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

Overview

Optical fibres and other photonic components are being increasingly implemented in many rapidly-growing and demanding areas, such as aviation electronics, telecommunications and the automotive industry. New reliable measurement techniques and improved metrology are needed to meet these demands. The project developed online and offline measurement techniques for dimensional and optical characterisation of advanced photonic components and devices as well as the necessary calibration techniques and artefacts to enable calibration of the newest generation of measuring instruments. The developed characterisation and calibration techniques will underpin the development and manufacture of novel photonics components thereby strengthening the competitiveness of the European photonics industry, enabling innovation and providing faster, cheaper data connection.

Need

The huge potential of photonics and fibre optics is evident from the Photonics21 Strategic Roadmap which lists the major photonic research and innovation challenges. One challenge has been that modern photonic systems utilise novel components, whose dimensional and optical properties cannot be reliably measured using current techniques: commercial instruments are often uncalibrated, provide insufficient accuracy and are available only for some of the required characteristics. Thus, new traceable and improved measurements and calibration methods were needed to make photonic measurement technology an enabling technology that will allow technological breakthroughs as well as commercialisation of sophisticated fibre optic components.

- Improving online measurements of dimensional parameters (diameters and concentricity) during fabrication will benefit manufacturing of special fibres and capillaries.
- Evaluation of the performance of photonic components in optical interconnects and the next-generation of microwave or THz transmission links, traceable measurements of key parameters (dynamic range, insertion loss, bandwidth, etc.) as well as industry standards is necessary.
- Development of traceable measurement techniques to study environmental effects on optical printed circuit boards the boards such as temperature cycling, ageing, humidity variation, etc. will help the data communications industry to understand the performance of optical printed circuit boards within their working environments.
- Coupling light without losses from fibres into optical circuits presents a challenge due to the large mode mismatch. Efficient solutions for matching conventional fibre-coupled systems to waveguides and nanophotonic devices are needed.
- Metrology for measuring modal distribution in multimode step-index optical fibres, as used in automotive systems, in industrial sensors and in medical applications is still not sufficient, leading to inconsistent measurement results that have a negative impact on the deployment of these systems.
- Novel optical fibre measuring instruments, like the high-resolution optical time-domain reflectometers, offer performances which cannot be adequately evaluated because of the lack of suitable calibration artefacts and procedures.

Optical communications, biophotonics, avionics, and automotive industries are examples of fields that will benefit from the improved measuring capabilities.

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

Objectives

The objectives of the project were:

- To develop traceable online and offline metrology techniques for characterisation of advanced optical fibres and photonic components – by developing measurement setups, procedures and numerical tools. Especially, the project will develop methods for thickness and concentricity measurements of different fibre layers with target accuracies of 0.5 µm and 1 µm, respectively, and for dispersion and optical parameter measurements in high power applications. The goal is to measure the relative content of light in the core with an accuracy of ±5 % for double clad fibres.
- To develop metrology for improved traceability of fibre optic measuring instruments – by developing calibration techniques and artefacts. The main goal is to develop a traceable measuring system for encircled angular flux, which is a key parameter allowing characterisation of modal distribution in step-index multimode fibres and components. Artefacts will be developed for the calibration of the attenuation scale of multimode optical time domain reflectometers (OTDR) and for the calibration of the distance scale of high-resolution optical reflectometers. Additionally, a novel portable primary standard radiometer based on carbon nanotubes at cryogenic temperatures will be developed to solve the issues inherent to existing transfer standard detectors, like spectral dependence and temporal drift, and shorten the traceability chain of optical power measurements. This will result in a lower measurement uncertainty (target accuracy better than 0.5 %).
- To develop metrology for terahertz transmission links – by developing traceable measurement standards and measurement procedures for key parameters (dynamic range, insertion loss, SNR, bit error ratio (BER) for various modulation formats, free spectral range and bandwidth) of THz transmission links. The target accuracy for dynamic range and insertion loss measurements is 5 %.
- To establish the metrology tools for performance characterisation of polymer waveguides mounted on electronic circuit backplanes used in high-speed data links – by developing measurement systems that can characterise the functional performance of waveguides incorporated onto short range interconnect boards. The systems will assess the key parameters of attenuation, isolation and BER. The usability of typical fibre-to-fibre connectors at high average powers will be investigated by monitoring transmission as well as the heating of the components (target accuracy: ±5 %). Measurement strategies to characterise evaluation boards will be developed with accuracy levels within ~ 1 dB for attenuation.
- To engage with the European photonics industry and photonics equipment manufacturers – to facilitate the take up of the technology and measurement techniques developed by the project, and to recommend what further actions are required to ensure uptake.

