Tailoring Large Scale Manufacturing of MCF to High-Capacity Subsea Systems

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Abstract: Multicore fiber (MCF) targeted for use in subsea systems is under active development. There are many variables and constraints which must be considered in the design, fabrication, and deployment of this new type of fiber to enable its success. This talk will expand upon the details and performance achieved to date by subsea fiber manufacturers through the lens of manufacturing suitability.

1. Motivation

The capacity of submarine cables has increased by over 5 orders of magnitude in the last 30 years, but the rate of increase is beginning to slow [1]. The industry is evaluating methods to allow continued bandwidth growth via additional wavelength spectra through C+L band use, more fiber pairs through reduced coating diameter or cable redesign and use of multicore fiber (MCF) [2,3]. MCF can be a viable alternative only if it can meet all the performance, cost, and deployment needs of a high-capacity subsea system.

To meet the cost and deployment needs, the fiber must be manufacturable. Defining what is 'manufacturable' is left to each of the fiber manufacturers but there are common themes which appear in many Design For Manufacturing texts and seminars. First, there must be sufficient market demand for the product you are making, the factory productivity and efficiency must be maintained through sufficiently high product yields, reuse of existing infrastructure assets helps moderate costs, and overall quality is paramount – especially in the subsea market.

2. Design and Fabrication of Multicore Fibers

There have been multiple MCF designs proposed and fabricated with both high counts of cores and cladding diameters larger than the traditional 125 µm glass diameter [4,5]. The submarine market has been deploying systems using ITU-T G.654-B and D-compliant fiber with >110 µm^2 effective area (A_{eff}) and ultra-low attenuation (<0.15dB/km). With a change from single core to MCF, additional care should be taken to maximize the probability of successful early deployments to build initial momentum and confidence and thus changing to a design with major departures from the current incumbents is not advised.

There is a strong preference in the industry to maintain the existing 125 µm cladding diameter requirement to ensure backwards compatibility with existing fiber geometry and fiber processing practices used today. The 125 µm cladding requirement effectively sets a limit for the maximum number of cores to around 4 as packing a larger number of cores would require one to compromise on transmission performance in each core or to select the use of less manufacturing-friendly core designs.

The early SDM discussions that took place industry-wide in 2020-2022 focused on two MCF designs: dual-core MCF and 4-core MCF, with the dual-core, large A_{eff} (110-115 µm2) design prevailing as the preferred choice for subsea systems as a lower overall risk option compared to a 4-core MCF. Despite some criticism that dual-core MCF only provides a modest (~2X) increase in capacity versus a single-core fiber with comparable optical characteristics, dual-core MCF has fewer overall barriers for adoption. Upon its successful deployment it will provide the industry with much needed confidence, thus paving the way towards eventual adoption of more complex designs. A dual-core MCF design also provides a convenient fiber granularity, whereby the end users can have a single fiber to cover the bi-directional traffic comparable to the use of a more traditional fiber pair. To further simplify initial adoption, the MCF should employ an "uncoupled" core design, where the two cores are placed with sufficient isolation to ensure minimal optical coupling (or crosstalk) between the cores. This will avoid any major redesigns to submarine line terminal equipment.

The core profile design should be selected to meet the targeted optical performance targets (MFD, CD, Attn, A_{eff}, Bend Loss, etc.) while having high manufacturing yields to minimize the cost of the resulting fiber. The choice of core-to-core pitch is driven by two considerations. As the cores are spread further apart, the crosstalk between the cores decreases but the radiation loss increases, as the proximity of cores to the edge of the cladding makes it easier for light to escape. Through modeling and experiments we concluded that the optimum value for the core-to-core pitch when using a manufacturing-friendly core profile is ~50 µm for co-propagating signal transmission, which balances out the impact of crosstalk and radiation loss (Fig.1). Assuming the industry will adopt use of counter-propagating transmission to allow a single MCF to replace a traditional fiber pair a slightly tighter core-to-core pitch can also be selected as optimal.

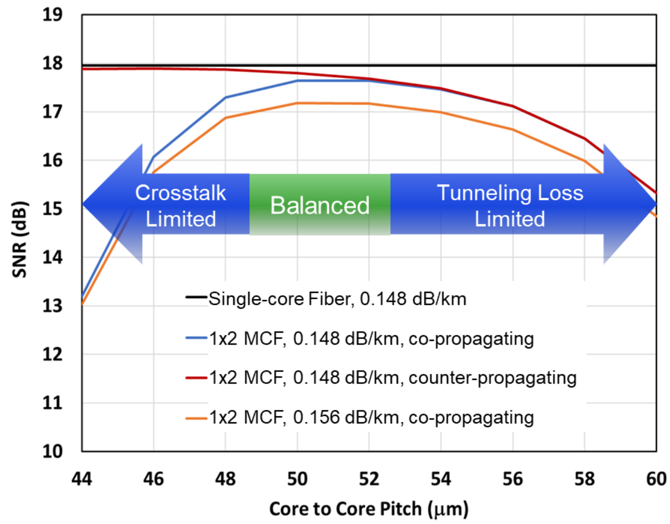

Figure 1. Modeled SNR as a function of core-to-core pitch for 20 spans at 100 km each.

