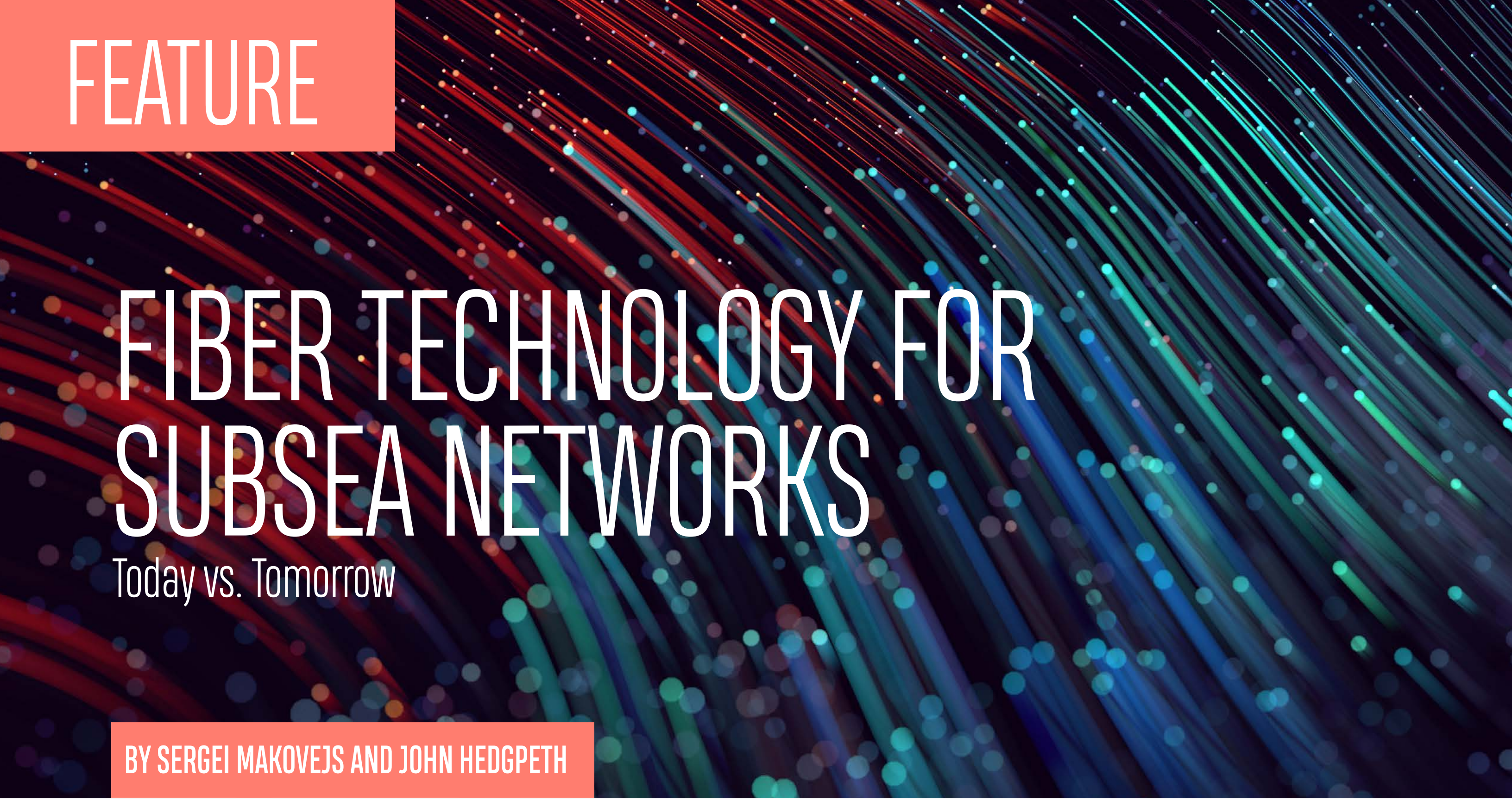
FEATURE



FIBER TECHNOLOGY FOR SUBSEA NETWORKS

Today vs. Tomorrow

BY SERGEI MAKOVEJS AND JOHN HEDGPETH

TODAY'S SUBMARINE FIBER OUTLOOK:

The subsea fiber and cable market continues to show strong demand, and multiple tens of new subsea projects are expected over the next few years, with a substantial portion of them representing long-haul routes. For these routes, space division multiplexing (SDM) with ≥12 fiber pairs per cable is rapidly becoming a de-facto technology to achieve lower cost/bit compared to traditional, non-linear systems.