Progress beyond the state of the art

A method for real-time characterisation of geometrical properties of optical fibres during manufacturing was developed as instruments available at the start of the project could only be used for offline characterisation.

Traceable measurements of modal distribution in multimode fibres have become important, since correct measurements of many quantities strongly depend on how different guided modes are populated in the fibre. However, current methods are not applicable to many type of fibres. The Enhanced Angular Flux (EAF) was proposed to overcome this issue. Commercially systems for EAF measurements exist but are not traceable. The project developed a fully traceable EAF measuring system for the calibration of the angular resolved modal properties of multimode systems.

The project developed a novel absolute primary standard radiometer for absolute optical radiation power based on carbon nanotubes at cryogenic temperatures with improved uncertainty and one-step traceability to the SI.

Probably the most thorough characterization to-date of THz emitters including measurements of spatial and spectral beam profiles was performed.

Innovative devices were developed for silicon photonics, with compact footprint and enhanced performance through the use of dispersion and anisotropy engineered subwavelength metamaterials. The devices developed in this project present either a higher resolution or a broader bandwidth than their counterparts known in the state of the art, while preserving a reduced footprint and circumventing minimum feature size reductions.

New calibration techniques and performance enhancement strategies for distributed and quasi-distributed fibre sensors were developed, providing improved uncertainty, simultaneous resolution and temperature calibration, and enhanced resolution and sensitivity, respectively.

Metrology that was not available at the start of the project was developed for optical printed circuit boards (OPCB) by implementing a characterised measurement system incorporating a variable launch condition to monitor board performance under a range of controlled environmental condition.

Results

Develop traceable online and offline metrology techniques for dimensional and optical characterisation of advanced optical fibres and photonic components

The project provided non-destructive and novel methods (offline) to measure dispersion and group velocities in optical fibres, measurement procedures for high power fibre optics, and online techniques for dimensional measurement of optical fibres.

Two novel set-ups for dispersion measurement of optical fibres were built. One utilises a supercontinuum laser, a MEMS based electrically tuneable Fabry-Perot interferometer for wavelength selection and White Rabbit technique for time synchronisation. This setup allows measurements of fibres of arbitrary length, including very short ones. The other is based on a SEA TADPOLE type white light spatial-spectral interferometer. The reached estimated uncertainty was 1.5×10^{-3}.

A setup for the evaluation of cladding light content at up to 400 W was successfully implemented and tested, reaching the target accuracy of ±5 % and allowing for the cladding light measurement in multi-clad fibre geometries.

A method based on the analysis of a laser scattering pattern, as the fibre is illuminated transversely during the drawing process was developed for real-time dimensional characterization of coating layers of an optical fibre. The method was implemented and tested in a prototype instrument in a production environment. The uncertainty for the coating diameter measurement of the tested fibre was 1.8 µm and the uncertainty for the coating eccentricity was 0.1 µm.

Develop metrology for improved traceability of fibre-optic measuring instruments

Several calibration techniques and artefacts were developed, characterised and successfully validated to improve traceability of fibre-optic measurements.

Artefacts for the calibration of the distance scale of very high resolution Optical Low Coherence Reflectometers (OLCR) and of high-resolution photon counting Optical Time Domain Reflectometers (OTDR) were developed. These artefacts allow calibrating in a simple and accurate way, which was until now not available.

New artefacts for the calibration of the attenuation scale of multimode OTDR in an absolute way were developed, validated by comparisons and tested by interested industry partners. These artefacts offer a very simple method for accurate calibration of the absolute attenuation scale of multimode OTDRs. Promising discussions were started with the working group active in this field within the IEC, with the aim to evaluate the future improvement of existing calibration standards using these new calibration artefacts and techniques.

Two fully traceable instruments for the measurement of the Encircled Angular Flux (EAF) were developed and validated by inter-comparisons. The EAF allows quantifying the modal distribution in large core multimode step-index and in plastic optical fibres by evaluating the far-field intensity pattern. A careful control of the modal distribution is fundamental in order to ensure comparable and repeatable measurement of quantities like bandwidth and losses in multimode systems.

Different models were developed to calculate the modal distribution in multimode fibres and to simulate excitation of these modes by a focused beam, using finite-element methods (FEM). Software were successfully tested for the estimation of the coupling efficiency between two fibres. These results pave the way to the determination of Encircled Angular Flux templates using FEM simulations and thus to contribute to the development of the IEC normative documents in that field.

