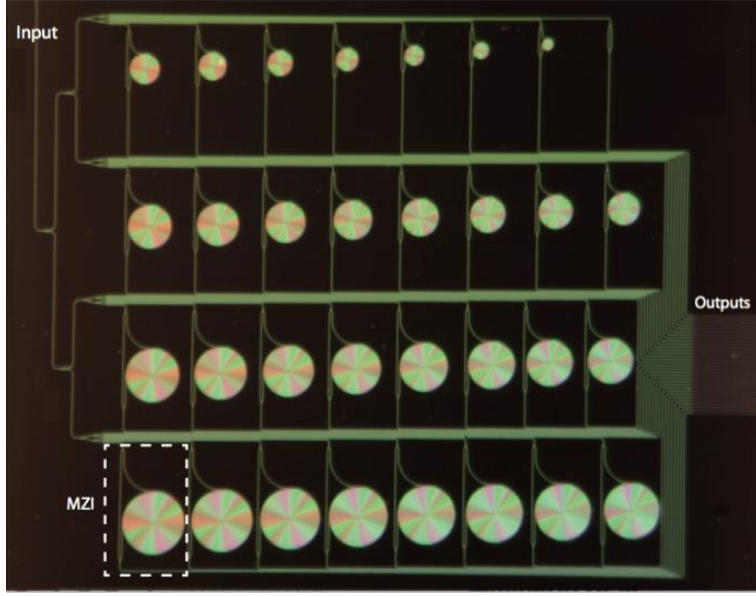
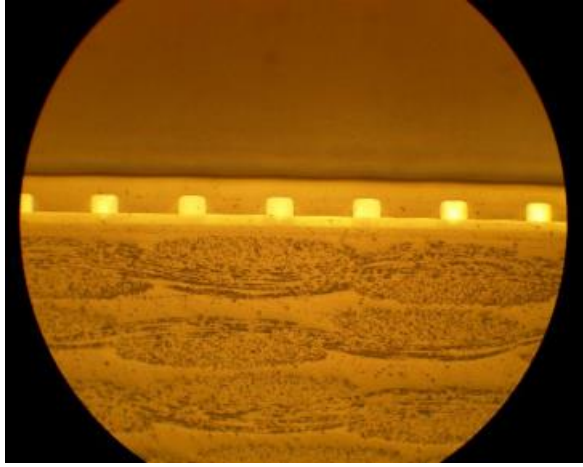


EMPIR 14IND13 PhotInd
Metrology for the photonics industry – optical fibres, waveguides and applications

A. Lassila, M. Shpak, A. Vaigu, M. Šmíd, A. Velasco, A. Pokatilov, I. Fatadin, R. Ferguson, D. Robinson, T. Walbaum, S. Burger, M. Haapalainen, P. Vahimaa, H. Lukner, W. Pernice, R. Pitwon, A. Deninger, J. Morel, N. Castagna, O. Peters, H. Husu

Outline

- EMPIR
- Project info & Partners
- Objectives
- Work Packages
- Conclusion



EMPIR

European Metrology Programme for Innovation and Research (EMPIR). EMPIR

- is the main programme for European research on metrology
- coordinates research projects to address grand challenges, supports and develops the SI system of measurement units.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

Project PhotIND

Motivation = Industry Needs

- Modern photonic components cannot be reliably measured using classical techniques

⇒ Need for new methods

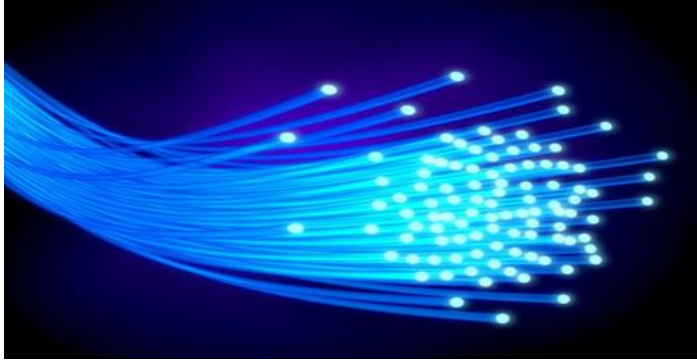
- Measuring instruments often uncalibrated and provide insufficient accuracy

⇒Need for improved metrology

Examples of needs:

- Online measurements in optical fibre manufacturing
- Measurements in high power laser applications
- Metrology of optical interconnects
- Calibration of high resolution optical time-domain reflectometers
- More accurate optical power measurements