The main premise of SDM design has not changed much since its inception and it continues to use lower fiber launch powers compared to traditional "non-linear optimum" to achieve linear or semi-linear transmission regime (Fig. 1). In this figure, generalized signal-to-noise ratio (GSNR) is an industry metric frequently used to determine the performance of the wet plant for open subsea cables. In the presence of inherent electrical power constraints, the reduction of launch power leads to lower capacity per fiber. However, this is offset by the ability to design cables with higher fiber counts, ultimately achieving higher overall cable capacity. As a rule of thumb, cost-optimized SDM design favors semi-linear transmission regime, whereas power-optimized SDM design pushes the fiber launch power into a more linear regime.

These design features have important implications for submarine fiber itself. To meet the needs of today's SDM designs, two optical fiber characteristics are often in the center of discussion: attenuation and effective area. Ultra-low attenuation continues to play a key role, and every 0.001 dB/km improvement is essential in the pursuit to further reduce overall cost per bit. Conversely, for SDM designs, effective area (Aeff) moves lower in the decision-making process for fiber choice. While non-SDM systems favored both ultra-low loss and ultra-large Aeff (e.g. 150 µm2) fibers, SDM systems typically gravitate towards 80 – 115 µm2 Aeff. This is because in SDM systems the value of fiber Aeff is somewhat diminished, while value of bend performance is significantly augmented. The latter is particularly important given that bend performance tends to deteriorate with Aeff. In addition, a transition from 80 to 115 µm2 Aeff provides a meaningful decrease in attenuation (approximately 0.01 dB/km), while beyond ~115 µm2 Aeff there is little or no further improvement in attenuation. For all those reasons, 80 – 115 µm2 seems to be a sweet spot for submarine SDM systems, with the specific choice of 80 vs. 115 µm2 Aeff being frequently driven by several inter-dependent, techno-economic factors.

NEAR FUTURE VIEW OF SUBMARINE FIBER:

As the industry continues to progress on the SDM trajectory, a drive towards fiber count densification in a cable to achieve further reduction in system cost per bit will continue. An expectation for the future is that both 80 and 115 µm2 Aeff fibers will continue to play an important role, but now in thinner 200 µm coating variants (Fig. 2) as well as the regular fiber outer diameter. The fiber choice will likely be decided on a project-by-project basis, using similar techno-economic arguments as the ones used today. As further advancements are made in SDM design, attenuation will remain the key attribute, and every 0.001 dB/km of attenuation reduction will continue to matter.

The most likely next step in near future cable design will be a move to higher fiber counts, to achieve further improvements in SDM cost per bit and power efficiency. To minimize cable redesign and cable manufacturing cost, submarine fibers with smaller form factors, such as those with 200 µm coating diameters, will enable up to 50% higher fiber density within an existing cable design. In the example of 200 µm, this form factor decrease is achieved via reduction in both primary and secondary coating, while maintaining cladding diameter at 125 µm to ensure that the existing fiber processing procedures can be used (Fig. 3). Key consideration on migrating to smaller diameter fibers will be to ensure adequate cabled product performance and mechanical reliability. Given that 200 µm has been successfully used in terrestrial cables over the past several years, applying similar best cabling practices to submarine cables should help minimize the learning curve and enable smooth adoption by the submarine industry.

With higher fiber density, there will also need to be a focus on fiber identification. Several options are available today, mainly involving combinations of solid colors and uniquely spaced ring-marks. Fiber identification will be essential to enable correct splicing during installation and future maintenance activities. Important additional requirements for any fiber identification technique is to ensure adequate discernibility of individual fibers, longevity of fiber identification when it is applied to the fiber, and to ensure that the fiber itself maintains its ultra-low attenuation after an identification has been applied.

LONGER TERM SUBMARINE FIBER OUTLOOK:

What could next-generation SDM look like? This one is difficult to answer with certainty.

