Publishable Summary for 20SIP05 KTOC
Knowledge Transfer for Optical Communications

Overview

This project has successfully delivered methods for the characterisation of high-density optical connector functional performance developed in EMRP project IND51 MORSE to component manufacturers, network engineers, and fibre installers within the expanding data centre industry. Interactions with the IEC TC86, have created impact through the development and contributions to standards that provide confidence in the uptake of high-density optical interconnects in the communications sector. In addition, the use of Error Vector Magnitude measurements as an efficient measurement tool for monitoring high-speed optical network performance employing multilevel modulation schemes such as QPSK and 64-QAM have been promoted to a wide stakeholder audience via large international conferences, publications and an exhibition.

Need

The IND51 MORSE results were extremely relevant for the wider high-speed data comms community and to the IEC standards committee as the global telecom infrastructure equipment market was expected to grow at 7 % annually and reach $504.56 billion by 2023. Serving the expanding needs of 5G fibre-optic connectivity required the development of next generation optical equipment for deployment in data centres, banking, and the semiconductor industry. Therefore, transceiver vendors, such as the Primary Supporter, SENKO Advanced Components Euro Ltd, needed to expand their manufacturing capacity to keep pace with increasing demands for 200 Gbit/s modules and faster, but a requirement for traceable high-speed measurements was hampering the progress.

The key output of EMRP project IND51 was the establishment of NMI-level traceability for measurements of high-speed optical communication systems. Extensive research was undertaken into measurements at 200 Gbit/s, and knowledge about precise connectivity calibration was obtained. Recent standard developments (IEC 62496-4-3/Ed1: Optical circuit boards - Part 4-3: Interface standards - Terminated waveguide OCB assembly using a single-row thirty-two-channel PMT connector intermateable with 250 µm pitch MPO 16), have worked towards terminated waveguide assembly using single-row 32-channel connectors with the aim of harmonising measurements. Modification of this standard was important for the provision of up-to-date information on connectivity as technology evolves. This was a requirement for enabling positional repeatability of +/- 1 µm and insertion losses of 2 dB complementing the standard IEC 61300-3-34: *Fibre optic interconnecting devices and passive components – Basic test and measurement procedures – Attenuation of random mated connectors*. The KTOC project contributed to the refinement and wider adoption of international standards for the measurements of advanced coupling interfaces for photonic integrated circuits and expanded fibre arrays, which addressed the emerging needs from the hyperscale industry for system embedded optics including co-packaged optical assembly. The project 20SIP05 KTOC helped to strengthen European competitiveness which will increase its total turnover through the development of state-of-the-art connectivity with inexpensive pluggable transceivers and integrated photonics.

For the research findings in EMRP project IND51 to be more widely adopted and to accelerate industrial uptake, more communication was required through conference engagement, standards contribution, publications and exhibition events. By presenting the research outputs from EMRP project IND51 MORSE through transferring the relevant knowledge of high-speed optical interconnect measurements and characterisation to normative standardisation committees IEC TC86, this project has enabled the committee members of GEL86/2 to exploit the fact that polymer waveguide cores share a common cladding and can be arranged far closer together than glass fibre cores. This enabled MT connectors with far smaller inter-channel pitches. In the proposed standard from this project a single row of 32 waveguides can be arranged over the same length as a single row of 16 glass fibre channels for high-density connectivity.

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There was also a need for manufacturers of advanced optical components, represented in this project by Resolute Photonics UK LTD and SENKO Advanced Components Euro Limited, as the Primary Supporter, to develop metrology techniques to evaluate the performance of optical communication systems. The requirements for EVM measurements have been demonstrated as a promising figure-of-merit to quantify the impact of performance degradation in high-seed optical networks employing multilevel modulation schemes such as 64-QAM. This will enable greater uptake of EVM measurements by suppliers to have greater confidence in optical performance monitoring.

Objectives

The overall goal of this project is to disseminate the results of EMRP project IND51 MORSE to photonic component manufacturers and standards bodies, in order to harmonise metrological best practice, maximise efficiency and provide knowledge transfer. The specific objectives of this project are:

1. To disseminate the research outputs from EMRP project IND51 MORSE by transferring the relevant knowledge of high-speed optical interconnect measurements/characterisation to normative standardisation committees such as IEC TC86 for potential inclusion into a revision of IEC 62496-4-1:2019.
2. To promote and improve adoption of a traceable Error Vector Magnitude metrological tool developed in EMRP project IND51 MORSE by writing and presenting papers and/or posters at events such as the IEEE British and Irish Conference on Optics and Photonics (BICOP) and exhibition through the European Conference on Optical Communications (ECOC) conference.

