

# Report on the International Symposium on Extremely Advanced Transmission Technologies (EXAT 2021)

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## 1. Introduction

The 6<sup>th</sup> international symposium on Extremely Advanced Transmission Technologies (EXAT 2021) was held from 3<sup>rd</sup> to 5<sup>th</sup> November 2021 [1]. It was organized by the IEICE Technical Committee on Extremely Advanced Transmission Technologies (EXAT) and the National Institute of Information and Communications Technology (NICT). Since its inauguration in 2008 the symposium's venue has traditionally been a town in Japan with a rich historical and cultural background. However, due to the special circumstances effectuated by the ongoing COVID-19 pandemic and the resultant travel restrictions for visitors from overseas, the organizing committee decided to present the symposium this time in an all-virtual format.

## 2. Background

The objective of the EXAT symposium is to discuss the status and future trends of optical fiber communication technologies with a focus on Space Division Multiplexing (SDM). SDM is seen as a promising solution to overcome the capacity limits of single-mode fiber and deal effectively with the exponential growth in data traffic experienced in optical networks over recent years. Research in this field aims at exploiting spatial diversity in network elements such as optical transceivers, fibers, and amplifiers and, over the past decade, has brought forth sophisticated multi-core and multi-mode fiber (MCF and MMF) components as well as transmission techniques that are capable of transporting beyond 100x more data than conventional technologies. Although the effectiveness of SDM so far has been demonstrated only in research laboratories, numerous efforts are also under way now to take SDM out of the laboratory and bring it closer to its adoption in commercial systems.

The EXAT community in Japan initiated the development of SDM technology in 2008 and since then has been playing a leading role in the investigations of the so-called 3M (multi-core, multi-mode, and multi-level modulation) technologies both in Japan and on the international stage. The symposium is held bi-yearly and forms one of the highlights in EXAT's activity to promote information exchange on SDM and optical communications technologies featuring presentations from world-renowned experts talking about the latest advancements in their respective field. This year's

symposium was very well attended with over 150 registrants from Japan and overseas and about 65 live participants per session on average. It featured 2 plenary and 19 invited talks, as well as an on-line poster session with 22 contributed posters where attendees could engage in in-depth discussions with the authors and thus gain an excellent overview of on-going SDM related research projects and some of the latest and hot research topics in this field.

## 3. Technical Sessions

On the first day, the symposium's morning session started with an opening remark by Dr. Itsuro Morita, the incumbent IEICE EXAT committee chair, presenting an overview of the symposium as shown in Fig. 1 on the left. After that, Prof. Joseph Kahn (Stanford University, USA), depicted in Fig. 1 on the right, gave a plenary talk about the progress on coherent detection for short-haul links such as data-center links and capacity optimization for ultra-long haul submarine transmission.

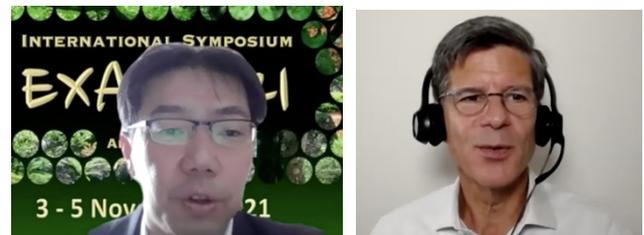


Fig. 1 Dr. Morita giving the opening remarks (left), and Prof. Kahn presenting the first plenary talk (right)

His talk was then followed by three invited talks. In the first one, Dr. Victor Kopp (Chiral Photonics, USA) reviewed the vanishing core technology that is used to fabricate efficient MCF fan-in/fan-out devices. Next, Dr. Yutaka Miyamoto (NTT, Japan) reviewed SDM photonic node technologies. In the third talk, Prof. Koji Igarashi (Osaka University, Japan) reported on the latest progress about real time digital signal processing techniques for mode-division multiplexed transmission systems. The afternoon session consisted of three invited and another plenary talk. First, Dr. Ricardo Veronese (Prysmian Group, Italy) presented his work on the characterization of few-mode fibers where he elaborated on a technique that he has been using to measure mode dispersion and modal birefringence between non-degenerate mode groups with high spatial resolution. In the second talk

Dr. Francesco Da Ros (Technical University of Denmark, Denmark) reviewed recent experimental work on all-optical nonlinearity compensation in few-mode fibers using optical phase conjunction. Next, Prof. Andrew Ellis (Aston University, UK), shown in Fig. 2 on the left, presented the second plenary talk where he first gave an overview of the evolution of optical communications and then shared some thoughts on challenges that need to be addressed in the future as well as the potential role of optical wireless communications in bringing high-speed Internet access to areas where deploying optical fiber may not be economically viable. Finally, in the last talk of the first day, Dr. Filipe Ferreira (University College London) discussed the modelling and simulation of SDM based lightwave systems to mitigate nonlinear effects.

