FROM THE SEA FLOOR TO THE SHORE –

EXTENDING THE TRANSOCEANIC LINK FROM THE OCEAN FLOOR TO THE INLAND DATA CENTER

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The massive changes in the telecom and datacom industries over the last ten years have made a significant impact in the submarine network space, which handles 99% of intercontinental internet traffic. Changes in consortium cable ownership, open cables, and the entrance of the new Cloud & Content Providers (CCPs) have dramatically changed the business environment. Many companies now want secure, redundant transmission paths across the oceans to connect hyperscale data centers on every continent. Growth of data in the cloud is a key factor in pushing data traffic over submarine links. This has driven an uptick in cable builds over the last few years with ever increasing expectations on performance. Now, not only traditional carriers but CCPs and private owners are vying to participate in new cable consortia, with CCPs often being the heavyweights amongst funding entities. These companies are interested in meeting the real-time demands of their customers and are therefore forced to store data closer to the end user. Table I shows a selection of current and recent submarine cable projects supported by some of these new investors.

Because of the "open cables" requirement of many investors today, there has been consolidation/partnering between the terminal gear vendors for ocean and terrestrial transport gear. Historically, ocean networks were designed as a unit, with Submarine Line Termination Equipment (SLTE) and cable plus repeaters delivered by the same company. In that way, the SLTE could be designed to maximally exploit the capacity of the optical fiber, repeaters and dispersion compensation in the link. This was considered the key to cost effectiveness when sinking thousands of kilometers of fiber and hundreds of repeaters into the ocean at great expense. This arrangement had certain cost disadvantages to the network owner as very limited set of companies are capable of manufacturing and laying submarine cable. Largely due to the advent of coherent transport technology, SLTE can now be purchased separately from the "wet plant" and much later in the design/deployment cycle, so that the latest SLTE technology can always be used (line card technology cycles today are quite short).1 A related follow-on effect has been the choice of termination point for the subsea link. Landing stations right on the shore have been traditionally used to house SLTE, with the concomitant inconvenience of optically linking those limited station locations to inland data centers or co-location facilities by a separate terrestrial transport link. As one example of the new trend, the Monet cable's Florida cable landing equipment is being placed in the Equinix MI3 International Business Exchange. This provides simplification in the cable owners' network design and eliminates the cost of a separate landing station. The users of this cable see advantage having the cable terminate in a multi-tenant data center with many options for connecting forward-going traffic.2

EXTENDING THE SUBMARINE LINK INLAND

Submarine optical fiber cable systems have always been highly engineered, compared to terrestrial ones. This is because of both the turnkey provision of a unified network of terminal equipment and cable (from the same vendor) as well as the natural isolation of the submarine cable installation (undersea, then terminating in stand-alone landing stations). In addition, the huge investment and difficulty of effecting repairs/changes tended to justify more upfront engineering. The predictable temperature and stress conditions of the ocean floor as well as a minimum number of

Name	Go-live date	Destinations	Non-traditional Investor
AEConnect	2016	Long Island - Ireland	Aqua Comms
Monet	2017	Miami - Brazil	Google
Marea	2017	Virginia Beach - Spain	Facebook, Microsoft
NCP	2017	Oregon – China, Japan, Korea	Microsoft
PLCN	2018	Hong Kong – Los Angeles	Facebook, Google
Hawaiki	2018	Oregon - Sydney	Hawaiki Networks

Table I. Some recent submarine cable projects with ownership interests outside the traditional carriers.

switching points along the link allowed exotic engineering to be employed to optimally choose transmission formats, compensate impairments, and space wavelengths so that capacity could be maximized. The deployment of submarine systems has been handled by a professional, highly trained craft.

Bringing the submarine link to an inland landing station introduces several new variables. All the uncertainties of the terrestrial environment come into play. The cable is deployed in short segments by a contract crew of uncertain training resulting in potential cable splicing and handling problems (every 5 km or so). The cable is exposed to more extreme environmental conditions, with constant day/night temperature and humidity changes. Amplifier hut spacing will likely vary along the route.

After solving these issues, the question arises as to the fiber type to use on the terrestrial spans. Today's submarine fiber is designed quite differently from terrestrial fiber, partly because of the radically different deployment circumstances outlined earlier. The link length plays a role as well, with submarine links extending two to five times further than terrestrial long-haul routes. This puts a huge premium on preserving optical signal-to-noise ratio (OSNR) throughout the transmission path. The two properties of modern fibers which are most important in this regard are attenuation and optical mode field diameter (or equivalently mode effective area). Low attenuation preserves the signal through the link with lower required amplification. Amplifiers generate noise, so the less gain required from them, the cleaner the transmission. Because the optical fiber core is so small, the light is confined in a very small cross-sectional area. Over long transmission distances tiny nonlinear interactions between the light and the glass fiber add up to problems. This is alleviated by spreading the light over a larger core size. The largest mode field diameter submarine fibers today use a cross-sectional area nearly twice that of standard single mode fibers. This allows more optical power to be launched into the fiber without hitting the nonlinear limits.