PhotInd

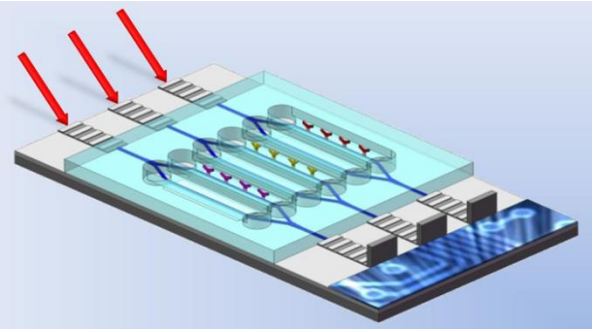


PhotIND

Metrology for the photonics industry - optical fibres, waveguides and applications

Coordinator: Antti Lassila (VTT MIKES)

Project Partners: NMIs, Companies, Universities
Aalto, CMI, IO-CSIC, METAS, VTT MIKES, Metrosert, NPL, Arden Photonics, JCMwave, Menlo Systems, nLIGHT, Oplatek, Seagate Systems, Toptica Photonics, Tartu Ulikool, Westfaelische Wilhelms-Universitaet Muenster, Fraunhofer, University of Eastern Finland



Duration: 8/2015-7/2019
Budget: 1.9 M€, direct cost. 225 person months

Project Objectives 1

- To develop traceable online and offline metrology techniques for characterisation of advanced optical fibres and photonic components:
  - online measurements for thickness and concentricity of fibre layers
  - dispersion and optical parameter measurements in high power applications
- To develop metrology for improved traceability of fibre optic measuring instruments:
  - traceable measuring system for encircled angular flux
  - methods for calibration of the attenuation scale and the distance scale of multimode optical time domain reflectometers (OTDR).
  - a novel portable absolute standard detector based on carbon nanotubes at cryogenic temperatures
- To develop metrology for terahertz transmission links – dynamic range, insertion loss, SNR, bit error ratio (BER) for various modulation formats, free spectral range and bandwidth

Project Objectives 2

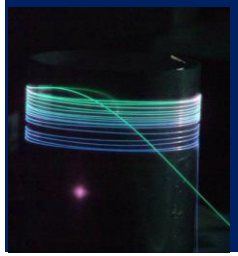
- To establish the metrology tools
  - for performance characterisation of polymer waveguides mounted on electronic circuit backplanes used in high-speed data links for parameters of attenuation, isolation and BER.
  - for developing fibre-to-fibre connectors at high average powers for transmission and the heating of the components

- To engage with the European photonics industry and photonics equipment manufacturers
  - take up of the technology and measurement techniques developed by the project, and to recommend what further actions are required to ensure uptake.

Work Packages

WP1

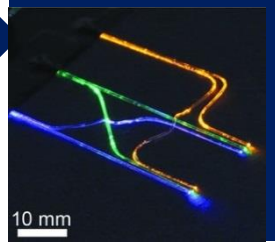
Development of measurements for characterization of advanced optical fibres



- Dimensional characterization
- Dispersion of advanced optical fibres
- High power optical characterization
- Supported by simulations

WP2

Development of metrology for photonic interconnects



- Fibre-to-fibre coupling in high power applications
- Advanced fibre-to-chip coupling
- Optical waveguides
- waveguide-based photonic devices
- THz interconnects

WP3

Development of fibre optic meas. instruments and artefacts

- Angular Encircled Flux measurements
- Optical time domain reflectometers with high spatial resolution
- Novel fibre coupled power detector

WP4

Measurement comparisons of the methods

- Dimensional
- Dispersion
- Fibre-to-chip coupling
- OTDRs

Online dimensional characterization of optical fibres in manufacturing

The goal of this work is to develop an on-line system for fibre geometry measurement.

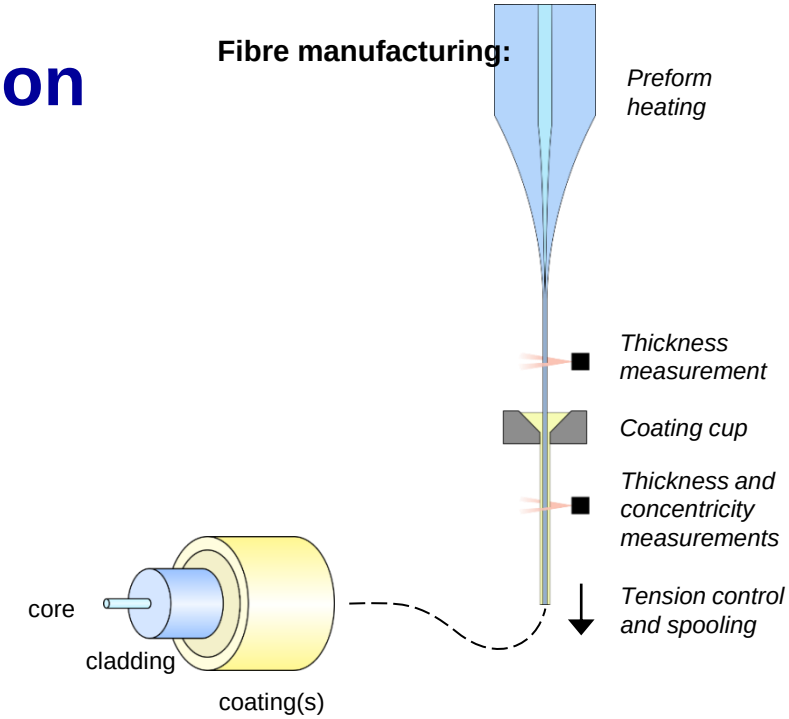
- Fibre/coating concentricity with 1 µm uncertainty
- Fibre and coating diameters with 0.5 µm uncertainty