On the one hand, the industry may decide to stay with the maximum of 24 fiber pairs in the cable, in which case future innovations will rely on continuous attenuation advancements of optical fiber to achieve the lower cost per bit cabling objective. An argument for staying with the maximum of 24 fiber pairs could be related to the desire to improve subsea data traffic resilience – bigger cables will naturally make subsea networks less resilient compared to more frequent and geographically diverse cables with fewer fiber pairs.

Another idea for increasing cabling capacity while reducing cost per bit is using C+L band technology, which will allow for an increase in cable capacity by utilizing fewer fiber pairs compared to C band only systems. Challenges with C+L band vs. C band only systems arise from higher fiber attenuation and bend losses in L band compared to C band, and the need for additional splitters and combiners. Perhaps an ultimate future solution will be based on very high fiber count cables (enabled by 200 µm fiber) in combination with C+L band technology and ultra-low attenuation.

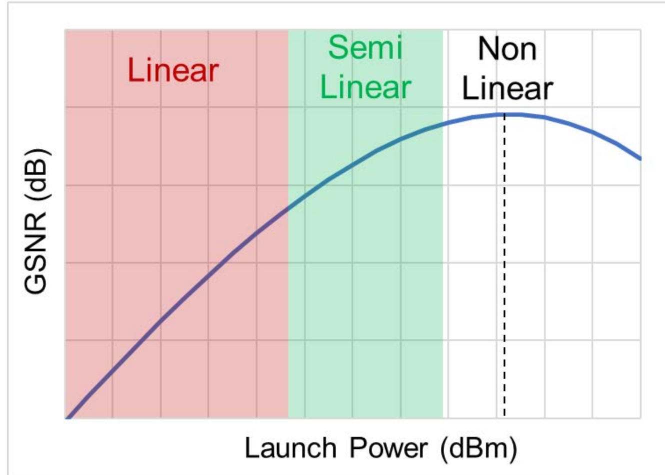


Fig. 1 Different subsea system designs: SDM (Linear or Semi-Linear) vs. non-SDM (non-Linear).

MULTI-CORE FIBER:

If the transition to more fibers (> 24 fiber pairs) in a cable continues, there is an argument for using multi-core fibers (MCF) to potentially overcome cable design limitations. For example, designing a 48 fiber pair single-core fiber cable for repeatered transmission could prove to be a difficult task, while 4-core MCF could leverage the existing 16 fiber pair cable design to achieve comparable cable capacity. It must be noted that MCF technology does not come without challenges. Additional loss from fanout devices and likely higher typical attenuation compared to single core fibers, will reduce an achievable cable capacity (i.e. 4-core MCF will have <4X capacity increase vs. 4 single-core fibers). It is also likely that the cost/per core of n-core MCF will be higher than cost of "n" individual fibers. With current cost and loss expectations MCF seems to be unable to achieve lower cost per bit compared to single-core counterparts, although this should be periodically re-evaluated as manufacturing techniques continue to evolve. There are additional, more practical challenges, such as test and measurement automation and need for bespoke core identification solution, which represent additional

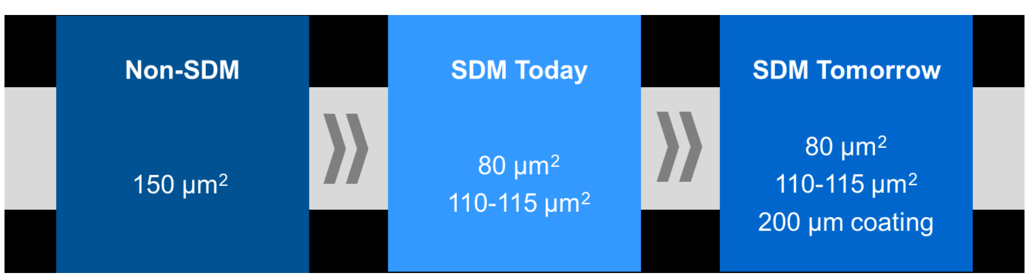


Fig. 2 Fiber evolution (past – today – future)