Advanced ITU-T G.654.E terrestrial fibers, such as TeraWave® ULL pure silica-core fiber, can provide the leading-edge performance common on today's most spectrally efficient fiber routes. Though these fibers do not have the ultimate lowest attenuations and largest mode field diameters of the best submarine fibers, they do have a well-established track record of success in the stressful environment of terrestrial installations. They also have substantially improved over the attenuation (only about half the optical loss over 100 km) and small mode field (50% larger cross-sectional area) of standard fibers.

However, there is an interest, for some installations, in continuing the terrestrial portion of the link with the original, highest performance submarine fiber. A state-of-the-art fiber

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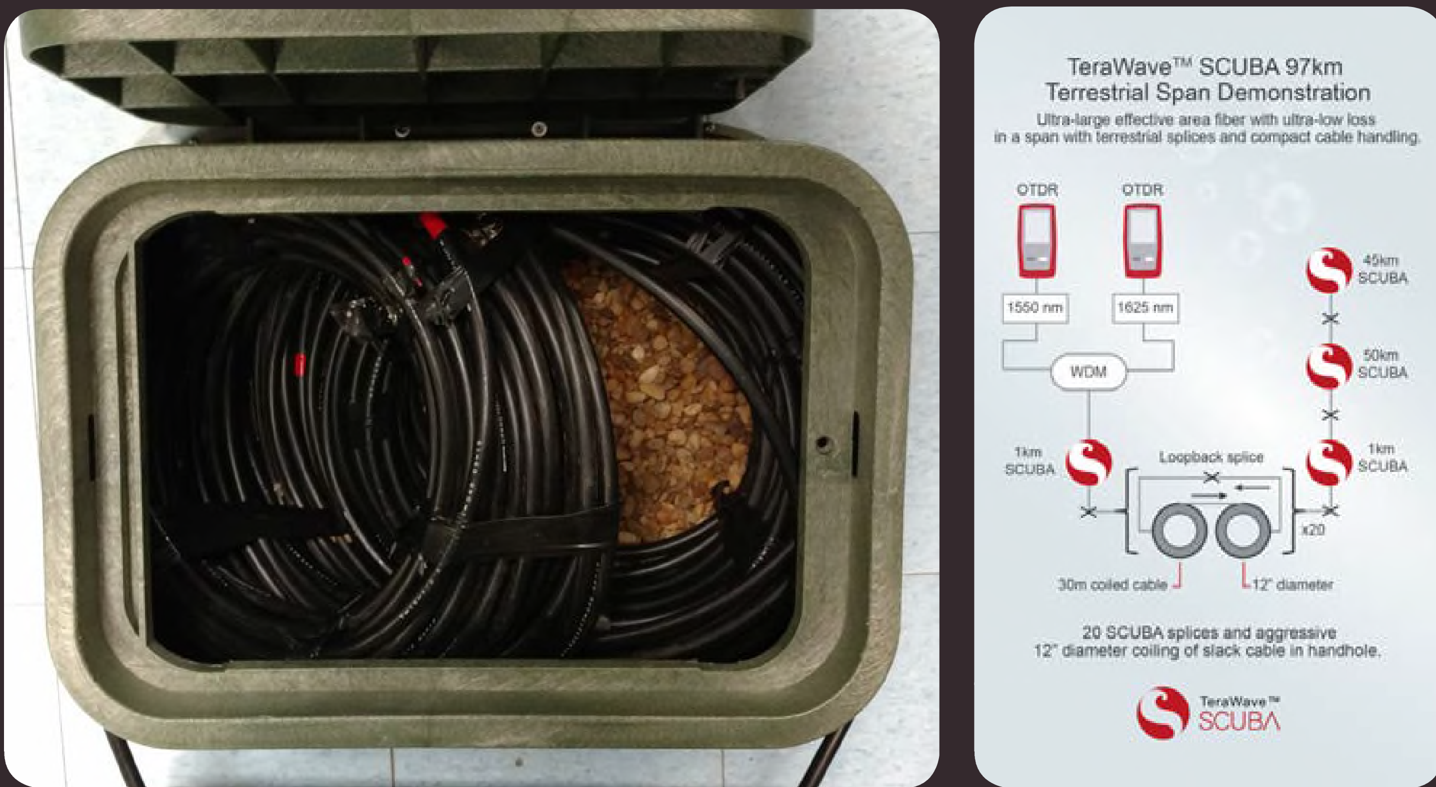

