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Federal Institute of Metrology METAS

14IND13 Photind

Metrology for the photonics industry optical fibres, waveguides and applications

WP3: Development of fibre optic measuring instruments and artefacts

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EURAMET

List of participants :

Arden PHOTONICS

ČESKÝ METROLOGICKÝ INSTITUT

CSIC

JCMwave

METAS

NPL National Physical Laboratory

Westfälische Wilhelms-Universität Münster

EURAMET

Motivation and Targets

The increasing needs of the optical fibre industry for traceable measuring instruments with improved performances require new measurement and calibration techniques.

The aim of WP3 is to develop:

1. A fully traceable instrument for the measurement of the angular resolved modal distribution in multimode fibres, *i.e.* encircled angular flux (EAF).

2. New artefacts and calibration techniques for the calibration of high resolution optical time-domain reflectometers (OTDR) and of optical fibre sensors.

3. A novel portable absolute standard fibre detector based on nanotubes at cryogenic temperature.

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Encircled Angular Flux

Guided modes in a multimode fibre experience different path lengths and losses. Correct measurements of quantities like insertion losses or bandwidth strongly depend on how different modes are populated.

Modal distribution metrics like Encircled Flux (EF) are already fully traceable but give no information about the angular distribution of the transmitted light.

The Encircled Angular Flux overcomes this lack of information. Instruments already exist, as well as normative documents, but :

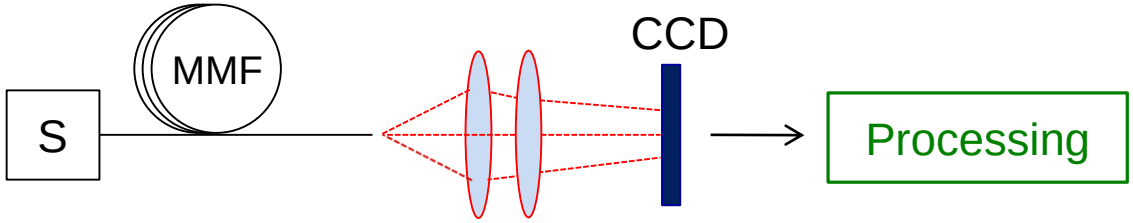
- They are not traceable
- There are no artefacts

→ Need of a fully traceable measuring instrument

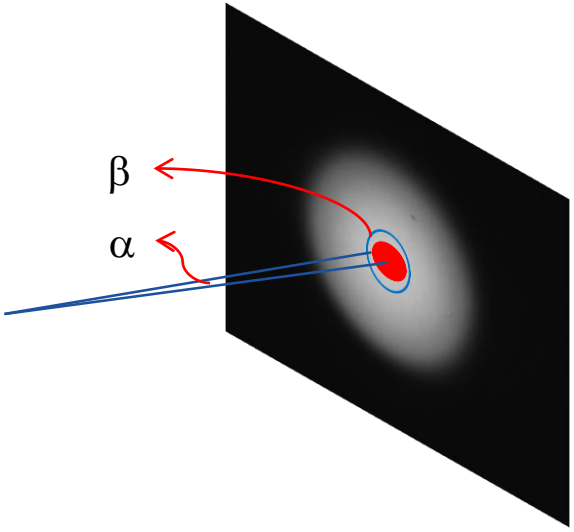
Encircled angular flux

Far field measurement :

Determination of the normalised angular distribution of the light at the output of the fibre.



$$EAF(\theta) = \frac{\int_0^{\theta} \int_0^{2\pi} I(\alpha,\beta) \cdot d\alpha \cdot d\beta}{\int_0^{\alpha\max} \int_0^{2\pi} I(\alpha,\beta) \cdot d\alpha \cdot d\beta}$$



Encircled angular flux: activities and challenges

- Design and construction of a traceable EAF measurement system (**Arden**, METAS)
  - Find the best possible structure regarding traceability and measurement uncertainties
- In depth analysis of the performance of the system (**METAS**, Arden)
  - Identify key parameters and develop suitable measurement systems
- Modeling of the modal distribution in multimode fibres as a function of the light source parameters and coupling geometry (**JCM**, Arden, METAS)
  - Identify suitable models for the determination of limit EAF values (templates)