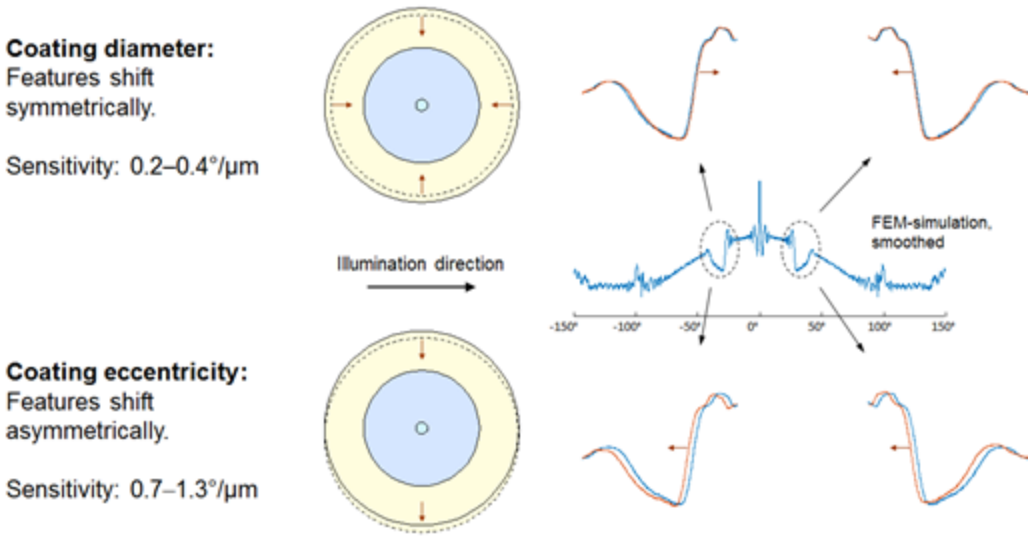
Measurement method:

- Transverse illumination with a laser beam
- Analysis of the scattered light angular intensity profile

Progress:

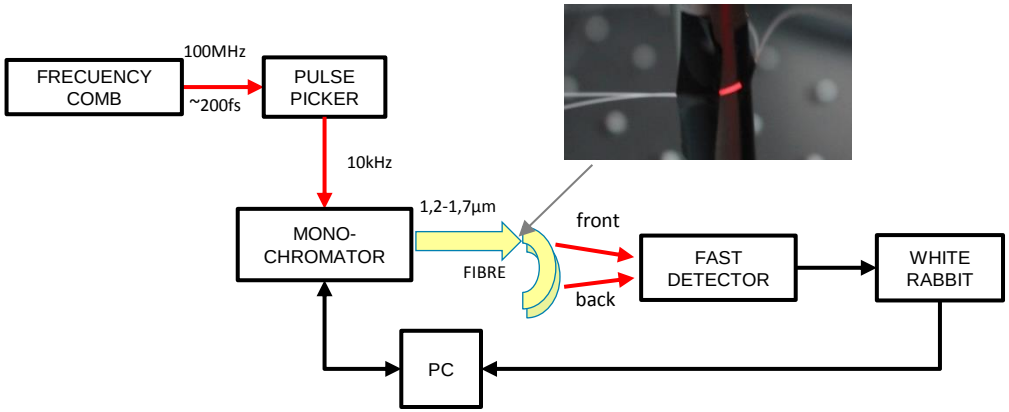
- Modelling with finite element and Fourier modal simulations
- Laboratory measurements and comparison with simulations
- Modelling of thickness and concentricity effects





