Activities concerning the EXAT Roadmap and Trends in Standardization of SDM Optical Fiber

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1. Introduction

The Ad Hoc Technical Committee on Rapid Advancement of Optical Communication Infrastructure Extremely Advanced Transmission Technologies (EXAT) was the world's first body to advocate the importance of the "3M" technologies: multi-core, multi-mode, and multi-level modulation. As a guidepost for the future innovation of optical communication infrastructure using 3M technologies, the first and second editions of the (EXAT) Roadmap were respectively published in 2017 and 2020[1]. In this report, first, the relationship between the EXAT roadmap and current trends in space division multiplexing (SDM) technology is reviewed and, second, trends in international standardization of SDM optical fiber are outlined.

2. EXAT Roadmap

The objectives of the EXAT roadmap are twofold: (i) promote networking among researchers related to 3M technologies and (ii) share the technology roadmap and efficiently deploy EXAT. Since 2010, research on SDM technology, including 3M technology, has been active worldwide[2], and the first objective of the EXAT roadmap has been fully achieved. Hereafter, the relationship between the deployment scenarios of SDM technology envisioned by the EXAT roadmap for 2017 to 2020 and associated current trends are examined. The three deployment phases of SDM technology as envisioned in the EXAT roadmap are shown schematically in Figure 1. In the first phase, SDM technology will be applied for optical wiring between data centers and within telecommunication stations; in the second phase, it will be applied for submarine systems and terrestrial trunk networks; in the third phase, the transition to SDM optical fiber will proceed in a variety of areas. Scenarios for deployment of SDM optical fiber envisioned in the EXAT roadmap are depicted graphically in Figure 2. According to Figure 2, the expansion of spatial multiplexing is expected to continue in three phases: (A) maintaining the standard cladding diameter, (B) switching to increased cladding diameter, and (C) applying spatial modes. It is expected that SDM optical fiber with standard cladding diameter will be deployed in short-haul sections of terrestrial trunk networks from the late 2020s and in submarine systems from the early 2030s.

Although SDM optical fiber has not been commercially deployed as of April 2024, Google announced plans to apply multi-core fiber (MCF) in some new submarine systems[3] in September 2023. Moreover, also in 2023, Sumitomo Electric Industries, Ltd. announced the productization of 2-core structured MCF[4]. According to Google's plan, they will consider applying two-core MCF while keeping the standard cladding diameter in a manner that is consistent with the image of expanded spatial multiplexing shown in Figure 2. On the contrary, while it is assumed in Figures 1 and 2 that SDM technology will be deployed for short-haul sections of terrestrial trunk networks, currently, it is first being deployed in undersea systems, which were considered the second-phase deployment area. This situation is thought to be due to the fact that the space for accommodating optical fibers in currently used submarine optical cables only allows fibers with diameter of a few millimeters, and increasing capacity by increasing the number of accommodated cores is already reaching its limit. In other words, space constraints are becoming apparent in the case of submarine systems. An important related issue is what technologies will be required to expand the scope of application of SDM technology to terrestrial systems and further accelerate the introduction of undersea SDM systems. The EXAT roadmap also suggests a direction for answering the question of what technologies will be required to expand the application scope of SDM technology. As for the short-distance applications of SDM technology envisioned in the first phase, bulk connection of multi-core optical fibers will be essential to efficiently operate a huge number of cores or spatial channels. Moreover, the widespread use of undersea SDM systems requires the implementation of SDM optical amplifiers with higher efficiency than that of existing single-core optical amplifiers in parallel use. Therefore, we believe that by referring

Figure 1: Three anticipated phases of implementation of SDM technology[1]

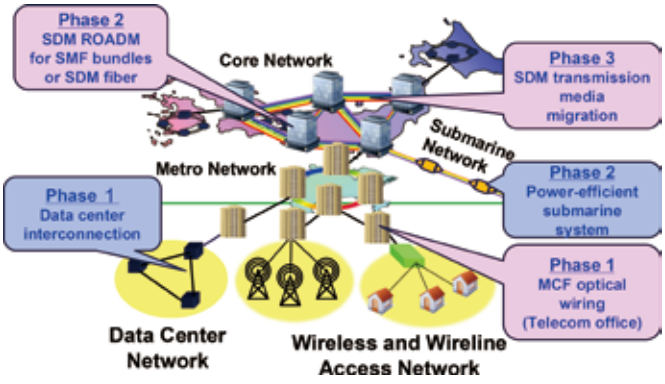
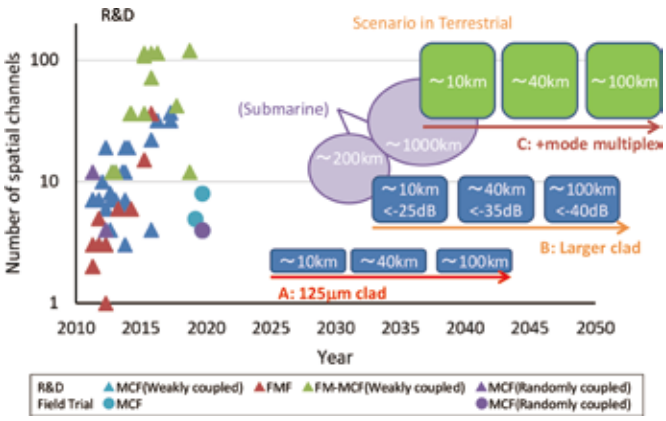


