Advances in Fiber Technologies for Subsea Systems

Marsha A. Spalding and Alexei Pilipetskii
SubCom, 250 Industrial Way West, Eatontown, NJ 07724, USA
marshaspalding@subcom.com

Abstract: This paper will provide a view of several future Space Division Multiplexing (SDM) approaches to support more transmission paths within a subsea cable and their effects on the practicalities of submarine system manufacturing and deployment. ©2023 The Author(s).

1. Increasing Capacities of Subsea Systems

An observation has been made [1] that during the past few years, subsea cable capacity has been growing exponentially, while available fiber capacity in the C-band is becoming saturated (Figure 1).

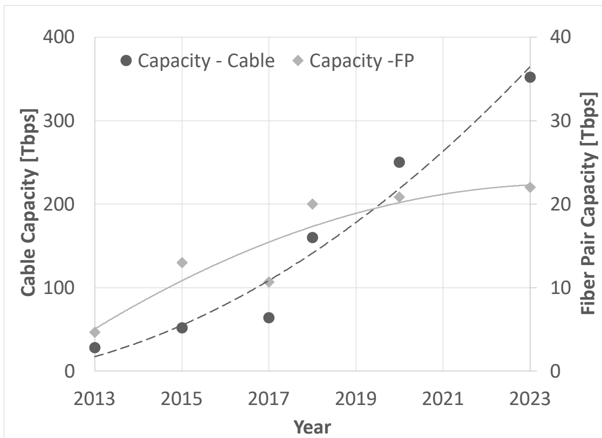

Fig. 1 Historical and Near-Future Capacity Trends

Given this trend, more transmission paths within a cable are needed to satisfy the demand for higher capacity cables. This was achieved in 2018-2020 in the trans-Atlantic SDM system [2]. That project implemented Space Division Multiplexing, which employed an increased fiber count within a standard cable structure by raising the fiber packing density (ratio of fiber area to cable core area). Presently 48 individual fibers can be contained within a standard 17mm outer diameter cable structure. Innovative advancements in fiber technologies are being pursued to further increase the number of transmission paths within a standard cable structure.

2. Practical Challenges for Subsea Systems

Subsea systems are fertile ground for new technologies because each project is custom designed and newly constructed; unlike terrestrial systems, there is little reuse of existing installed fiber or repeaters. But subsea system designs must also provide optimal cost and performance, including a balance of equipment, installation, and maintenance costs, all of which are strongly influenced by transmission technology. History has shown that new technologies are typically implemented first in terrestrial networks, where there is significantly less disruption from repairs or replacement than in subsea networks.

When considering new technology, there is significant infrastructure globally that relies on a standard-sized cable structure, particularly the fleets of vessels (Figure 2a) that install and maintain global cable systems. These vessels are expensive capital investments, with high operational costs that can be burdensome when vessels transit from the cable factory to the work site to replenish the cable on board. Therefore, loading the longest system length onto each vessel is important for reducing system costs. The maximum cable load is limited by the volumetric capacity of the ship's cable tanks (Figure 2b). Typically, for standard 17mm sized subsea cable, the deep water portions of a trans-Atlantic system can be stored in the cable tanks of a single lay vessel. Increasing the cable size would subsequently result in more ship loads, thus substantially increasing system cost.

These ships are also equipped with cable jointing equipment for installation and repairs to splice together the optical fibers and then restore the electrical insulation integrity across cable-to-cable joints. There are hundreds of these splicing machines across the industry globally which reflect a substantial capital investment.

The subsea cable structure itself (Figure 2c) has multiple challenging functions in addition to safely housing as many optical cores as possible: the cable provides a low-resistance electrical conductor for repeater and network element powering and insulates that power path from the ocean sea ground. Those power requirements increase with the cable capacity, so the industry is being challenged to provide more conductive cables in the same standard structure. The cable structure strength must support deployment and recovery of several kilometers of cable at deep ocean depths, plus the subsea network elements such as repeaters, branching units, and WSS ROADMs. Finally, reliability is crucial in subsea networks. Any subsea repairs require the mobilization of a marine vessel along with a multi-day operation of recovery, repair and redeployment, likely costing hundreds of thousands of dollars. Utilizing field-proven technology reduces the risk of repairs and maintenance costs.

Fig. 2(a) SubCom Cable Ship with Cable Tanks

Fig. 2(b) SubCom Cable Ship Tank

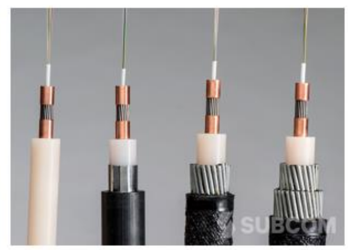

Fig. 2(c) Example SubCom Subsea Optical Cable

3. Candidate Fiber Technologies for Near-Term Subsea Systems

More optical paths can take the form of more optical cores or more optical bandwidth. The "more bandwidth" approach was used in a trans-Pacific system in 2015 to nearly double the per-fiber capacity with C and L band transmission as compared with the same fiber count for C-band only [3]. No significant changes in the optical fiber were required to support the L-band. This field-proven approach may be less attractive than "more paths" for network owners, because capacity management among multiple users could require fiber pair sharing. Also, C and L may require more complex network elements for wavelength management in Branching Units and ROADMs. Unlike terrestrial networks, C and L band transmission has not yet been fully leveraged in subsea networks, perhaps due to the more complex amplifier architecture and the electrical power inefficiencies hindering use for the longest system distances [4].