A novel absolute primary standard radiometer for optical fibre power measurement based on carbon nanotubes at cryogenic temperatures was developed. It acts now as a new primary standard detector providing in one-step direct traceability of optical radiation power measurements in optical fibres to the SI. The system solved the issues of current transfer standard detectors, i.e. spectral dependence and temporal drift and decreased the measurement uncertainty by more than 30 % and the achieved relative uncertainty was 0.3 %.

New calibration techniques and performance enhancement strategies for distributed and quasi-distributed fibre sensors were developed. A reference artefact for simultaneous resolution and temperature calibration of distributed fibre sensors was developed as well as two calibration methods for fibre Bragg grating interrogators, providing uncertainties down to ±0.65 pm. All these methods have been incorporated to calibration capabilities already. Regarding sensor enhancement an OTDR with a photonic differentiation detector providing high resolution and sensitivity temperature measurements and a coherent-OTDR for distributed vibration measurement providing single pulse characterization with high resolution and sensitivity were developed.

Develop metrology of terahertz transmission links

The project developed measurement standards and standard measurement procedures for THz transmission systems by investigating the operation, functionality and characterisation of devices used in THz links.

Characterisation of THZ emitters and detectors require measurement of a number of different parameters but at present only the power and frequency of emitters can be measured to adequate metrological standards. The project developed methods for reliable determination of spectral performance and emitter beam profiles, as these were identified by industry partners to be the most important parameters that could not be measured.

A lamellar interferometer suitable for broadband spectroscopy at THz frequencies was designed and built. It was used for emitter spectral profile measurements of devices from industrial partners. The uncertainty for dynamic range in these measurements was found to be better than 5 %. A spatial beam profiler was implemented and configured to characterise emitter beam profiles and detector acceptance cones. Beam profiles of emitters provided by project industrial partners were measured successfully. Moreover, a THz transmission link was set up and used for characterisation of passive components, e.g. insertion loss of filters, beam-splitters and windows, and beam-forming properties of lenses. The mean uncertainty in the loss measurement was 3 %.

Establish metrology tools for performance characterisation of polymer waveguides mounted on electronic circuit backplanes used in high-speed data links

The project established metrology for optical printed circuit boards and contributed towards standardisation of key parameters, such as coupling loss, attenuation, crosstalk and BER, of short range interconnects. Novel fibre-to-chip couplers were developed to overcome existing barriers in conventional technologies. Moreover, the project studied a high-resolution Spatial-heterodyne Fourier Transform (SHFT) spectrometer, which most benefits from enhanced multi-fibre light coupling and metrology in integrated photonics.

A temperature chamber was set up to characterise the performance of the boards under different environmental conditions and BER measurements with accuracy levels of 0.001 were performed to investigate the thermal impact on data transmission. Observable changes were measured that correlated with the applied thermal load: increased thermal load to a section of waveguides showed a decrease in total attenuation and associated drop in the BER. The Encircled Flux measurements reveal a corresponding shift in the power distribution across the waveguides resulting in a compromising of the prescribed standardised EF limits. The research will have far reaching consequences for board designers, manufacturers and standardisation bodies.

For the high power characterisation at Watt level a set-up for the measurement of fibre connector transmission was built, and dependency of the connector performance on optical power investigated. It was observed that high quality connectors (AVIM, Mini-AVIM) kept their performance as specified at lower power when used at Watt-level average power, but standard connectors (FC/APC) exhibited increased loss at powers over 300 mW. The target accuracy (± 5 %) was achieved for power levels exceeding 500 mW. A method for online core temperature measurement was successfully adapted for large mode area fibres and tested at over a hundred Watts in a thulium amplifier. A Good Practice Guide titled "Guidelines on measurement procedures for high power fibre optics" combines the results from all high power experiments.

Three different coupling architectures for injecting and extracting light from planar photonic chips were investigated: grating coupling structures for achieving high coupling efficiency with moderate coupling bandwidth, broadband coupling devices using adiabatic tapering for wide optical mode matching, as well as a combination of 3D architectures combining grating structures with 3D components. Simulations were performed to optimise the couplers. Coupling efficiency of up to 70 % with optical bandwidth of 30 nm was obtained for grating coupling devices and broadband transmission from visible to telecommunication wavelengths with minimum coupling loss of –1.4 dB was achieved for 3D adiabatic couplers.