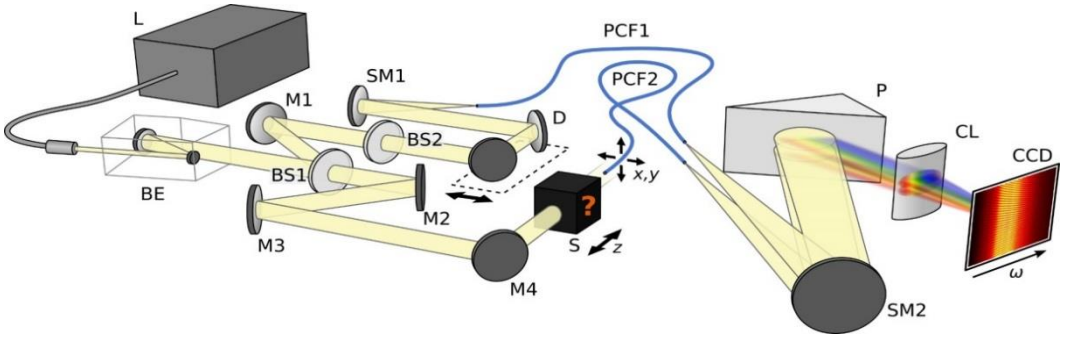
Dispersion of advanced optical fibres

Novel non-destructive methods for dispersion and group velocities measurements in optical fibres.

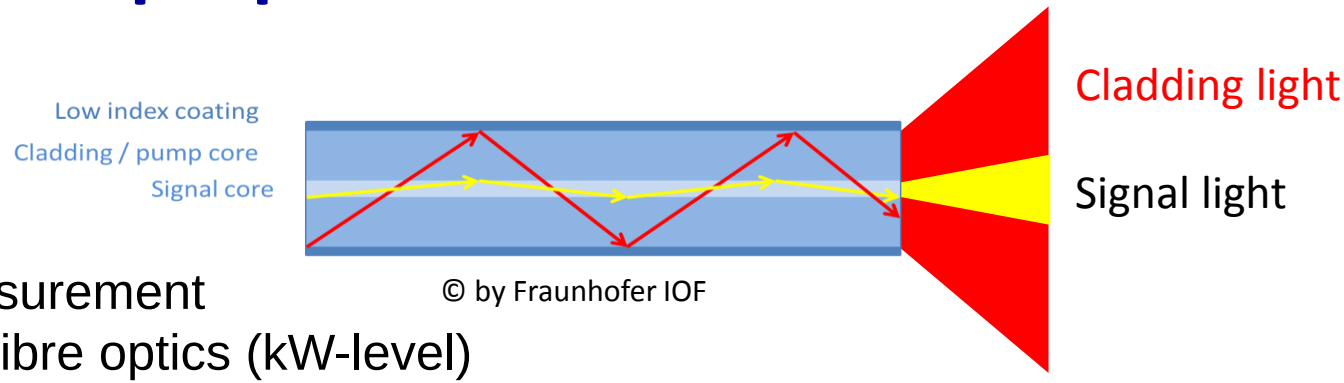


- Method 1: Time stamping of pulses using White Rabbit technique with a tuneable pulsed light source. Accuracy ~55 ps rms.

- Method 2: Modify a SEA TADPOLE-type spatial-spectral interferometer to measure spectral phase/dispersion curve in octave spanning range ca 450-1000 nm. 3 fs temporal and 3 µm spatial resolution.



High power optical properties characterisation



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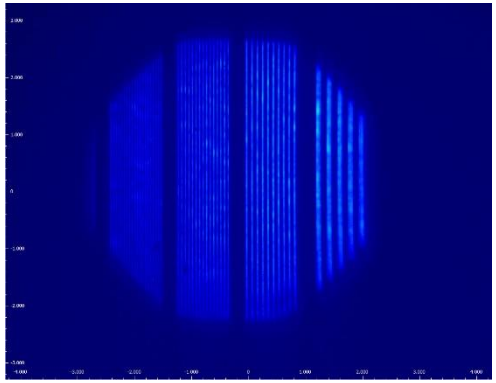
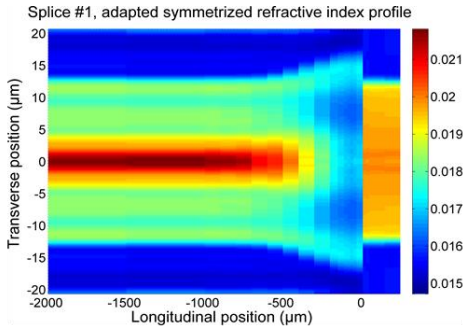
Develop guidelines on measurement procedures for high power fibre optics (kW-level)

- Measurement procedure to compare the transmission loss of double-clad fibres at high power
- Measurement procedure for the longitudinal temperature distribution of active fibres during high power operation using OBR
- Method for measurement light in the cladding.
  - Cladding modes hard to identify due to spatial overlap with core light and low NA content
  - Standard methods either complex & costly (like adding cladding light strippers) or not precise (measuring far field with camera, goniometer).
  - New method developed based on local intensity measurement and extrapolation



