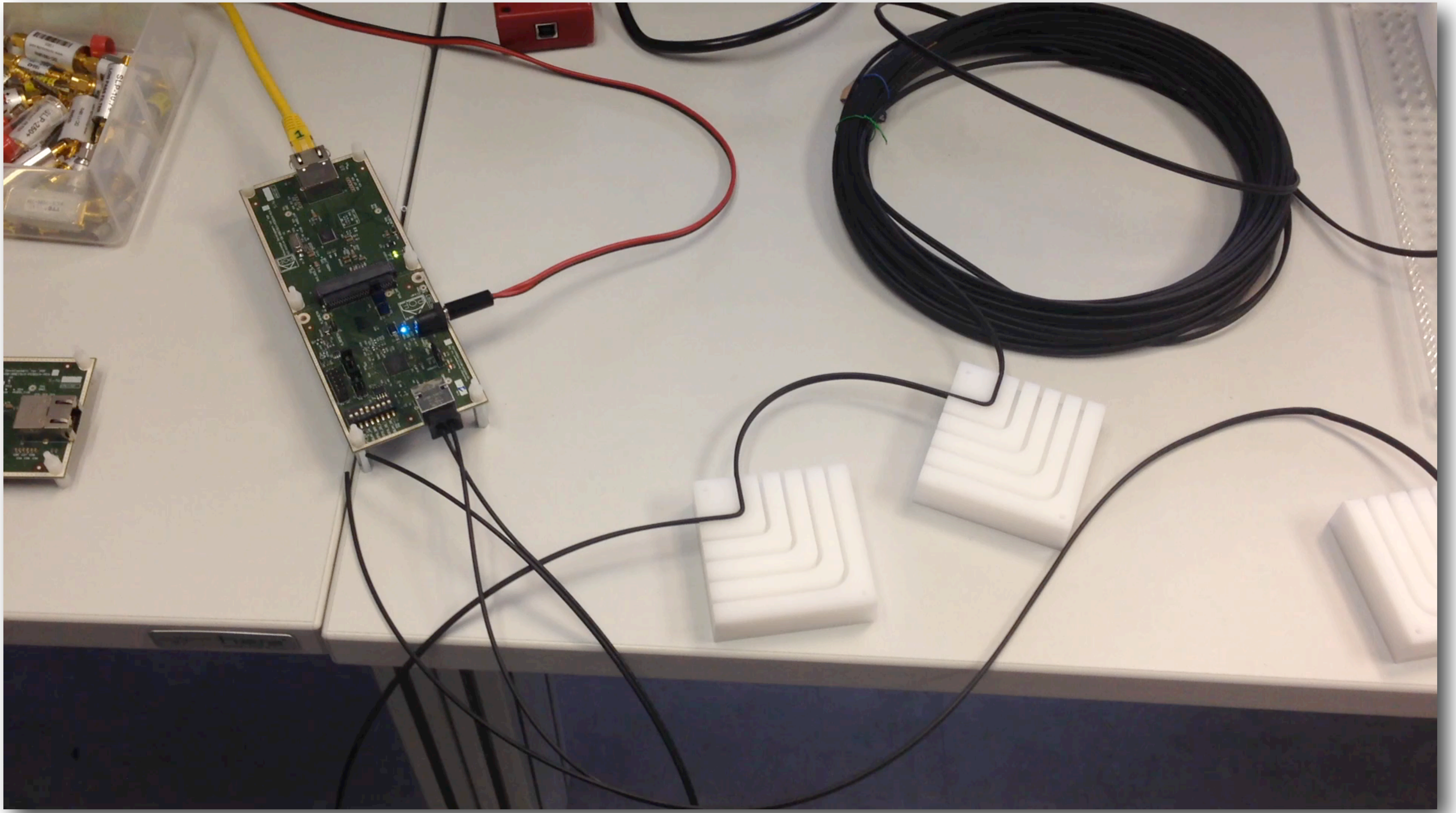
Bending experiments - measurement results



- The multi-bending experiments show a Gigabit link over 50m of the most common POF (GH4002) operating with 4 dBo extra margin to allocate attenuation produced by bending