The program of the second day consisted of five invited talks in the morning and a poster session in afternoon. In the first talk, Dr. Ming-Jun Li (Corning Incorporated, USA) reviewed his recent work on the design and experimental investigations with high core counts MCF for short-haul interconnects. In the second one, Dr. Haoshuo Chen (Nokia Bell Labs, USA) presented a mode-multiplexing transmission system consisting of a 2D VCSEL based transmitter and a MMF to transmit 200 Gb/s with direct detection and discussed its potential application toward co-packaged optics. Next, Dr. Shigehiro Takasaka (Furukawa Electric, Japan) reviewed his work on SDM optical amplifiers and optimization techniques to reduce the amplifier's power consumption. In the fourth talk, Prof. Ryo Nagase (Chiba Institute of Technology, Japan) reviewed the optical connector technology that will be required to build future optical networks based on SDM fibers. Finally, Dr. Yuta Wakayama (KDDI Research, Japan) discussed the capacity impact of SDM transmission and summarized recent record transmission demonstrations over transoceanic distances. The topics of the poster session ranged from SDM fiber design, fabrication and characterization methods to mode converters and wide-band transmission. After an introductory session where each poster author presented a 3-minute summary of his work, individual on-line breakout rooms were provided for each poster where the attendants could directly engage in free discussions with the poster authors.

The third day was divided again in a morning and afternoon session with four invited talks each. In the first talk of the morning session, Dr. David Neilson (Nokia Bell Labs, USA) reviewed the factors that contribute to exponential traffic growth in optical networks and shared his vision on the upcoming era of optical communications where massive and efficient parallel optical data transport will become critical to sustain the ongoing traffic growth. Next, Dr. Lara Garrett (SubCom, USA) reviewed trends in undersea system architecture and discussed the importance of flexible capacity routing to build future systems. In the third talk, Dr. Hirotaka Sakuma (Sumitomo Electric, Japan) presented the latest progress on fabrication techniques for low loss uncoupled and coupled MCFs to be used in long-haul

transmission systems. Finally, in the last talk of the morning session, Dr. Takashi Matsui (NTT, Japan) discussed the progress on the design of MCFs with a standard cladding diameter of 125  $\mu\text{m}$  and introduced the roadmap toward standardization of SDM fiber components. The afternoon session started with a talk by Prof. Christian Koos who summarized his group's impressive work on silicon photonics covering silicon-organic hybrid integration, silicon nanowire waveguides as well as multi-chip integration with application in high-speed optical communications as well as on-chip THz signal processing. Next, Prof. Hervé Rigneault discussed some interesting application of MCF to endoscopy for microscopic imaging of biological tissue in vivo. In the third talk, Prof. Robert Thomson (Heriot Watt University, UK) reviewed the field of spatial multiplexers with a focus on ultrafast laser inscribed 3D waveguides that have been used as fan-in/fan-out devices of SDM fibers. Finally, Dr. Tiago Alves (Institute of Telecommunications, Portugal) presented an overview of the impact of inter-core crosstalk in weakly-coupled MCFs on direct-detection systems.

In the closing session, Dr. Naoto Kadowaki, Vice President of NICT shown in Fig. 2, asserted the importance of international collaboration and information exchange through events such as the EXAT symposium after describing NICT's and the EXAT community's pivotal role in promoting the development and standardization of SDM technology.



Fig.2 Prof. Ellis presenting the second plenary talk (left), and Dr. Kadowaki giving the closing remarks (right)

#### 4. Conclusion

Owing to the effort of all speakers preparing presentations of outstanding quality despite the daily challenges everybody has been facing in this ongoing COVID-19 pandemic, and the possibility to attend the symposium from anywhere in the world, EXAT 2021 closed with great success offering ample opportunity for learning new aspects as well as exchanging ideas on cutting-edge SDM technologies and optical fiber communications. The symposium organizers would like to express their sincere thanks to all the invited speakers as well as poster presenters and participants for having made the symposium such a wonderful forum of information sharing information in this rapidly growing field of communications.

#### Reference

[1] <https://exat-sympo.org/2021>