Another key topic for enabling use of MCF is core identification. For system level integration and assembly two constraints must be met: 1) polarity to enable consistent channel identification throughout link; 2) Avoidance of Tx and Rx channel mixing. For long-term maintenance and repairs it may also be advantageous to trace each individual core within a fiber. There are two commonly proposed methods for MCF core identification: addition of a structure to function as a 'marker core' or offsetting of core positions within the cladding to enable identification through visual positional differences.

Once a target design has been selected, the targeted fiber must be manufactured. The choice of preform manufacturing method will impact the ability to achieve other attributes such as core position error, yield due to surface-related breaks and voids and overall manufacturing costs due to costs of additional process steps and scalability of the resulting preform size. Many processes have been demonstrated [6,7] and drilled glass is the most prevalent method to date. Once a preform has been made, the fiber draw and proof testing can be performed with well-known single-core fiber manufacturing methods reusing much of the existing manufacturing infrastructure, especially when the cladding is maintained at 125 µm OD. Measurement of the resulting fiber adds new challenges and attributes as light must be directed into and out of each core to measure traditional attributes such as loss, chromatic dispersion, and mode field diameter. New MCF specific attributes are also present, such as, core-to-core crosstalk and core position error (analogous to core clad concentricity error in single-core fiber), which are currently un-defined by any standards bodies. Gaining international consensus on the definitions and testing methodology of these MCF specific attributes is necessary to facilitate a common understanding of the performance of MCF manufactured by different vendors.

The overall performance of the measured fiber will impact the subsea system both in cost and performance. Generating high yields on each attribute is of critical importance, especially as number of cores increases, as the overall fiber yield will scale as attribute yield raised to the power of the number of cores. One path to higher yields would be to relax the specifications on individual attributes but care must be taken to not impair the overall system performance when viewed in comparison to a single-core fiber system so each specification relaxation should be carefully considered. Attenuation, for example, has a direct impact on overall SNR and so demonstration of similar attenuation to standard single-core fibers is an important milestone (Fig. 2)[8]. Additionally, having low and non-systematic differences in performance of attributes such as attenuation, mode field, and dispersion between the cores will simplify system layout as a systematic loss difference between the cores of a MCF will lead to concatenation issues in a subsea network.

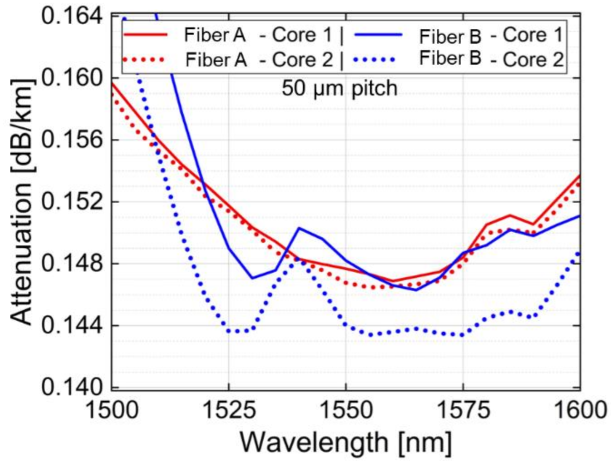

Figure 2. Measured MCF fiber loss showing attenuation results on par with single-core fibers.

3. Ecosystem Considerations

Once a suitable MCF has been designed and fabricated there are additional challenges to address prior to deployment in a subsea network. The first area that needs to be considered is the change in performance of the MCF as it is deployed in a subsea cable. The bending spectrum in a cable is different than on a shipping reel and understanding the impact on parameters such as attenuation and crosstalk is necessary to allow for sufficient margin to be applied during the manufacturing process to enable overall system success. Splice loss of an MCF-to-MCF splice is the next area of consideration. There are multiple fusion splicer vendors developing splicers suitable for MCF splicing where an additional rotational alignment step is needed in addition to the traditional splicer alignment needs. The splicer also needs to be able to identify and align the selected marker method to ensure proper polarity in the resulting system. The loss of the resulting splices has been improving with time and is nearing the results achievable for single-core splicing [9]. In order to get the signals into and out of the fiber it is necessary to have a way to Fan In and Fan Out (FIFO) and components capable of doing so have been demonstrated in large-scale system demonstrations [10]. FIFOs are likely to be used in the initial deployments of dual-core MCF in subsea systems to allow connection to the EDFAs at each repeater as a subsea rated MCF EDFA is not yet commercially available.

4. Conclusions

Fibers, components, and processes which meet the initial needs of subsea systems have been demonstrated. Scaling these products up to meet the long-term cost and performance requirements necessary to become the new incumbent technology is underway. Initial field deployments are being prepared and the industry will soon gain valuable knowledge about the suitability of MCF in subsea networks.

5. References

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