Outcomes :

- Traceable instrument for EAF measurements
- Impact on relevant normalisation documents
- Report on the uncertainty budget

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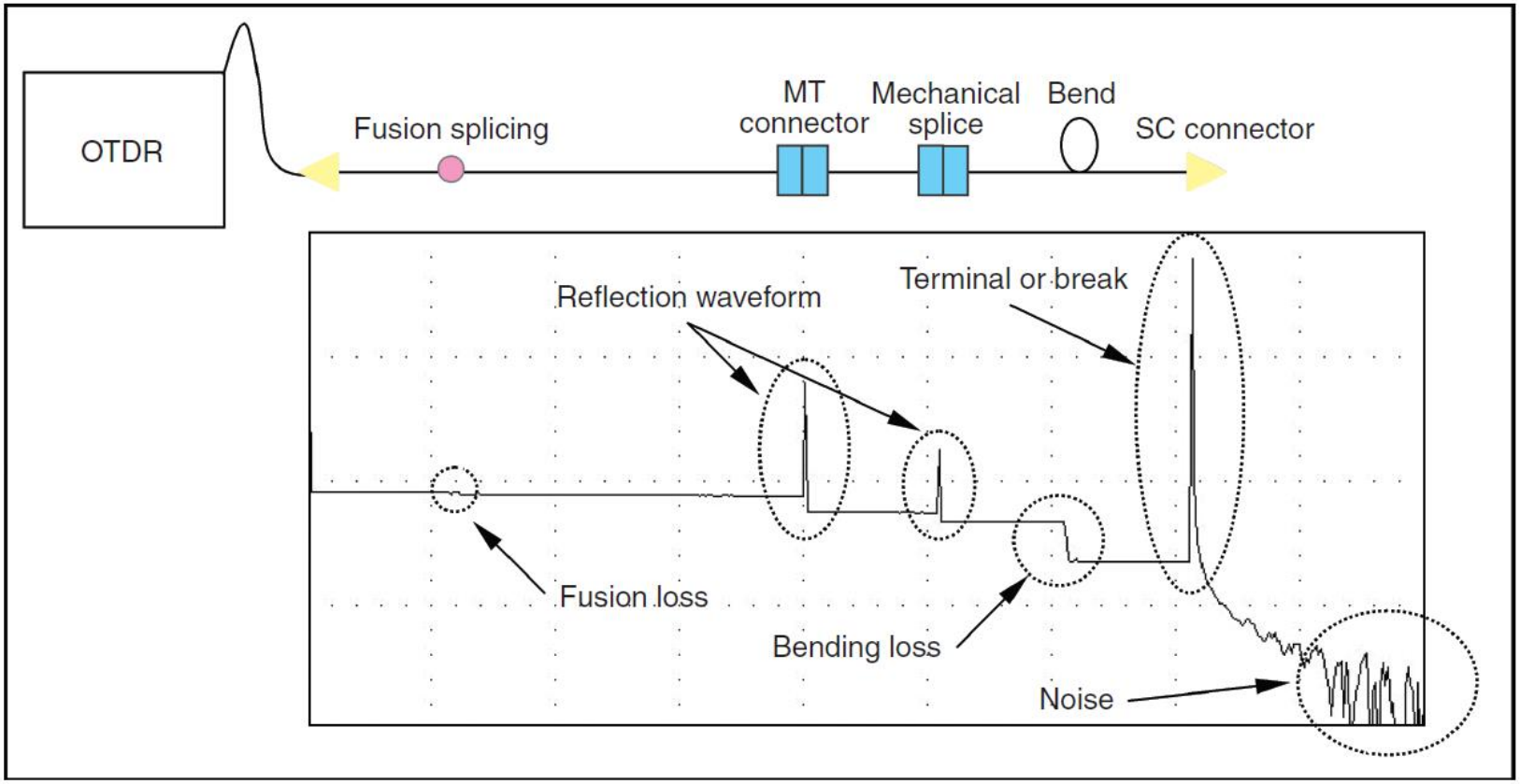
OTDR

OTDRs measure the length and the attenuation of optical fibres.