For silicon photonics, several innovative devices with compact footprint and enhanced performance were developed using subwavelength metamaterials. The dispersion and anisotropy engineering provided by these structures enable to mitigate traditional drawbacks of this platform, such as high birefringence, thermal dependence and sensitivity to fabrication errors. In particular, an integrated Spatial-heterodyne Fourier Transform microspectrometer with a resolution down to 17 pm in a device of only 20 mm^2 was experimentally demonstrated, with a remarkable potential for microsatellites, biological sensing or handheld spectroscopy. New temperature-sensitive calibration and spectral retrieval methods were demonstrated for integrated Fourier transform microspectrometers, hence mitigating the stabilization requirements otherwise associated to resolution enhancements in this kind of devices. Other developed waveguide-based photonic devices include broadband mode multiplexers, power splitters and polarization splitters. Key technical insight into the anisotropic properties of sub-wavelength grating (SWG) structures was gained, enabling to engineer the polarization-dependent properties of the SWG metamaterial by rotating the facets of its composing elements. This principle was successfully applied to the polarization splitter based on multimode interference couplers, as well as to a directional coupler polarization splitter and a polarization independent monomode waveguide.

Impact

The project addressed the urgent metrology needs of photonics industry manufacturing and innovation. The European photonics industry will significantly benefit from the online and offline characterisation techniques for advanced optical fibres and photonic components as well as from the calibration techniques and artefacts developed in the project. The new metrological tools will support development and manufacturing of completely new products, which will be a competitive factor. The co-operation with European Photonics Industry Consortium, EOSAM and national photonics organisations guarantees effective dissemination.

Dissemination

The project results were disseminated widely to the stakeholder community via 11 open-access peer-reviewed papers, 4 published peer-reviewed proceedings and more than 50 conference presentation and posters, numerous different training events both for project partners and wider audience and the project website at http://www.photind.eu/.

In spring 2018, a two-day workshop was held to disseminate the project's results to all the interested industrial and academic parties) as a special session at SPIE Photonics West Conference: The PhotIND topics were divided under two sessions: Session 6: Applications and Metrology and Session 8: Special Session: PHOTIND EMPIR European Project. The number of attendees was 50–60.

A Good Practice Guide "Guidelines on measurement procedures for high power fibre optics application and calibration of non-conventional sensors" was developed and is available for download on the project website.

Impact on relevant standards

This project has had an impact on the work of IEC standardisation groups together with metrology committees of CCPR and EURAMET TC-PR. Project partners have taken part in at least 16 different technical committee meetings. Project partners have provided advice for the updating of existing national (AENOR) and international standards (IEC TC76) and contributed to new standards related to the calibration of fibre optics measuring instruments (IEC TC86/WG4), to the characterization of fibre optic interconnecting devices (IEC TC86/SC86A/SC86B/WG4) and to the functional performance of short range interconnects (IEC TC86/TC91, JWG9).

The project partners have also provided advice on the improvement of calibration techniques to CCPR task groups on fibre optics (TG6) and on OTDR length calibration (TG9).

The performance of EAF measurements were validated by an inter-comparison, which showed excellent results. Arden and METAS wrote a report including an uncertainty estimation on the system for traceable EAF measurement. Discussions have been carried out with the technical committee IEC/TC86/SC86B/WG4, which is in charge of developing the relevant standards for EAF measurements and need to be further pursued. Jointly with the Swiss IEC TC86 committee (TK86) METAS will disseminate the results of our activities on EAF measurements within the IEC TC86/SC86B/WG4 in the form of a short report or of a presentation, after the end of the project.

This work informs the standards development within the International Electrotechnical Commission (IEC), principally through the work of the IEC technical committee 86, improving the standardisation of key measurements as well as making use of recently the proposed adoption of a reliable measurement definition system for optical interconnect (62496-2:2017 (E) - Optical circuit boards - Basic test and measurement procedures - Part 2: General guidance for definition of measurement conditions for optical characteristics of optical circuit boards. The work will be presented to the relevant national committees GEL/86/2 and 3, that feed into the international IEC JWG9 Optical functionality for electronic assemblies) under TC86. This research has far reaching consequences for electro-optical printed circuit board designers, manufacturers and standards bodies. The unavoidable increase in board complexity and hybridization, in the drive to accommodate higher and higher data rates, will need to take into account these performance and functional limitations imposed by the application of thermal loading.

Impact on industrial and other user communities

The manufacturers of advanced optical fibres will benefit from the project through the availability of novel tools for high-level characterisation of dimensional and optical properties. The development of techniques for online monitoring and control of the fabrication process will have a significant impact on the fibre industry, which would improve the quality of the production, increase the yield of the processes and reduce costs. The online fibre characterisation device development within the project is an interesting tool for the fibre drawing quality control. A fibre manufacturing producer has presented interest on the method.