Bending experiments - demo video, multi-core

AsahiKASEI HMCKU-1000W 1mm 19 cores NA 0.5 SI-POF, IEC 60793-2-40 A4a.2

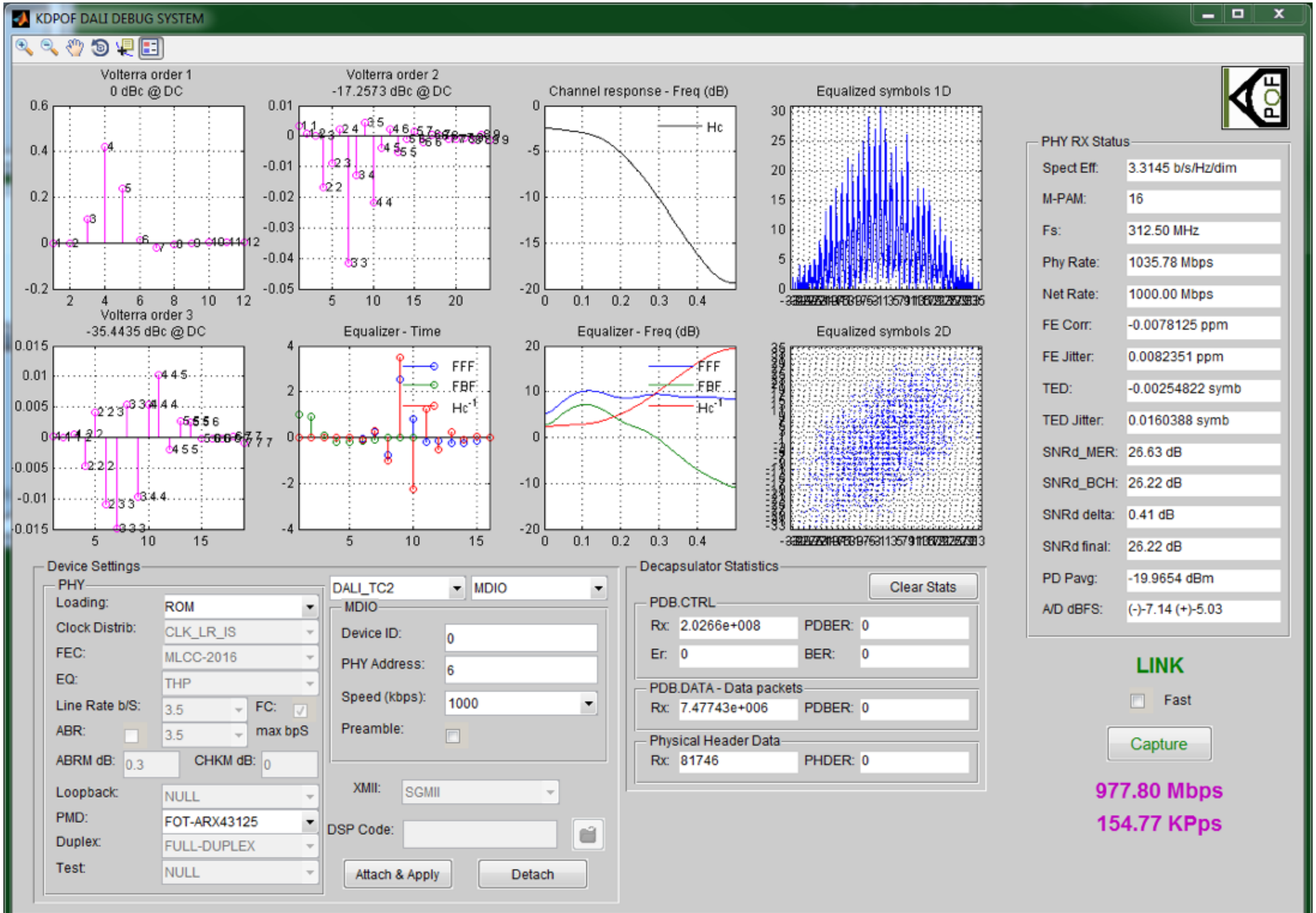