Another near-term approach toward more optical paths is to add more optical cores in the same cable cross-sectional space [5]. This is achievable in at least two different ways: a smaller physical fiber cross-section than the standard 250µm outer diameter, or more cores in the standard 250µm fiber cross-section. The former approach, using 200µm outer diameter fiber ("reduced OD" fiber), has already been field proven in countless terrestrial networks. The major subsea fiber suppliers have made thousands of kilometers of terrestrial cable with 200µm fiber, and they have been implemented in networks over the last five years. The 200µm fiber has the same intrinsic strength as standard fiber, owing to the same glass outer diameter of 125µm. However, it has a thinner plastic protective coating, so the cabling process must be benign and well-controlled to maintain fiber integrity.

Translating this reduced-OD fiber to subsea cable use is straightforward. No additional repeater or subsea network element components are needed. Cabled fiber performance is equivalent to standard 250µm when a benign cabling process is used, and post-cabled fiber strength is being shown to meet all strength requirements. Splicing of this fiber is essentially the same as standard 250µm fiber, with the exception that splicing machines need to be fitted with smaller fiber clamps. These clamps are quite inexpensive, so this is not expected to be burdensome for the world's subsea installation and repair vessels. This approach is expected to achieve up to 50 percent additional capacity.

An alternative capacity increase approach is the incorporation of multiple, independent optical cores in a single standard 250µm outer diameter fiber. Subsea fiber manufacturers are investigating this "Uncoupled Core" (UC) Multiple Core Fiber (MCF) technology for both 2 cores per fiber and 4 cores per fiber [6]. While MCF appears to be the most technically-challenging approach, it has the potential to provide the highest increase in capacity, reaching 50 percent to nearly 100 percent of current single core cables. The challenges are discussed below.

These fibers require new index profiles as well as new manufacturing processes. The index profiles are optimized for low loss approaching single core fiber levels, and for reduced crosstalk amongst the optical cores. New manufacturing processes are needed to precisely place the optical cores within the cladding and to implement a marker or other indexing mechanism to uniquely identify each optical core within the glass cladding. These new fiber manufacturing processes may take some time to industrialize.

Subsea systems require precise amplifier designs to bridge trans-oceanic distances. At this time, each optical core within an MCF fiber needs to be amplified individually to meet subsea design requirements. Therefore, the cores need to be separated and recombined on each side of a repeater or subsea network element. This separation and recombination uses fan-in/fan-out (FIFO) devices, specifically designed to match to each type of Multi-Core Fiber (MCF) [7]; and such devices are not yet subsea qualified. The two FIFOs for each fiber would consume valuable space within the pressure housing, and these FIFOs are fiber manufacturer-specific, and would reduce the flexibility of supply for system manufacturing and sparing. The incorporation of FIFOs in the repeaters and subsea network elements also adds cost to the system and results in increased span loss, possibly necessitating additional repeaters and further increasing system cost.

Another aspect of MCF that deserves discussion is fiber splicing. To correctly match the optical cores within the MCF, splicing machines that can actively optimize fiber orientation are necessary. Such splicing machines were initially developed for polarization maintaining fiber and, while some machines are available on the market, their use has been limited. Upgrading the splicing machines across the world's subsea vessel fleet could prove quite costly.

4. Future Fiber Technologies for Possible use in Subsea Systems

Progress is being made toward MCF with coupled cores as well as with Multi-Mode Fibers [8]. A significant advantage of these technologies is that they could achieve well over 100 percent capacity increases. However, specialized terminal equipment is required to disaggregate the received signals, and this development may not synergize with similar equipment for terrestrial networks. Technology introduction costs would again likely be borne by the subsea industry. Speculating on the practical introduction rate of this technology is most difficult at this time.

5. Conclusion

With several potential technologies for increased network capacity, it is possible that subsea system suppliers and network owners may not all choose the same first step. There are near-term commercial barriers for these technologies especially when considered in the face of the downward pressure on system pricing. The cost-effectiveness, ease of implementation, and capacity gains must all be evaluated, and may vary for different network topologies. Multi-Core Fiber, both 2-core uncoupled and 4-core uncoupled, is in active development with fiber suppliers. MCF feasibility is being proven in standard subsea cable structures and its performance within subsea cable is being characterized under various environmental conditions used for subsea qualification. 200µm outer diameter fiber, already qualified and deployed terrestrially, is currently being qualified for subsea use. And, as mentioned earlier, C and L band transmission has already been demonstrated in subsea systems, so utilizing it in higher fiber count systems is straightforward. Which of these technologies will be the first next step to significant increased cable capacity is yet to be determined. However, it is very encouraging to note that using these technologies in combination will yield approximately one order of magnitude increase in cable capacity in the near-term.

6. References

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