Characterizing the wavelength-dependent phase delay induced by optical fibre (both single or multimode) in broad spectral range using SEA TADPOLE interferometer allows to measure dispersion and spatial distribution of different modes of ca 1 m long fibres. In case the implementation is successful, the technique is of great scientific and practical interest for speciality fibre characterization.

The development of new calibration techniques for the latest generation fibre optics will benefit industrial applications in the field of sensors. High-resolution spatial measurements of distance and attenuation scale calibrations would improve the accuracy of sensors.

The developed EAF measuring instrument is planned to be for sale by one of the project partners. This will allow industry to better characterise output properties of different fibres.

New measurement method for cladding light content has already been implemented, allowing identification of pedestal light content in more complex fibres. Test are being made to use the method for industrial product characterization.

Numerical methods for simulating measurement setups for dimensional characterisation of optical fibres have proven high efficiency and accuracy in the project. Interfaces to these methods will be implemented in the commercial software package JCMsuite.

Finite-element based numerical methods for simulating fibre chip coupling are found to perform very well for problems with large computational domains. The problem to optimize the device is a high-dimensional optimization problem. Methods to solve the optimization problem efficiently have been tested. These will be part of the commercial software package JCMsuite.

Numerical methods for accurately computing overlap integrals of diverse finite-element simulation results representing optical modes in optical fibers have shown high efficiency. An interface to compute the integrals directly from the FEM solution without prior export to a regular mesh is to be implemented in the commercial solver JCMsuite and to be transferred to the user community of this tool.

Developments in optical fibres and fibre connections, polymer waveguides, and THz interconnects enable more economic and faster data connections with optical Fibre-To-The-Home. Manufacturers of microwave photonics components including THz communications equipment would benefit from the project by having the means and procedures for characterising their equipment performance.

The coupling components developed in this project will provide a flexible architecture for multi-port access to integrated optical devices. This is of relevance for manufacturers of integrated optical circuits, as well as for the production of nanoscale photonic systems with macroscopic fibre connectors. The establishment of hybrid planar-3D photonic systems will satisfy the need to move beyond traditional optical designs and provide possibilities to transfer knowledge from free-space optics to on-chip circuits. This will be important for the manufacturers of 3D lithography equipment.

More reliable characterisation methods for high-power fibre lasers and components will reduce the effort required for the developers of these devices. By having reliably characterised high-power fibre connectors readily available, the spread of modular systems could also be increased, leading to more flexibility for companies using lasers.

The innovative silicon photonic devices developed within the project (namely the SHFT microspectrometer and the auxiliary devices as polarization controllers and mode multiplexers) offer a remarkable opportunity for technological transfer. This is showcased by the recent creation of the spin-off company Alcyon Photonics, which is already licensing two of the national patent applications ("Integrated mode converter and multiplexer" and "Integrated polarization beam splitter") created within this project, and is in the process of licensing the third one ("Waveguide, fabrication method thereof and polarization beamsplitter using said waveguide"). All patents will be extended to international PCT applications within 12 months of their submission dates.

CSIC submitted two national patent applications regarding distributed fibre sensing: "System and method of distributed scattering profile characterisation of an optical fibre" and "System and method of distributed characterisation of refractive index variations of an optical fibre". Both patents submission are under examination and have been extended internationally through PCT applications. Both patents will be licensed to co-applicant FOCUS (Fiber Optics Consulting Services and Technologies S.L.) a spin-off company, which incorporates in their products our earlier OTDR developments and has already declared their interest on both patented technologies to enhance the performance of their optical reflectometry equipment. FOCUS will exploit the results by integrating the technologies proposed in the patents into their two commercial products, hence improving their sensitivity and resolution: FINDAS (distributed acoustic sensor) and FINEST (distributed temperature and strain sensor.

The consortium collaborated closely with companies interested in the results of the project. Several companies were in the project stakeholder committee and ten participated in the stakeholders meetings. Also, the co-operation with the European Photonics Industry Consortium (EPIC) and European Optical Society Biennial Meeting (EOSAM) guarantees effective dissemination.