50 meters link, with 10 x 4mm bends

How the communication system works

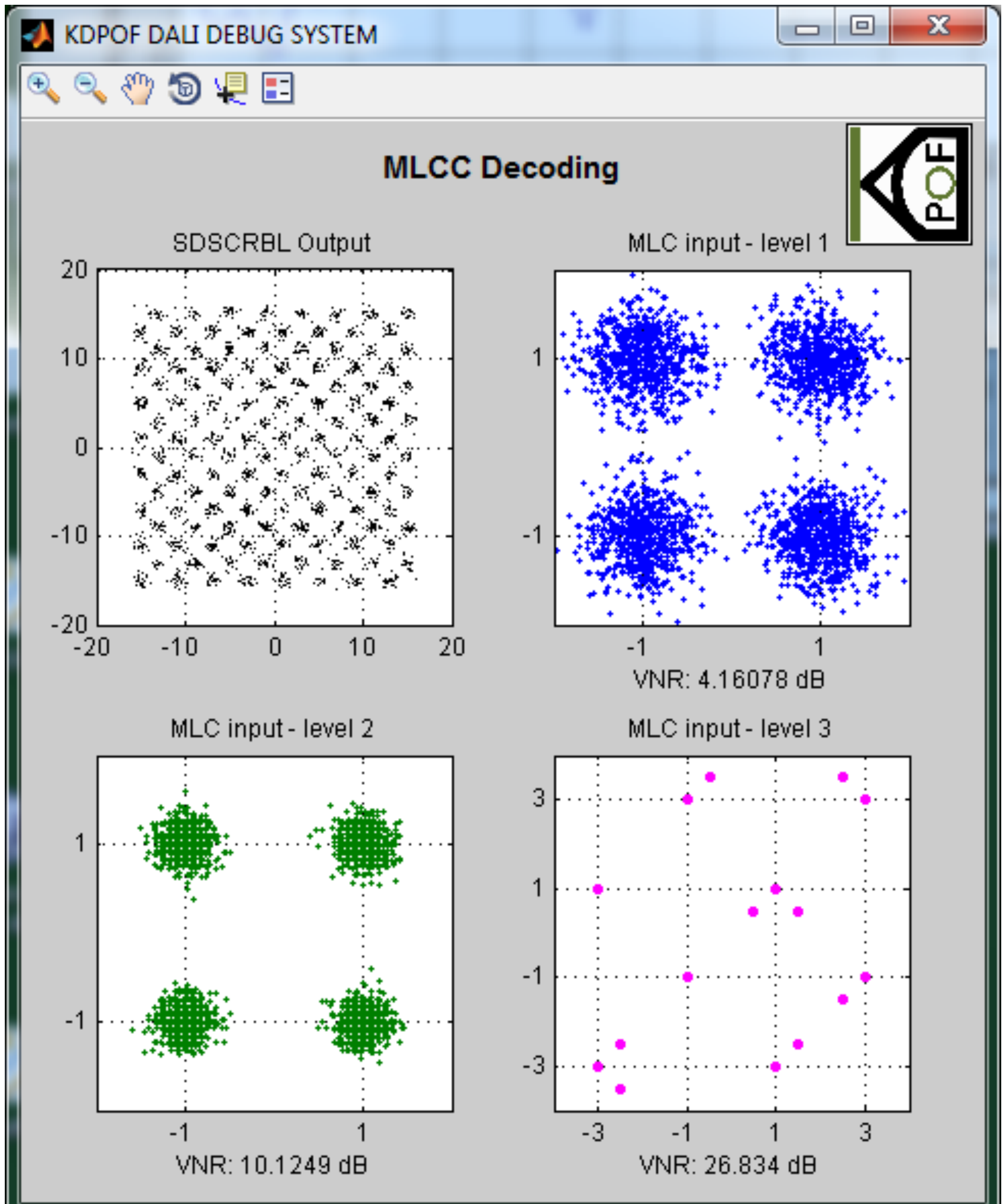
How the technology works

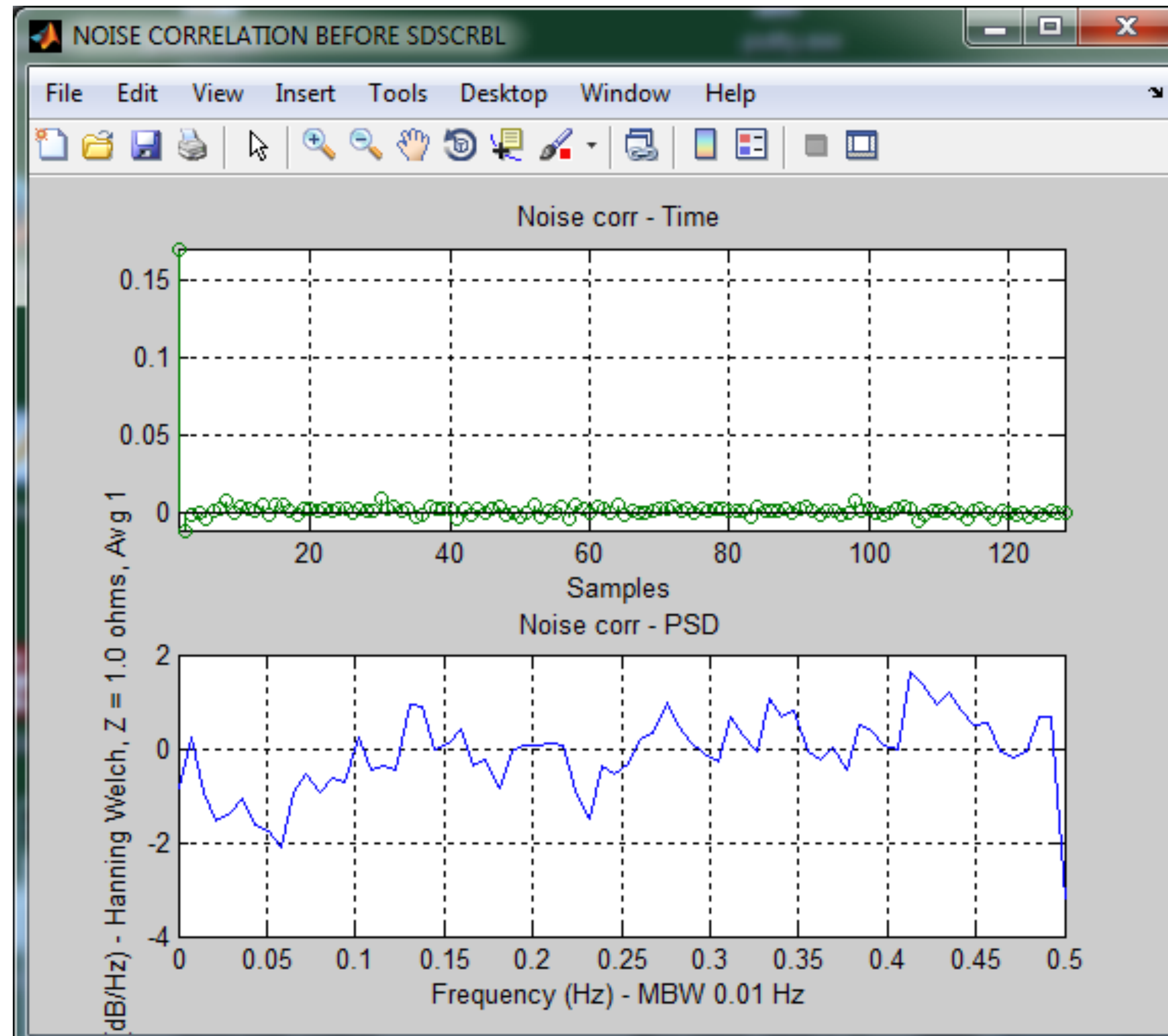
Real-time captures for 50m GH4002 + bending



How the technology works

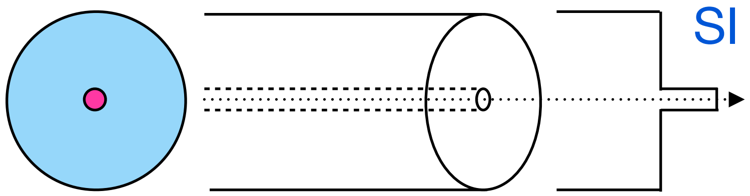
Real-time captures for 50m GH4002 + bending