High power photonic interconnects & waveguides

- Evaluate methods for fibre interconnects to high power operation
- Develop and test advanced fibre-to-chip coupling solutions
- Metrology for waveguides



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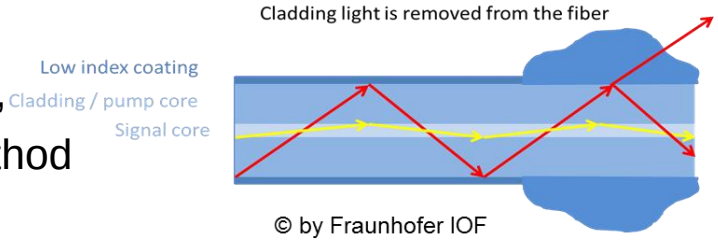
Tasks:

- Evaluation of different kind of fibre connector; FC/PC, FC/APC, Mini-AVIM, spliced fibre connections
  - loss, temperature, refractive index along splice connection,
  - vary splice parameters, simulate via beam propagation method
- Evaluation of cladding strippers
- New fibre to chip couplers
  - Broadband 3D coupler w lithography
  - 3D printed fibre to chip couplers
- Develop metrology for waveguide-based photonic devices: birefringence, thermal dependence, fabrication limitations



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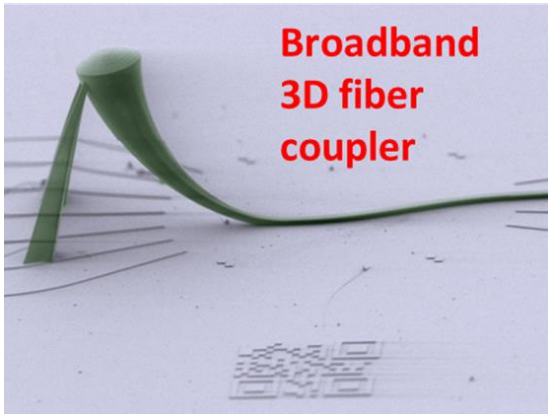
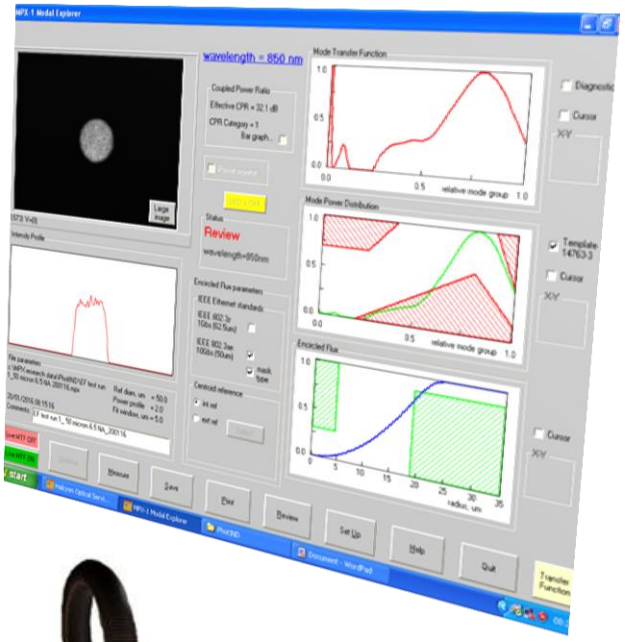


Optical Printed Circuit Boards

Establish the metrology tools for performance characterisation of polymer waveguides mounted on electronic circuit backplanes used in high-speed data links for parameters of attenuation, isolation and BER.

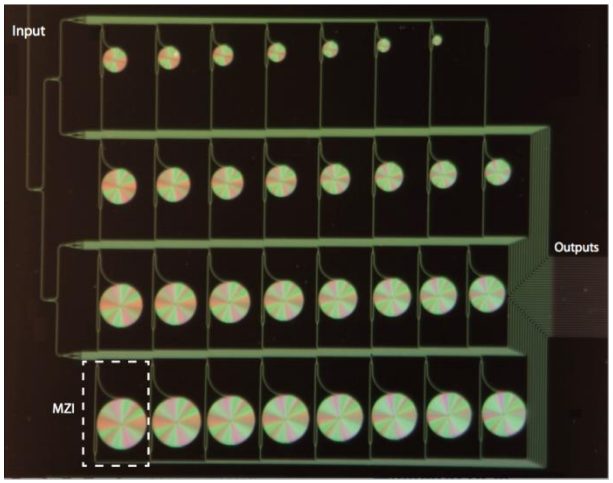


- Determine industry needs regarding functional specification and key parameters of interconnect boards in line with current standards development (GEL\86\2,3 and IEC/TC86\WG9).
- Design and build thermal control system capable of testing interconnect board incorporating suitable launch/detection optics.
- Evaluate commercial PCB test boards.