At the end of the project, a formal questionnaire was distributed to the industrial partners and the collaborators to determine the uptake of the project outcomes by the photonic industry. The most useful project outcomes for the stakeholders were: "Measurement techniques for characterisation of advanced optical fibres and photonic components", also "Artefacts for the calibration of high resolution optical reflectometers (OTDR and OLCR)" were rated positive. A report on the uptake of project outcomes by the photonics industry, along with recommendations on how to increase the uptake was written containing results from the questionnaire and an exploitation plan for the key outputs.

Impact on the metrological and scientific communities

A better understanding of the optical properties of advanced optical fibres will benefit the fibre optic community. Especially, new techniques for EAF and OTDR high resolution measurements requires a deep analysis of optics, optical detection and image processing; the outcomes of which will be beneficial for the scientific communities. Results from intercomparisons of OTDR measurements and comparisons between modal distribution simulations and measurements will be shared with the metrological community.

In particular, the advances in fibre-to-chip light coupling and photonic metrology provided by this project will be used in many areas of integrated photonic circuits. By simplifying light coupling and providing a better waveguide characterisation, scientific communities will be able to focus their effort on the actual chip functionalities, increasing research efficiency and impact.

Terahertz communications is now at the research stage, focusing significant attention from the scientific community. Given its novelty, metrological communities still need to develop appropriate characterisation systems and standards. The results of the project will therefore greatly benefit all the aforementioned parties.

The developed methods to establish traceability will be a key part in the development of new photonics measurement techniques.

The following new calibration services, available at project partners, were established as a result of the project:

- Simultaneous resolution and temperature calibration of distributed fibre sensors.
- Fibre Bragg grating interrogator calibration based on a tuneable simulated Bragg grating.
- Fibre Bragg grating interrogator calibration based on calibrated absorption gas cells
  Traceable Encircled Angular Flux calibrations in multimode optical fibre systems
- Artefact for the calibration of the distance scale of OLCR.

- Artefact for the calibration of the distance scale of high-resolution OTDR.
- Artefact for the calibration of the attenuation scale of multimode OTDR.
- Low uncertainty calibration of fibre optics power meters on absolute cryogenic standard radiometer.

Longer-term economic, social and environmental impacts

The worldwide photonics market was 447 billion Euro in 2015 and it is expected to grow to 615 billion Euro in 2020. A global market share of 15.5 % makes Europe the world's second-biggest supplier of photonics, after China. European Photonics Production has increased by over 62 % over the last 10 years, which is much stronger growth than industrial production in Europe in general. Similar to electronics, photonics products are used products in a wide range of sectors of which production technology, optical measurements & image processing and optical communication & information technology are the most important ones.

The development of the optical fibre characterisation techniques, efficient photonic interconnects and metrology instruments in this project will undoubtedly benefit this ever-growing industry, strengthening European competitiveness and increasing its total turnover.

Reliable high power characterisation of fibre components will enable more reliable laser-based production methods. This will lead to reduced costs and thus make precision-engineered items available to a wider audience. Examples include miniaturised medical devices, components in automobile construction and functionalisation of surfaces.

The advances in optical fibres and their manufacture as well as better characterisation of transmission links will improve the whole communication infrastructure, which will have a positive effect on the economy and European citizens, for example via Fibre-To-The-Home.

Optical communication infrastructure is the most environmentally friendly method for data transfer. Replacing metal wire based local connections with optical connections (Fibre-To-The-Home) will reduce energy consumption while increasing bandwidths. Furthermore, data interconnects in super-computers require colossal amounts of energy that limit their operation and significantly impact the environment. By providing efficient and low-power all-optical interconnects, this hazard would be greatly reduced.

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<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 August 2015, 36 months</td></tr>
<tr><td colspan="3">Coordinator: Antti Lassila, VTT, Tel: +358 40 767 8584 E-mail: antti.lassila@vtt.fi
Project website address: http://www.photind.eu/</td></tr>
<tr><td>Internal Funded Partners:
Partner 1 VTT, Finland
Partner 2 Aalto, Finland
Partner 3 CMI, Czech Republic
Partner 4 CSIC, Spain
Partner 5 Metrosert, Estonia
Partner 6 NPL, United Kingdom</td><td>External Funded Partners:
Partner 7 Arden, United Kingdom
Partner 8 FhG, Germany
Partner 9 JCM, Germany
Partner 10 Oplatek, Finland
Partner 11 UEF, Finland
Partner 12 UT, Estonia
Partner 13 WWU, Germany</td><td>Unfunded Partners:
Partner 14 Menlo, Germany
Partner 15 METAS, Switzerland
Partner 16 nLight, Finland
Partner 17 Seagate, United Kingdom
Partner 18 Toptica, Germany</td></tr>
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