Results

To disseminate the research outputs from EMRP project IND51 MORSE by transferring the relevant knowledge of high-speed optical interconnect measurements/characterisation to normative standardisation committees such as IEC TC86 for potential inclusion into a revision of IEC 62496-4-1:2019.(Objective 1)

The consortium had close interactions with the BSI and IEC TC86 Standards committees including 5 working groups: SC86C/WG4, JWG9, SC86B/WG6, GEL86/2, SC86B/WG6. This includes presentation of consortium activities and general participation in committees' meetings. Higher interface densities are possible with polymer waveguides to enable smaller centre-to-centre pitches than would be possible with glass fibres. New standards were therefore required for PMTs with higher channel densities. To this end, the consortium fully supported and contributed to a new standard: IEC 62496-4-3/Ed1: (Optical circuit boards - Part 4-3: Interface standards - Terminated waveguide OCB assembly using a single-row thirty-two-channel PMT connector intermateable with 250 µm pitch MPO 16), which allowed a single row of 32 waveguides thereby increasing the data capacity by a factor > 2 compared to 12 channels.

The original standard IEC 62496-4-1:2019 - Optical circuit boards - Part 4-1: Interface standards - Terminated waveguide OCB assembly using single-row twelve-channel PMT connectors) was published in 2019. The acronym PMT stands for "Planar MT", where "MT" itself is the leading type of multi-fibre ferrule in the optical communications industry. The acronym "MT" historically stands for "Multi-Terminal". Although the original standard IEC 62496-4-1 was published before this project began, it led to the development of a more advanced standard: IEC 62496-4-3/Ed1: (Optical circuit boards - Part 4-3: Interface standards - Terminated waveguide OCB assembly using a single-row thirty-two-channel PMT connector intermateable with 250 µm pitch MPO 16), which allowed a single row of 32 waveguides. The new standard IEC 62496-4-3 Ed 1 was assessed, and comments compiled by NPL as part of this project. These comments were submitted in accordance with the BSI (British Standards Institute) mechanism for submitting comments to IEC standards in progress. The intermediary standard draft, to which comments were submitted had the IEC designation "86/584 CDV", where CDV stands for "Committee Draft for Vote". In accordance with IEC procedure the comments were circulated to the IEC TC86 – Fibre Optics (the IEC technical committee, in which Joint Working Group 9 resides) via its BSI mirror committee "GEL/86". The BSI document with the submitted comments has the BSI designation "GEL/86_21_0014". Confirmation that the comments were received were provided by the BSI Committee Service Centre.

As part of this objective, the project consortium also initiated discussions on a new standard, which further doubled the channel density IEC 62496-4-3 to a single row 64 channel PMT, which cannot be matched by optical fibres and truly showcased the fundamental benefit of polymer waveguides over multi-fibre ferrules. This proposal will be developed over the coming years to build on the results disseminated in this project for the single row of 32 waveguides.

This objective was achieved successfully.

To promote and improve adoption of a traceable Error Vector Magnitude metrological tool developed in EMRP project IND51 MORSE by writing and presenting papers and/or posters at events such as the IEEE British and Irish Conference on Optics and Photonics (BICOP) and exhibition through the European Conference on Optical Communications (ECOC) conference.(Objective 2)

Preparation and delivery of conference paper on the technology transfer from IND51 MORSE presented at the 7th Laser and Optoelectronics Conference (LOC 2021). The paper entitled 'Metrology of Optical Communication Systems Using Error Vector Magnitude' has been published as an Open Access peer-reviewed paper in Journal of Applied Mathematics and Physics. The consortium has further disseminated the results at the International European Conference on Optical Communications (ECOC) conference in September 2022. An exhibition was attended at ECOC conference (September 2022) in collaboration with the project partners, Senko Advanced components and Resolute Photonics, to disseminate IND51 MORSE results through 3 posters presentation on (i) Optical performance monitoring using error vector magnitude, (ii) Knowledge transfer for optical communications – metrology for high-speed data interconnects, and (iii) Knowledge transfer for optical communications – metrology and standardization high density pluggable optical interconnects. EVM was demonstrated as an efficient metrological tool for characterising the performance of high-speed connectivity in optical communications as developed in the EMRP project IND51 MORSE.

A paper on 'Characterization of Quantum Grade Interconnects' was also presented by the project partners to disseminate the metrology results from IND51. It was demonstrated that high end classical systems such as those at National Measurement Institutes (NMI), can also be used to more fully characterise commercial quantum grade fibre as well as innovative hollow core fibre (HCF) which have up till now, been measured at much lower uncertainties or lack traceability altogether. The results showed that active involvement is needed in National and International standards bodies to harmonise the global approach towards standards thereby supporting industry and future research and development of emerging technologies. This showed that the established expertise developed in IND51 for optical communication technologies can be used as a basis to extend existing or develop new traceable systems.

This objective was achieved successfully.