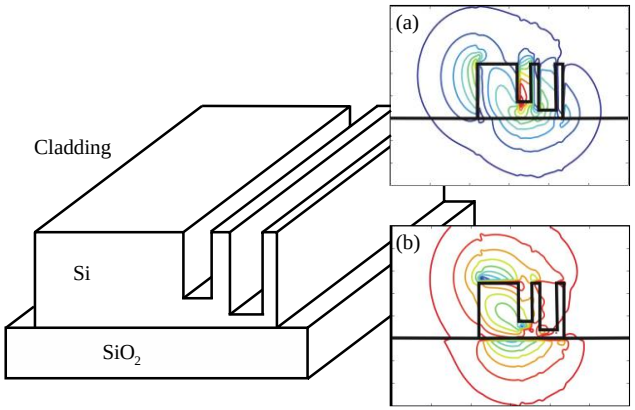
Metrology in waveguide-based photonic devices

- Development of metrology tools for the characterization of waveguide-based photonic devices
  Case study: development of an integrated high-resolution spectrometers with enhanced robustness against environmental variations.

  - Based on Mach Zehnder interferometer arrays
  - Dual approach: hardware (athermal waveguides) + software (retrieval algorithms)
  - Birrefringence mitigation through ultracompact polarization converters
  - Numerical analysis of dimensional deviations and temperature effects.



Fourier Transform Microspectrometer

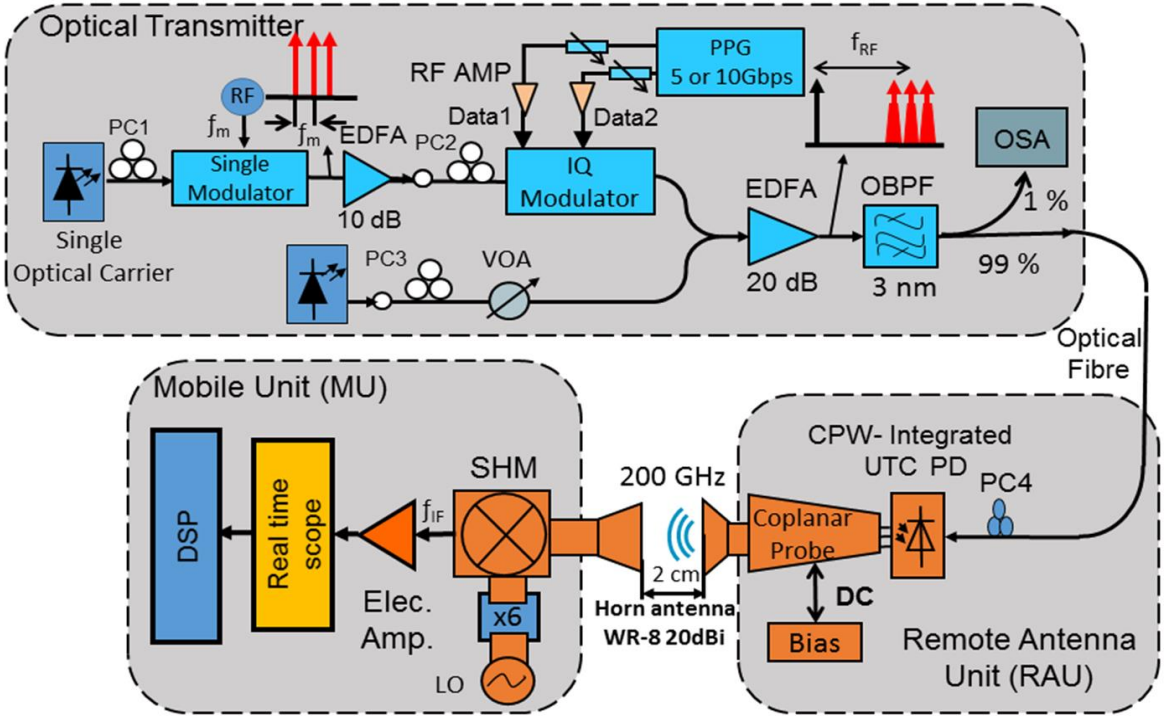


Polarization rotator

THz interconnects

Develop measurement procedures and standards for THz communication links.