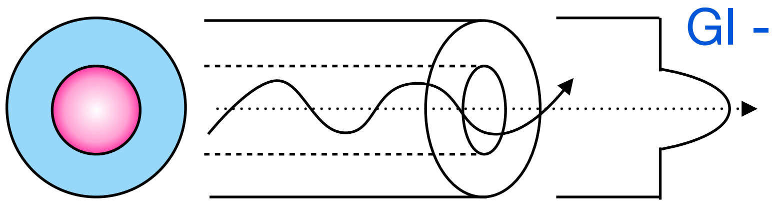


Appendix: intro to POF characteristics

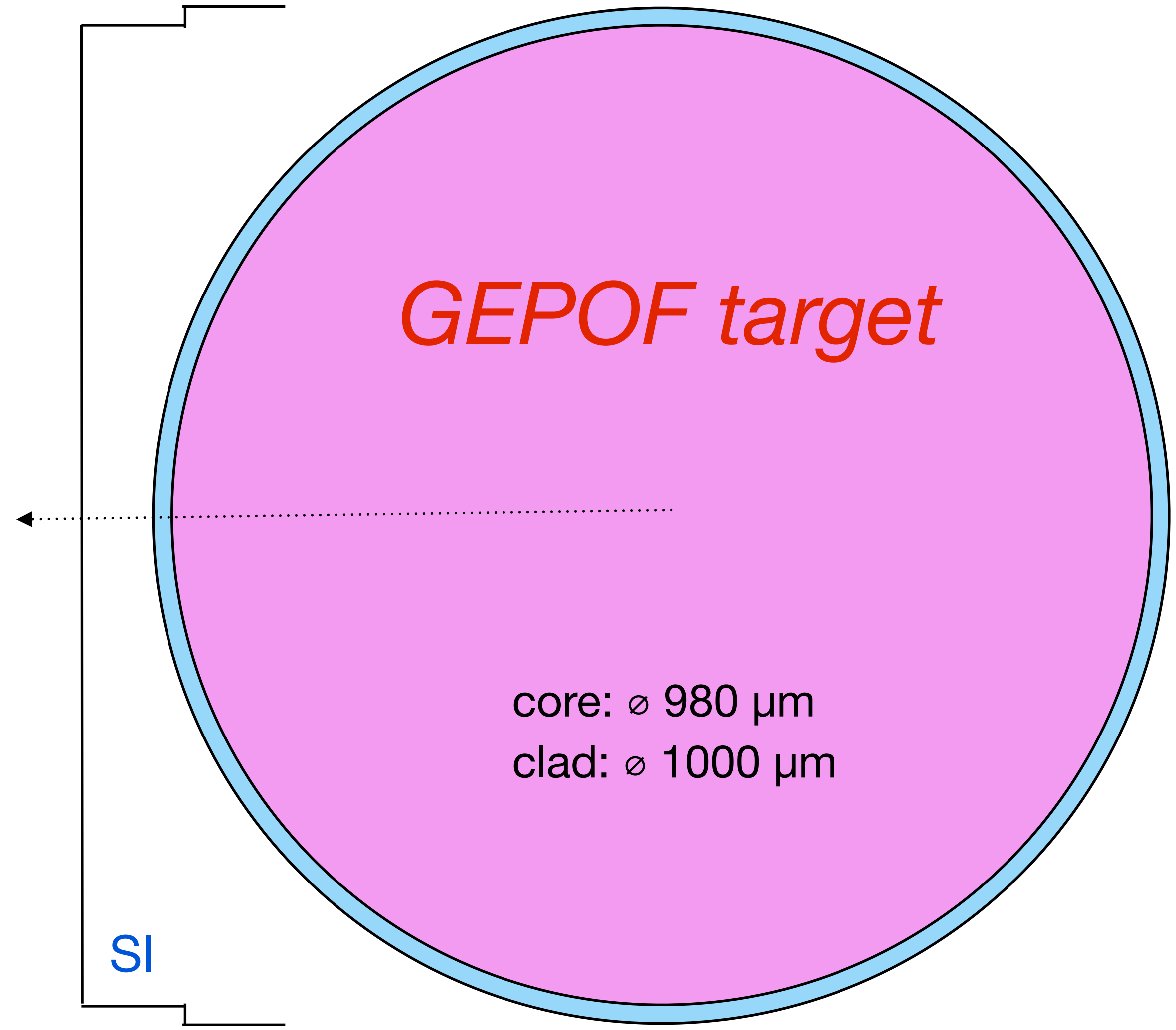
What is POF? - optical fibers



SM-GOF for long-distance transmission



MM-GOF for data-centers, office-LAN



Glass Optical Fibers (GOF)