Impact

The overall aim of 20SPI05 KTOC was to create additional impact from the work carried out in the EMRP project IND51 MORSE. The KTOC consortium participated actively with the BSI and IEC TC86 Standards committees including 5 working groups: SC86C/WG4, JWG9, SC86B/WG6, GEL86/2, SC86B/WG6. This included presentation of consortium activities and general participation in committees' meetings. In addition, the paper entitled 'Metrology of Optical Communication Systems Using Error Vector Magnitude' has been presented at the 7th Laser and Optoelectronics Conference (LOC 2021). A total of 4 open access journal papers have been generated in this project (see list below). Furthermore, 10 presentations were made at national and international conferences creating additional impact from the work carried out in EMRP project IND51 MORSE. This had relevance to optical networks directly, and also to wider general use of photonic components in other industries such as connectivity in data centres. Error Vector Magnitude (EVM) measurement results were published demonstrating that EVM is a promising figure-of-merit to quantify the impact of performance degradation in high-seed optical networks employing higher-order modulation formats such as QPSK, 16-QAM and 64-QAM. Greater uptake of EVM measurements by the user community enabled both users and suppliers to have greater confidence in optical performance monitoring.

With continuous pressure to be faster and more cost effective, the focus on optics was to overcome the limitation of copper in every aspect including speed and power dissipation. This encouraged the development of optical interconnects for different applications with the potential to replace certain functionality of electronics such as optical switching, optical storage, and also optical signal processing to address future challenges. The research results related to photonic interconnects were disseminated to transfer this knowledge to industry and academia and therefore gave potential for new improved products and innovations across Europe. The project also promoted new methodologies for more accurate measurements of optical communication systems such as error vector magnitude and bit error ratio measurements. Dissemination of the EMRP project IND51 project results has enhanced understanding for the photonic industry and the researchers regarding the significance of traceability and uncertainty in monitoring optical networks through our interactions at conferences (e.g. at ECOC conference and the joint symposium on quantum technologies), exhibition, posters and publications. This project had demonstrable impact in providing improved and new calibration services for customers throughout the photonic communication industry in Europe and internationally through standardisation engagements. By promoting the findings of EMRP project IND51 to the IEC International committee, the IEC 62496-4-1 standards were able to evolve in harmony with the technological advances of the photonic industry. New proposals for high-speed connectors enabled vertical density reduction from photonic components manufacturers compared to traditional connectors. This allowed connectivity for quantum computing, optical switching, and optical storage to name a few applications. The results dissemination in this project facilitated wider continuous innovation in optical connectivity which will continue to impact future data centre networks and machine-to-machine communications for Industry 4.0.

The project's Primary Supporter, Senko Advanced Components, recognised the necessity for the refinement and wider adoption of international standards regarding metrology techniques to evaluate the performance of optical communication systems. Accurate determinations of optical performance were needed to maintain compatibility of coupling interfaces with the rest of the installed fibre and network switch infrastructure. The results obtained in the EMRP project IND51, with the support of partners in this project has facilititated the transfer of this measurement approach and technology into industrial use via their membership and interactions with IEC TC86 SC86B. Therefore, Resolute Photonics, together with the project team, contributed towards future standards developed by standardisation bodies such as the Internal Electrotechnical Commission (IEC). This boosted confidence in the usage of interface standards (terminated waveguide OCB assembly using a single-row thirty-two-channel PMT connector intermateable with 250 µm pitch MPO 16) which allowed a single row of 32 waveguides to enable high-speed connectivity.

Direct impact has been achieved by working with the Primary Supporter, SENKO, who manufacture advanced optical connectors for data centre interconnects. This project also had demonstrable impact across Europe and internationally through contributions to Standards documents with the support of Resolute Photonics, as an external partner in this project and chair of IEC subcommittee SC86B – *Fibre optic interconnecting devices and passive components*, to facilitate early adoption of advanced components from manufacturers such as SENKO and the stakeholder, Arden Photonics Ltd. The project partner, Dr Richard Pitwon from Resolute Photonics, has also been appointed as the new chair of GEL86/2 and ran the first meeting disseminating the results from 19SIP05 KTOC. The Primary Supporter, SENKO, has gained knowledge transfer in optical connectivity beyond that available in published papers. SENKO has manufactured the CS^{TM} and the SN^{TM} connectors e.g. the duplex LCTM connector constructed with a zirconia ferrule that is spring loaded to ensure that an adequate mating force was applied to get a reliable fibre connection with a consistent low insertion loss. The dissemination activities within this project based on the results from EMRP project IND51 led to bandwidth optimisation within high-speed optical networks enabling the Primary Supporter to demonstrate the performance and significance of their photonic components to the wider photonic community as a global manufacturer developing advanced photonic components, therefore playing a major role in the relevant standards. The work within this project has led to bandwidth optimisation to meet the exponential growth in data rates for the next generation of optical networks important for high-speed communications. The contributions to IEC 62496-4-3/Ed1 to define the standard interface dimensions for a terminated waveguide optical circuit board assembly using single-row 32-channel waveguides that can be interconnected with a terminated MT ferrule for high-speed connectivity has, for example, enabled the Primary Supporter to demonstrate high-speed connectivity to the wider photonics community. Since, SENKO are one of only a few global manufacturers for photonic connectivity components, their involvement in this project facilitated the uptake and exploitation of traceable measurements by the photonic industry across Europe and internationally through active participation with world-leading standardisation bodies. This supported the "Europe's age of light! How photonics will power growth and innovation" Strategic Roadmap. Additionally, the project has facilitated the transfer of design specifications to the Primary Supporter's customer base including to the KTOC stakeholder, Arden Photonics Ltd, to enable improvements in data infrastructure and future growth. This has enhanced the Primary Supporter's and the stakeholder's position as an early adopter of the innovative technology demonstrated in IND51 MORSE. It also enabled them to become a lead advocate for good measurement practice, such as the use of Error Vector Magnitude as an efficient metrological tool, for optical performance monitoring in high-speed communication systems.