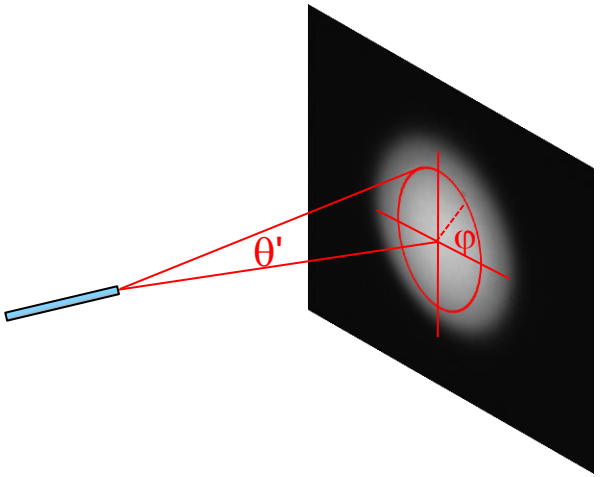
- Liaise with industrial partners to identify the crucial performance parameters and required specifications for THz links.
- Develop metrological tools to underpin standardisation.
- In particular, to establish techniques for the measurement of bit error ratio (BER), bandwidth, and Q-factor; and to investigate suitability and performance of different modulation techniques.



AJ Seeds et al., J Lightwave Tech **33** (2015) 579-587

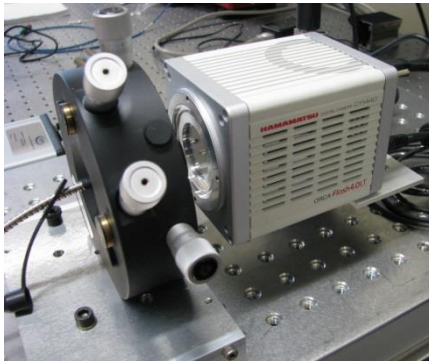
Angular Encircled Flux (EAF) measurements

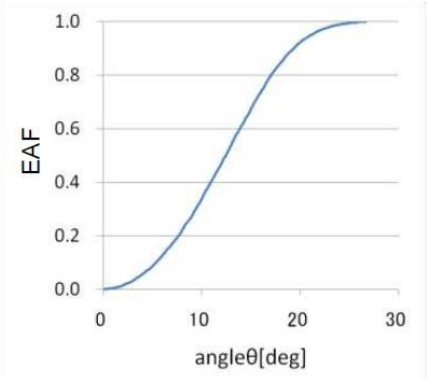
Development of traceable methods for the determination of the modal distribution at the output of multimode Step Index and Plastic Optical Fibres by measuring the far field EAF



- Design and construction of a fully traceable EAF measurement system
- Analysis of the performances and validation by inter-comparison
- Modelling of the modal distribution in multimode fibres by finite elements methods
- Contribution to the development of improved calibration standards (normalization).

$$EAF(\theta') = \frac{\int_0^{2\pi}\int_0^{\theta'} I(\theta,\varphi)\cdot\frac{\sin(\theta)}{\cos^3(\theta)}\cdot d\theta\cdot d\varphi}{\int_0^{2\pi}\int_0^{\theta_{max}} I(\theta,\varphi)\cdot\frac{\sin(\theta)}{\cos^3(\theta)}\cdot d\theta\cdot d\varphi}$$



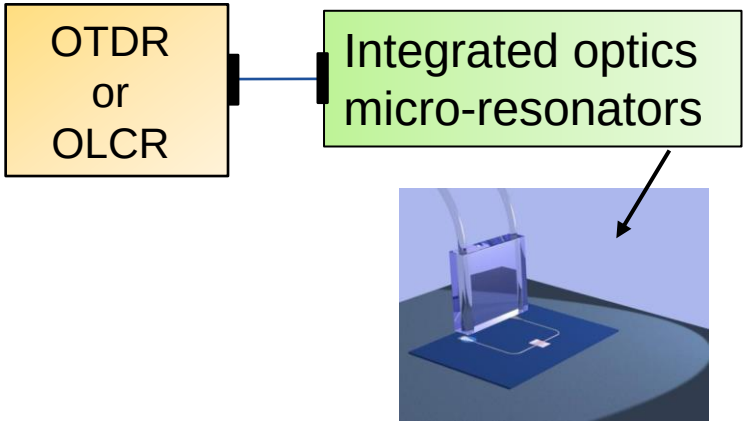


M. Kagami, A, Kawasaski, M. Yonemura, et al. , Encircled Angular Flux representation of the modal power distribution and its behavior in a step index multimode fiber, J. of Lighwwave Technol., **34**, 943-951, February 2016.