- Very high bandwidth
- Very low attenuation
- Infrared light
- **Therefore:**
  - **Ideal as communication channel**
- **But**:
  - Requires for high precision connections
  - Requires for professional installers and tools
  - No robust for misalignments and vibrations

PMMA-POF: low performance applications?

- Large diameter core:
  - Connector-less termination
  - Robust for misalignment and vibrations
  - Visible light (usually red LEDs)
  - Do-it-yourself simplicity
- SI-POF: 40MHz x 100m, att 180 dB/km @ 650 nm
  - Low bending losses
  - Very low cost: optoelectronics, fiber & installation
- **We showed that it is also suitable for high capacity**

Mitsubishi Eska GH4001 (1core NA 0.5)

Table 1

Item		GH-4001-P Specification Unit	Min.	Typ.	Max.
Optical Fiber	Core Material	–	Polymethyl-Methacrylate Resin		
	Cladding Material	–	Fluorinated Polymer		
	Core Refractive Index	–	1.49		
	Refractive Index Profile	–	Step Index		
	Numerical Aperture	–	0.5		
	Core Diameter	μm	920	980	1,040
	Cladding Diameter	μm	940	1,000	1,060
Jacket	Material	–	Polyethylene		
	Color	–	Black		
	Diameter	mm	2.13	2.20	2.27
Approximate Weight		g/m	4		
Indication on the Jacket		–	・・・・・ESKA PREMIER・・・・・:Pink		

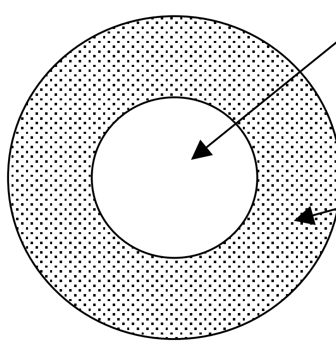


Table 2

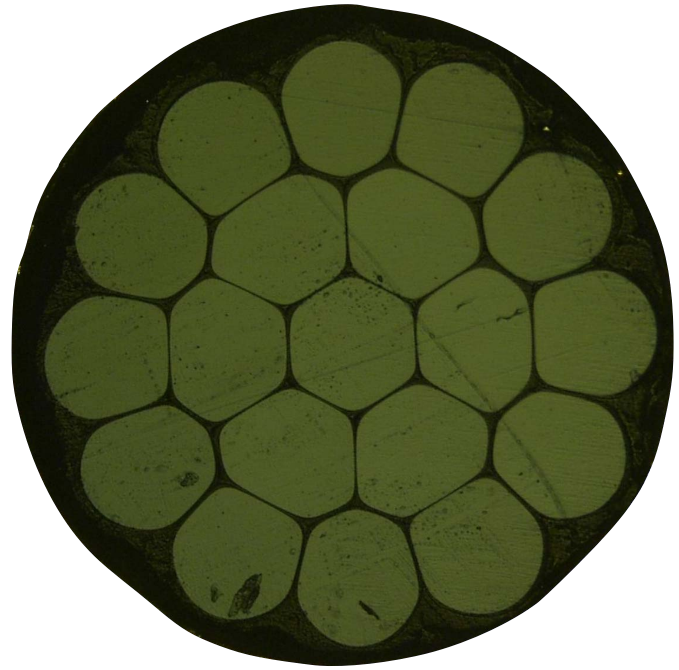
Item		Acceptance Criterion and/or [Test Condition]	GH-4001-P Specification Unit	Min.	Typ.	Max.
Maximum Rating	Storage Temperature	No Physical Deterioration [in a Dry Atmosphere]	℃	-55	–	+85
	Operation Temperature	No Deterioration in Optical Properties* [in a Dry Atmosphere]	℃	-55	–	+85
		No Deterioration in Optical Properties** [under 95%RH condition]	℃	–	–	+75
Optical Properties	Transmission Loss [650nm Collimated Light]	[25℃ 50%RH]	dB/km	–	–	170
		[Operation Temperature]	dB/km	–	–	190
Mechanical Characteristics	Minimum Bend Radius	Loss Increment ≦0.5dB [A Quarter Bend]	mm	25	–	–
	Repeated Bending Endurance	Loss Increment ≦1dB [in Conformity to the JIS C 6861]***	Times	10,000	–	–
	Tensile Strength	Tensile Force at 5% Elongation; in Conformity to the JIS C 6861]	N	70	–	–
	Twisting Endurance	Loss Increment ≦1dB [Sample Length : 1m Tensile Force : 4.9N]	Times	5	–	–
	Impact Endurance	Loss Increment ≦1dB [in Conformity to the JIS C 6861]	N・m	0.4	–	–