@NTT Technical Review

OTDR

OTDRs perform distance resolved measurements of the back-coupled light using time of flight techniques

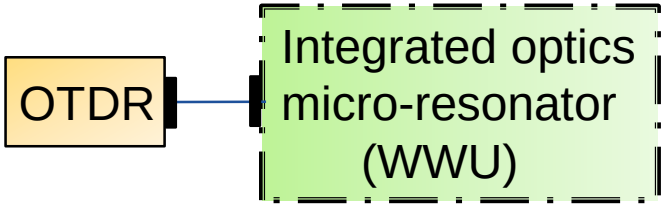
- Both attenuation and distance measurements need to be traceable
- Calibration is achieved by comparison with length and attenuation references (artefacts)

→ New generations of instruments like high spatial resolution OTDR, low coherence reflectometers (OLCR) or multimode OTDR need new and/or improved calibration techniques and artefacts

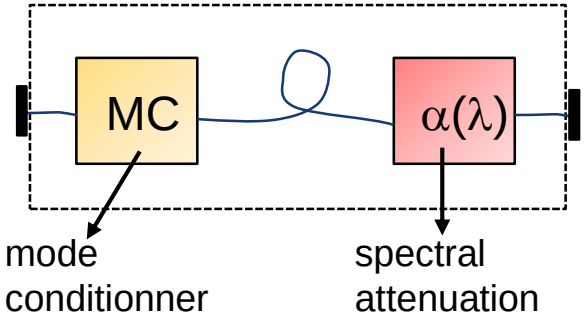
OTDR

The aim of this WP is:

- To fabricate artefacts for distance scale calibration of reflectometers at the cm level and below



- To develop an artefact for the calibration of the attenuation scale of multimode OTDRs