Figure 2: Roadmap for implementing SDM optical fiber[1]



to the existing EXAT roadmap and clarifying the technologies that will be implemented in the near future, it will be possible to accelerate the deployment of SDM technology.

3. Standardization activities concerning SDM optical fiber

Today's international standards for optical-fiber cables and optical-connection technologies are established and revised through the collaborative efforts of the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) and the International Electrotechnical Committee (IEC). Discussions regarding MCF optical connectors are already underway within the IEC, and standard documents for test methods and optical compatibility have been established[5, 6]. As for SDM optical fiber, on the contrary, in 2022, the ITU-T will issue a new technical report summarizing the technical trends concerning SDM optical-fiber cables and the issues toward their standardization[7], and it will define six types of optical fiber as candidates for SDM optical fiber, as shown in Figure 3. Meanwhile, in accordance with a proposal from Japan, at the meeting in November 2023, it was agreed to discuss establishing a new SDM-optical-fiber recommendation after clarifying the areas and timing of application of the various types of SDM optical fibers shown in Figure 3. For that reason, it is expected that discussions toward standardization of SDM optical fibers will progress in the future; however, it is important to note that it will be essential to establish an SDM ecosystem, including related technical standards, to create the conditions in which SDM transmission systems can be widely used.

An illustration of the roadmap for implementing the SDM ecosystem is shown in Figure 4. As shown in the figure, even if we limit ourselves to technical standards for the physical layer when building the SDM ecosystem, it will be necessary to define standards for not only optical fiber but also optical cables, test methods, connection technologies, subsystems and optical components, and system interfaces. Even under the assumption that each standard requires at least two years of discussion and that related technology fields are examined in parallel, it will still take approximately six years to establish all the standards. If the goal is to implement terrestrial SDM transmission systems widely in the early 2030s, it is thus necessary to begin formulating SDM-optical-fiber standards from around 2025 and to promote planned standardization through close cooperation between the ITU-T and IEC.

Figure 3: Six types of SDM optical fibers defined in the ITU-T technical report[7]

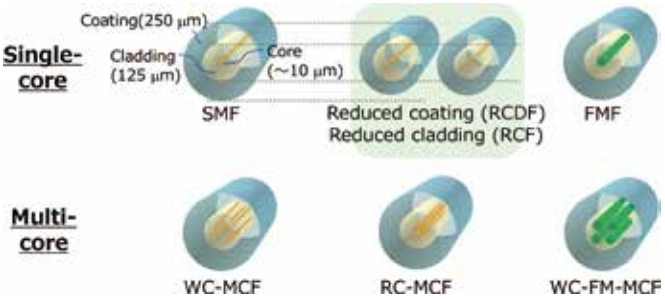
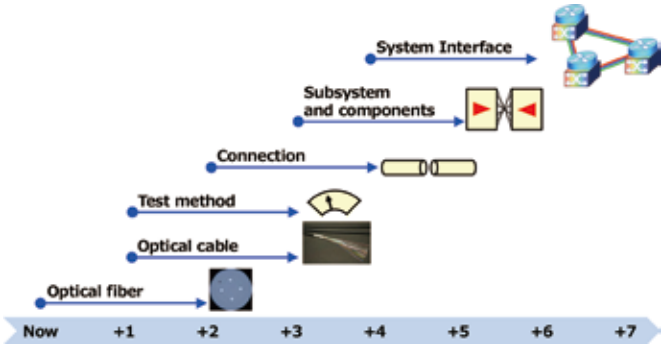


Figure 4: Standardization roadmap for implementing the SDM ecosystem



4. Conclusion

The relationship between the EXAT roadmap and the current state of SDM technology, as well as trends in international standardization of SDM technology, were outlined in this report. As deployment of standard-cladding-diameter MCF is expected, it is hoped that systematic international-standardization activities will be promoted toward the implementation of an SDM ecosystem, which will focus on deployment of SDM transmission systems in various fields in the early 2030s.

References

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[2] W. Klaus et al., in Proceedings of the IEEE, vol. 110, no. 11, pp. 1619-1654, Nov. 2022.
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[5] IEC 61300-3-4 (2023).
[6] IEC PAS 63503-3-30 (2023).
[7] ITU-T Technical Report GSTR-SDM (2022).