All tests are carried out under temperature of 25℃ unless otherwise specified.

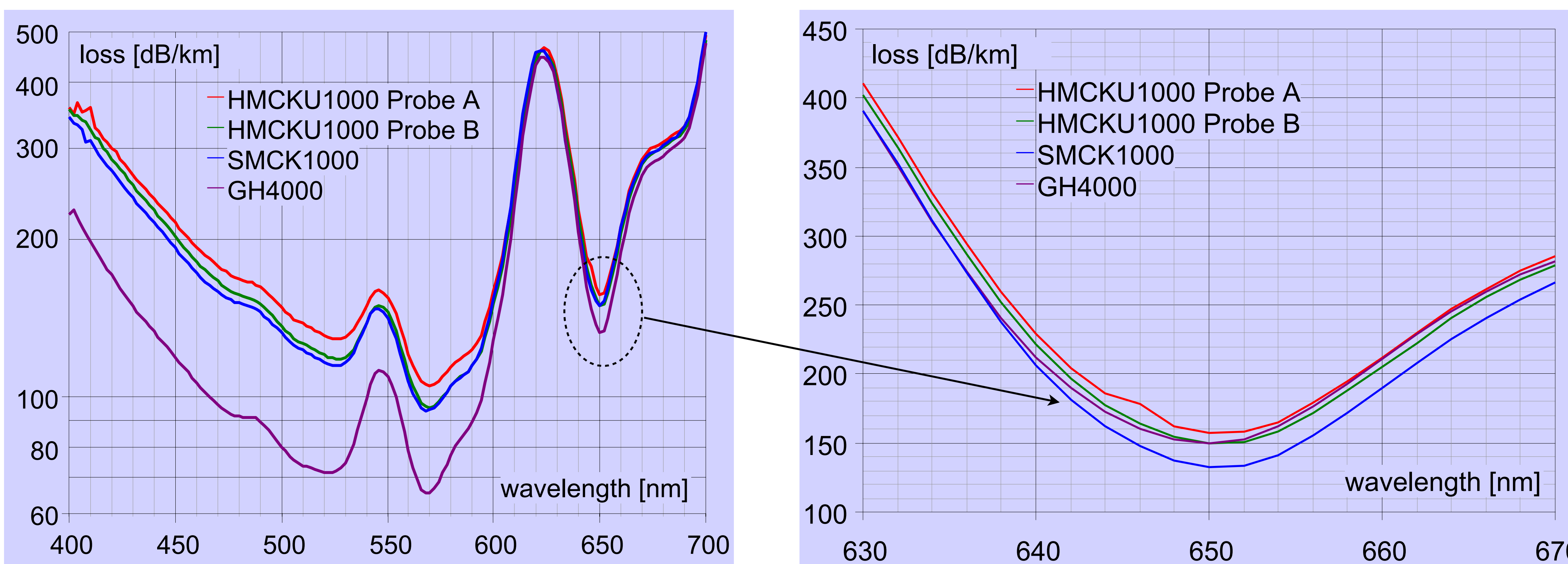
* Attenuation change shall be within +/- 10% after 1,000 hours.
** Attenuation change shall be within +/- 10% after 1,000 hours, except that due to absorbed water.
*** Bend Angle +/-90° ,Bend Radius 15mm,Tension 500g