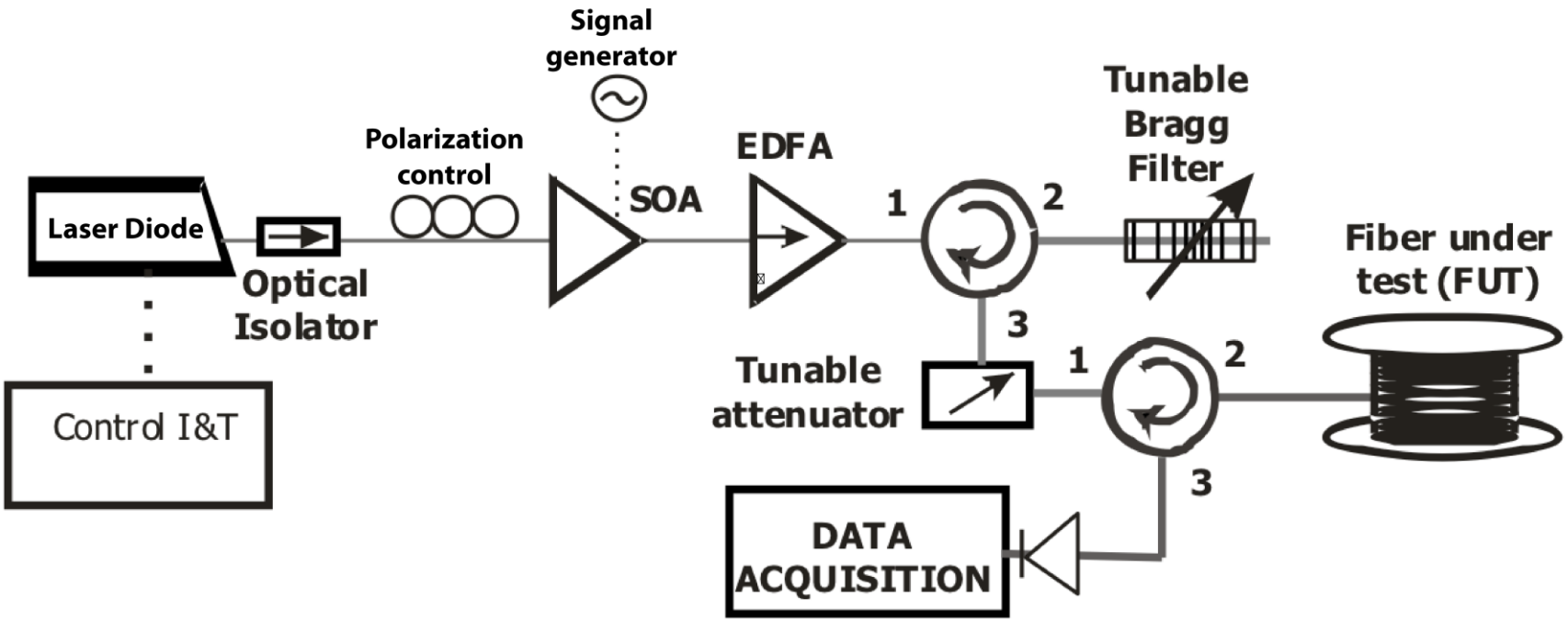


- To develop calibration techniques for optical fibre-based temperature and vibration sensors

Distributed opt-fibre sensors (CSIC)

OTDR

Phase-sensitive OTDR for vibration detection:



OTDR:
activities and challenges

- Design of a fibre-coupled waveguide micro-resonator for the calibration of the distance scale of high resolution OTDR with cm and/or mm resolution (**WWU**, METAS).
- Fabrication of a distance scale calibration artefact and evaluation of its performance (**METAS**,WWU).
  - Identify the structure of suitable resonators
- Design and fabrication of a traceable artefact for the calibration of the attenuation scale of multimode OTDR and evaluation of its performance through comparison measurements (**METAS**, NPL and CSIC).
  - Full understanding of modal behaviour in OTDR and of its effect on attenuation measurements

OTDR:
activities and challenges

- Development of reference systems and calibration techniques for temperature measurement in OTDR distributed optical-fibre sensors and in Bragg-grating-based quasi-distributed optical-fibre sensors (**CSIC**, NPL).
  - Identify key parameters and develop suitable measurement systems
- Development of reference systems and calibration techniques for vibration measurements in distributed OTDR optical-fibre sensors (**CSIC**).
  - Identify key parameters and develop suitable measurement systems

Outcomes :

- Improved calibration artefacts for new instruments
- Impact on relevant normalisation documents
- Report on the uncertainty budget

Motivation and Targets

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Fibre cryogenic radiometer

Classical cryogenic radiometer allow achieving absolute power calibrations at the 10^{-4} level of uncertainty or even better, but:

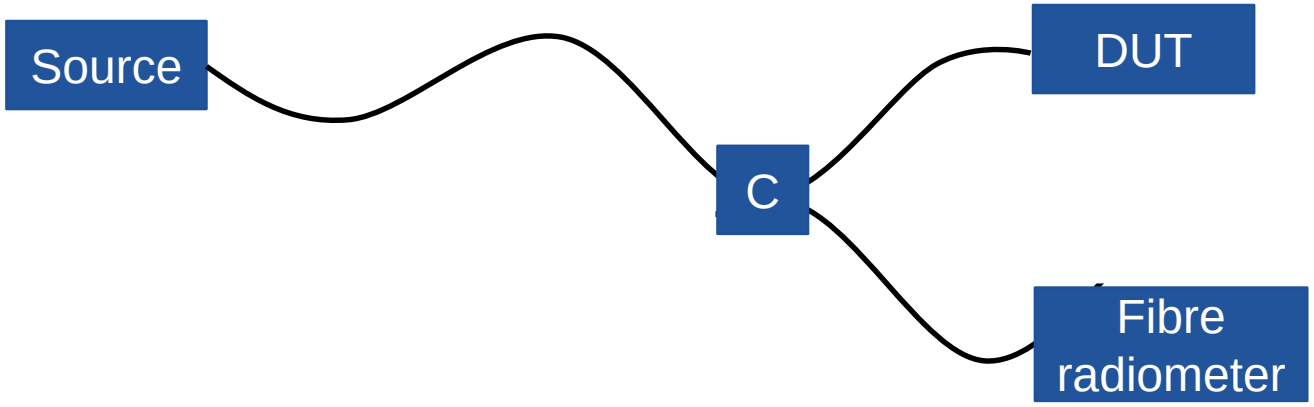
- They are not transportable
- They are extremely sensitive to stray light, coupling geometry and polarisation
- They are consequently not applicable for industrial calibration purposes