Dissemination of EMRP project IND51 outcomes and the Primary Supporter's involvement with the project, has through standardisation widened their customer base and raise their profile on an international level helping to promote and realise the methodologies associated with increasing the high-speed, high-bandwidth capabilities of optical networks across Europe. Knowledge obtained through the metrology of high-speed photonic components facilitated the development of next generation optical interconnects operating at higher transmission speeds than currently possible. The Primary Supporter directly benefitted from the development of the relevant standards for a terminated waveguide optical circuit board assembly for high-speed connectivity and from the detailed knowledge of the standards generated in this project, therefore ensuring the compliance of their commercial product line optimised for 400 Gbit/s new generation data centres and rack level optical interconnect migration. The knowledge transfer in this project also expedited replacement of existing optical splices thereby improving modularity in limited space applications through innovative interconnect technology with photonic components used throughout the data industry, serving as vital parts of modern communications. This project resulted in new products from the primary supporter SENKO, e.g. duplex LCTM connector constructed with a zirconia ferrule to support next generation of optical communications equipment, leading to potential financial savings and environmental benefits being realised by the communications industry. The developments undertaken in the project further enabled the deployment of novel fibre-optic infrastructures for intra-data centres and machine-to-machine communications. The work carried out has relevance not only to data centres directly, but also for wider general use of photonic components in other industries enabling them to expand their manufacturing capacity to keep pace with the demand for 200 Gbit/s modules and above.

Finally, the development of photonic interconnects and optical network performance monitoring in 20SIP05 KTOC directly benefitted the energy costs associated with data centres reducing energy consumption and carbon footprint through improved coupling efficiencies for high-speed communication links. The early establishment of relevant metrology services developed in EMRP project IND51 has supported this development e.g. the contributions to IEC standards and development of metrology tools such error vector magnitude for performance monitoring. Alongside this research into optical connectivity and performance monitoring, understanding and minimising coupling losses can lead to energy savings in excess of 30%, directly reducing the electricity consumption required for cooling through the development of a new generation of high-capacity energy-efficient optical connectivity to strengthen Europe's leading position in integrated photonics. In terms of social impact, the project has improved bandwidth efficiencies associated with optical networks to enable high-speed, high-definition mobile streaming to consumers helping to meet the significant data growth. The project demonstrated that reliable characterisation of optical interconnects enabled more efficient production methods thereby driving component costs down and thus making precision engineered items available to a wider audience increasing societal impact by meeting the demand for higher network bandwidth for applications such the social media platforms, 4K video streaming, increased number of smartphone users and the emergence of High-Performance Computing (HPC) in data centres and Internet of Things (IoT).

List of publications

Fatadin, I. (2021) 'Metrology of Optical Communication Systems Using Error Vector Magnitude', Journal of Applied Mathematics and Physics, 9, 2918-2926. https://doi.org/10.4236/jamp.2021.911185

R Ferguson et al (2022) 'Characterization of Quantum Grade Interconnects' J. Phys.: Conf. Ser. 2416 012003. https://iopscience.iop.org/article/10.1088/1742-6596/2416/1/012003/pdf

Y Gui et al (2022) 'Metrology Challenges in Quantum Key Distribution' J. Phys.: Conf. Ser. 2416 012005. https://iopscience.iop.org/article/10.1088/1742-6596/2416/1/012005/pdf

This list is also available here: https://www.euramet.org/repository/research-publications-repository-link/

Project start date and duration:		01 August 2021, 18 months
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Internal Funded Partners: 1. NPL, UK	External Funded Partners: 2. RP, UK	Unfunded Partners: 3. SAC, UK