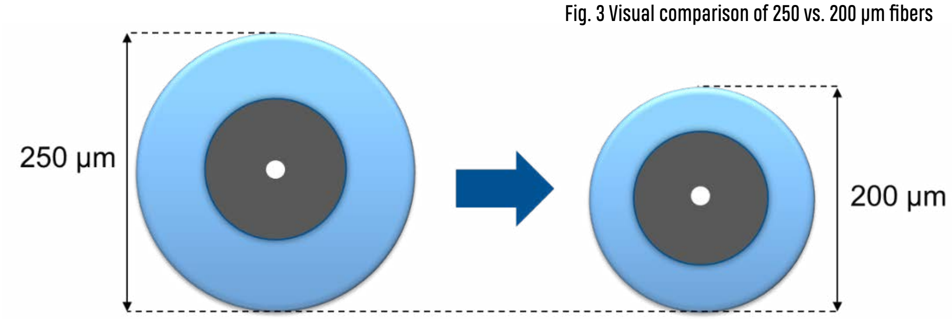


Fig. 3 Visual comparison of 250 vs. 200 μm fibers

(albeit, not fundamental) barriers of adoption for MCF technology.

FEW-MODE FIBER

Other novel fiber option that is occasionally being discussed for subsea transmission is few mode fiber (FMF). While FMF is more manufacturing-friendly compared to MCF and can potentially provide comparable spatial path density, it is also expected to have higher attenuation compared to single-mode fiber (and even likely to exceed MCF attenuation). The biggest challenge for FMF adoption is the complexity associated with need for mode coupling compensation in the receiver - for transoceanic transmission this will likely remain a significant challenge.

SMALLER FIBER

The final option involves single mode, single core fibers with lower than 200 μm coating diameter. This can be achieved via reduction in cladding diameter (<125 μm), while keeping coating thickness the same. Alternatively, one could preserve 125 μm cladding diameter for backwards compatibility with existing fiber handling procedures, but to instead reduce coating thickness to below 200 μm. Both pathways can achieve higher packing density compared to fibers used today but will create some additional challenges related to bend performance, hence suitability of these fibers for subsea transmission will be driven by cable design considerations.

CLOSING STATEMENT:

All indicators suggest ongoing growth in the subsea market. Several reports indicate >30% CAGR in global bandwidth, and conference or seminar presentations by subsea global subject matter experts suggest that such bandwidth growth is unlikely to abate. Newly designed cables are migrating to SDM designs, in which cost per bit and power efficiency are essential design metrics. As such, fiber attenuation becomes the single most important optical fiber attribute, and as higher fiber density SDM systems gain prominence, smaller diameter (200 μm) fiber emerges as a frontrunner solution to allow for higher fiber density without a significant cable redesign.

Further into the future, more study into revolutionary fiber options (MCF, FMF, RCF) is needed to determine whether either of those options are going to succeed for subsea transmission, given the desire for next-generation SDM systems to be more cost-effective than the current ones. Ability to manufacture ultra-low loss MCF, FMF, or RCF fibers with consistent quality and in large volume is a necessary condition for those fibers to compete with well-established, ultra-low attenuation single core fibers. STF


JOHN HEDGPETH *is a Product Line Manager at Corning, responsible for submarine and high data rate optical fiber products. John has held several positions during his nine year tenure at Corning, including manufacturing support and quality management. In addition to his work at Corning, John's career has allowed for experience in process engineering, R&D and product management, all gained through working in the electronic component industry. John holds a BS in Chemical Engineering from NC State University.*


SERGEI MAKOVEJS *is a Market and Technology Development Manager at Corning, where he has global strategic responsibility for marketing, market development and product development direction of long-haul and submarine fiber segments. Sergei received a Ph.D. in electronic and electrical engineering from UCL, U.K. and an Executive MBA from Warwick Business School, U.K. Sergei has authored and co-authored more than 50 peer-reviewed papers in the field of optical communications. He is a regular presenter at international conferences and seminars on emerging technology trends that shape long-haul terrestrial and submarine networks.*

Table. 1 *Comparison of different future fiber options*

	Reduced coating fiber *(=200 μm)*	**Reduced coating fiber *(<200 μm OD)***	**RCF *(<125 μm core)***	**MCF**	**FMF**
Pros	Closer to reality, learnings from terrestrial	Leverages existing ecosystem	Less disruptive vs. MCF/RCF	Spatial path density	Spatial path density, cost
Cons	Nothing major	Bend	Bend, splicing to 125 μm cladding	Cost, fanouts, loss, amplifiers, ecosystem not available	Loss, DSP, mux/demux, amplifiers