CMI, in collaboration with METAS, will develop a standalone portable fibre coupled absolute cryogenic radiometer based on carbon nanotube absorbers

Target :

- Accuracy better than 0.5%
- Relative uncertainty better than 0.25% (k=2)

Fibre cryogenic radiometer



Requirements :

- Polarisation independent fibre coupling
- Dual ports for simultaneous measurements with the fibre-based cryogenic radiometer and with the device under test (DUT)

Validation :

- By simultaneous comparison with classical cryo-radiometer standards

Fibre cryogenic radiometer: activities and challenges

METAS

- *Integration of a carbon* nanotube based chip into a suitable cryostat and electronic readout instrumentation (**CMI**, METAS)
  - Identify a suitable detector
- Design, manufacture and characterisation of an optical fibre coupling unit (**METAS**, CMI)
  - Polarisation independent coupling
- Prototype assembling (**CMI**)
  - Thermal conductivity control
- Comparison of the assembled prototype with the highest standard radiometer (**CMI**, METAS)

Outcomes :

- New portable instrument
- Report on the uncertainty budget

Deliverables

The activities carried out in WP3 lead to following deliverables:

- **D6**: Report on the demonstration of a fully traceable system for EAF measurements. Delivery date : M34.

- **D7**: Report on the demonstration and validation, by intercomparison, of fully traceable artefacts for the calibration of the distance scale of high resolution OTDR and for the attenuation scale of multimode OTDR.
  Delivery date : M34.

- **D8**: Report on the development and performance evaluation of a prototype fibre coupled carbon nanotube based on cryogenic radiometer, with a target accuracy better than 0.5% and the capability to measure optical power at 1550nm with a relative uncertainty of less than 0.25%. Delivery date : M34.

Next steps

- **Arden** and **METAS** will define and design the optical setup for the measurement of the EAF.
- **WWU** and **METAS** will define the dimensions and design a fibre-coupled waveguide optical resonator for cm resolution distance scale OTDR.
- **JCM** will develop interfaces for computing mode profiles in multimode fibres and will transfer the interfaces.
- **CSIC** will start to develop reference systems and calibration technique for temperature measurements in OTDR. **NPL** will contribute with the characterisation of OTDR.
- **CMI and METAS** will define an optimum structure for the all-fibre radiometer.

Thank you very much for your attention

Fibre cryogenic radiometer

NIST Carbon nanotube technology:

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Carbon nanotube electrical-substitution cryogenic radiometer: initial results

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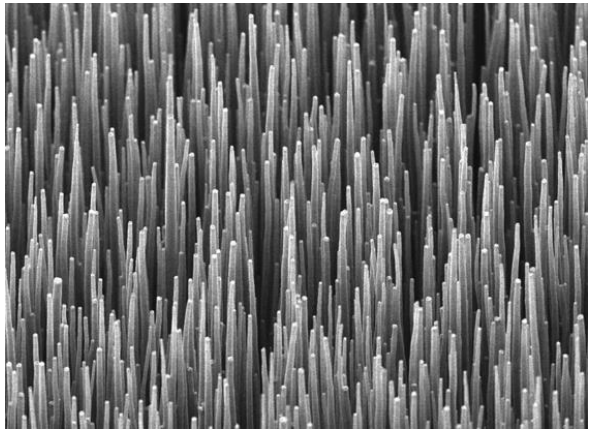

Standard deviation power fluctuations (k=2): 10μW, limited by temperature stabilisation. Measurement range from 50 μW to 1.5 mW.