AsahiKASEI HMCKU-1000PW (19 cores)

ITEM	UNIT	SMCKU-1000PW
CORE MATERIAL		PMMA
CLAD MATERIAL		Fluoro Polymer
JACKETING		PE (black) Halogen-free Non-flammable
NA		0,50
CORE NUMBER		19
CORE DIA.	µm	200
FIBER DIA.	mm	1,0 ± 0,06
CABLE DIA.	mm	2,2x4,4 ± 0,07
BENDING RADIUS[3)]	mm	Min. 2
ATTENUATION [1)]	dB/m	<0,18
TENSILE STRENGTH [2)]	N	> 80
TEMPERATURE RANGE	℃	-40 / +75



- DSI-MC-POF
  - First claddings surrounding PMMA cores, and further they are immersed in a sea of second cladding
- NA 0.5
- Very low att. per bending



Courtesy of Dr. Olaf Ziemann (POFAC)

Table A.3 – Transmission requirements specific to A4a fibres

Attributes	Unit	Limits		Reference
		A4a.1 (4)	A4a.2 (4)	
Attenuation at 650 nm when using an overfilled launch	dB/100 m (1)	≤ 40	≤ 40	3.3
Attenuation at 650 nm when using an equilibrium mode distribution launch (3)	dB/100 m (1)	≤ 30	≤ 18	3.3
Minimum modal bandwidth at 650 nm	MHz over 100 m (2)	10	-	3.3
Minimum modal bandwidth at 650 nm using RML	MHz over 100 m (2)	-	40	3.3
Theoretical numerical aperture	Unitless	0,50 ± 0,15	0,485 ± 0,045	3.3
Macrobending loss at 650 nm (10 turns around a 25 mm radius quarter circle)	dB	≤ 0,5	≤ 0,5	3.3

(1) The unit of 100 m is used because this is typical of the fibre length actually used. Attenuation values expressed in dB/100 m can be approximately compared to values stated in dB/km by multiplying the dB/100 m values by 10.

(2) The unit of MHz over 100 m is used because this is typical of the fibre length actually used. Bandwidth values expressed in MHz over 100 m can be approximately compared to values stated in MHz-km by dividing the MHz over 100 m values by 10.

(3) See Annex I

Table A.1 – Dimensional requirements specific to A4a fibres

Attributes	Unit	Limits	Reference
Cladding diameter	µm	1000 ± 60	3.1
Cladding non-circularity	%	≤ 6	3.1
Core diameter	µm	[See 3.1]	3.1
Fibre length	km	[See 3.1]	3.1

Table A.2 – Mechanical requirements specific to A4a fibres

Attributes	Unit	Limits	Reference
Tensile load at yield peak	N	≥ 56	3.2.1
Elongation at yield peak	%	≥ 4,0	3.2.1

Conclusions

- Technical feasibility of GEPOF has been experimentally demonstrated with fabricated PHY ICs and optical transceivers currently available in the market
- The reported experiments show the robust operation of Gigabit Ethernet over 50m of POF in worst case scenarios of consumer applications
- Experiments of gigabit POF link are also reported under automotive grade conditions
- Deep insight of a real product operation has been provided, as a practical application of all the theoretical background explained in previous meetings

References

- [1] *Rubén Pérez-Aranda, "High spectrally efficient modulation schemes for GEPOF technical feasibility", GEPOF SG, Plenary Meeting, July 2014*
- [2] *Rubén Pérez-Aranda, "Optical transmitter characteristics for GEPOF technical feasibility", GEPOF SG, Interim Meeting, May 2014*
- [3] *Rubén Pérez-Aranda, "Shannon's capacity analysis of GEPOF for technical feasibility assessment", GEPOF SG, Interim Meeting, May 2014*
- [4] *Rubén Pérez-Aranda, "Proposal of a Physical Coding Sublayer for GEPOF technical feasibility", GEPOF SG, Plenary Meeting, July 2014*
- [5] *Rubén Pérez-Aranda, "Proposal of a Physical Medium Attachment for GEPOF technical feasibility", GEPOF SG, Plenary Meeting, July 2014*

Questions?