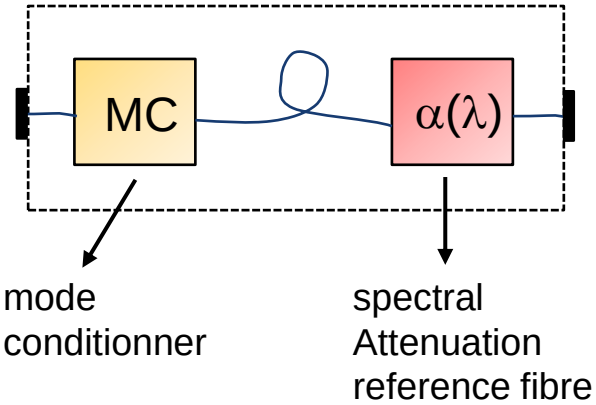
Optical (time-domain) reflectometers

Develop traceability for distance and attenuation scales of single and multimode fibre reflectometers

- To fabricate artefacts for distance scale calibration of reflectometers at the cm level and below
  - Fibre-coupled waveguide micro-resonator (100 μm accuracy)
  - Fibre based mini-resonaors (1 mm accuracy)



- To develop a fully traceable artefact for the calibration of the attenuation scale of multimode OTDRs

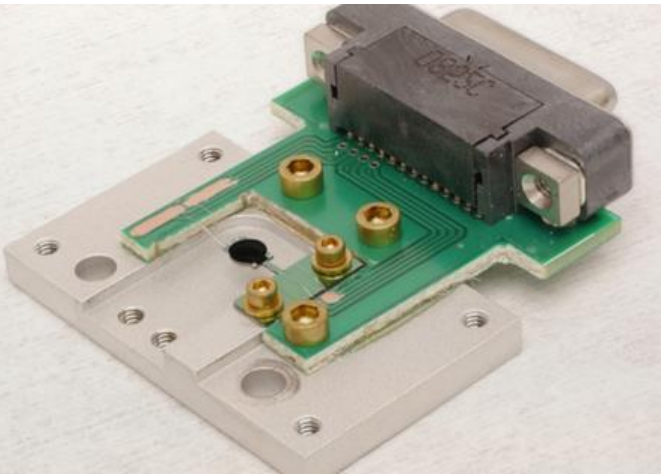


- To develop calibration techniques for optical fibre-based temperature and vibration sensors
  - OTDR or Bragg-grating-based quasi-distributed optical-fibre sensors

Fibre coupled power detector

Develop a new portable carbon nanotube based absolute primary standard detector suitable for in-field measurements in industry.

- Design and implement complete portable fibre coupled absolute cryogenic detector based on carbon nanotube absorbers
- Target accuracy better than 0.5 %
- For optical power @ λ ~1550 nm with uncertainty < 0.25 % (k=2).
- Provides significant shortening of traceability chain

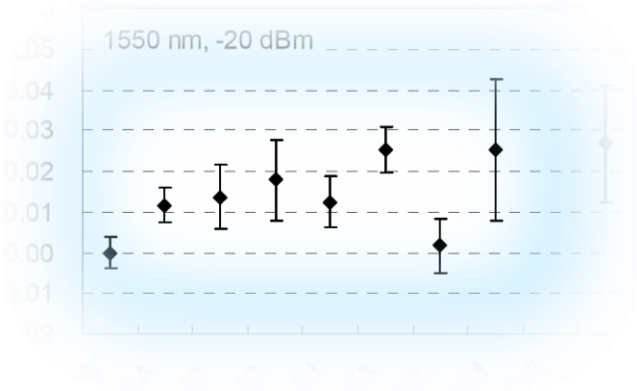


N A Tomlin, M White, I Vayshenker, S I Woods and J H Lehman,
Planar electrical-substitution carbon nanotubes cryogenic radiometer,
Metrologia **52** (2015) 376–383

Comparisons of the methods

Comparison of methods developed in technical work packages WP1-WP3

- with each other and to existing methods.



Comparisons for

- dimensional characterization of fibres
- optical fibre dispersion measurements
- fibre-to-chip coupling methods
- comparison of OTDR calibrations,
  - interested parties from (for example) the European Photonics Industry Consortium (EPIC) members will be invited to attend

Impact

- Stakeholder committee
  - To exchange information and gather guidance from industry and academia
  - If interested: email: Šmíd Marek msmid@cmi.cz or Antti Lassila antti.lassila@vtt.fi
- Webpages: http://www.photind.eu/
- Articles in peer reviewed journals
- International and national conferences
- Standardization IEC TC86 / TC91
- Workshop for industrial and academic parties
- E-learning courses

Conclusion

- 7 NMIs, 7 companies and 4 universities/institutes are working for improved photonics measurements
- Project started 8/2015
- Plenty of interesting topics for photonics industry

⇒ Improved traceable metrology for photonics manufacture and characterisations

PhotInd

Thank you for your attention

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John Molloy	NPL	Kimmo Saastamoinen	UEF		

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union’s Horizon 2020 research and innovation programme