Figure 1. (a) Detail of the aggressive coiling of the loose tube cable in 12" diameter loops, (b) schematic of the optical loss testing performed in C and L-bands though the equivalent of a 97-km span.

today, such as OFS's TeraWave SCUBA fiber, will have a pure silica core and the largest practical mode field diameter yet demonstrated, leading to ultra-low optical attenuation and allowing high optical power in transmission. Using the submarine fiber for the whole link will provide an advantage in OSNR as well as simplifying the link simulations during the design phase. An open question is "how well will the submarine fiber perform in the installed terrestrial cable?" This is a nontrivial issue as the resistance of the large mode field fiber to bending and stress is not as robust as for standard terrestrial fibers. In addition, the reach extensions of the link at either end could amount to 300 – 600 km or more, enough distance to seriously impair the performance should cabling issues arise in the terrestrial portion. So as a "bleeding edge" example of what could be achieved in a shore link, the next section describes a demonstration of the capabilities of TeraWave SCUBA in a terrestrial environment.

DEMONSTRATION OF TERAWAVETM SCUBA PERFORMANCE IN TERRESTRIAL CABLE

OFS did a live demonstration of optical loss accumulation in a mocked-up 100 km terrestrial fiber span at OFC 2017. This showed the capability of the SCUBA fiber to be cabled in a conventional loose tube terrestrial design and to be installed using particularly aggressive coiling in a prototypical handhole. The cable used was an OFS DryBlockâ Armored Loose Tube design with four tubes with varying numbers of SCUBA fibers (tube fill varies from 4 to 12 fibers with 28 fibers total). A worst case handhole is chosen, one that requires a 12" coil diameter with no integrated splice tray. This occurs in space constrained stations where excess cable is stored outside the equipment rack housing. The demo shows three 30-meter coils (typical slack cable lengths at splice points) coiled inside the handhole (see Fig. 1(a)) with splices looping back through the cable coils 20 times. This setup represents the effective optical loss seen over the approximately 20 splice points in a 100-km span (cable lengths are typically 5 km or so in a terrestrial installation). To fill out the rest of the span, 96 km of SCUBA fiber is spliced on to the fiber exiting the cable coils. This setup is outline in Figure 1(b).

OTDRs measure the optical loss through the coils and fiber spools at 1550 and 1625 nm. Traces obtained from these tests are shown in Figure 2. Here we have an overall view of the loss through the link at 1550 nm, with a blow-up of the results through the coils at 1625 nm (worst case). Figure 2(a) shows that the bulk of the span has the low 0 0.154 dB/km loss of the TeraWave SCUBA optical fiber at 1550 nm (0.164 dB/

km at 1625 nm). A separate view (Fig. 2(b)) shows a detailed OTDR measurement of the loss through the coils and splices at 1625 nm. In this measurement, two 1 km sections are cut from the same SCUBA fiber spool and positioned at the ends of the coils (between the red markers 0 – 1 km into the span, and between the red markers from 2.75 – 3.75 km) also shown in the schematic in Fig. 1(b). These fiber spools (since they have identical mode field diameter) allow accurate unidirectional loss measurements to be made with the OTDR. The various OTDR features seen in the range 1 – 2.75 km are due to the OTDR backscatter differences in SCUBA fibers of slightly different mode field size. The apparent losses and "gainers" in this region are artifacts of the measurement, and not true optical loss. In fact, measurements of these splices show an average loss below 0.03 dB. The net estimated loss of 1.051 dB is quite low considering the number of splices and length of fiber involved in the 20 looped passes through the cable coils. Using the average splice loss, the number of splices, the 1625 nm attenuation of the fiber, and the fiber length; one estimates an expected loss of 24 x 0.03 + 1.75 x 0.1644 = 1.008 dB. This implies that the effect of the cable coiling is very small, ~ 0.04 dB, which is added for each 100-km span. Measurements at 1550 nm show no measurable added loss from the cable coiling. So, we show here that the TeraWave SCUBA fiber design is sufficient to withstand the rigors of cabling and handling in a standard terrestrial loose tube construction. Even the most sensitive long wavelengths show little impairment from this application. To be sure, further consideration should be taken towards terrestrial craft capabilities, temperature variations and end-of-life performance before assuming that the link will behave simply as a longer submarine link.

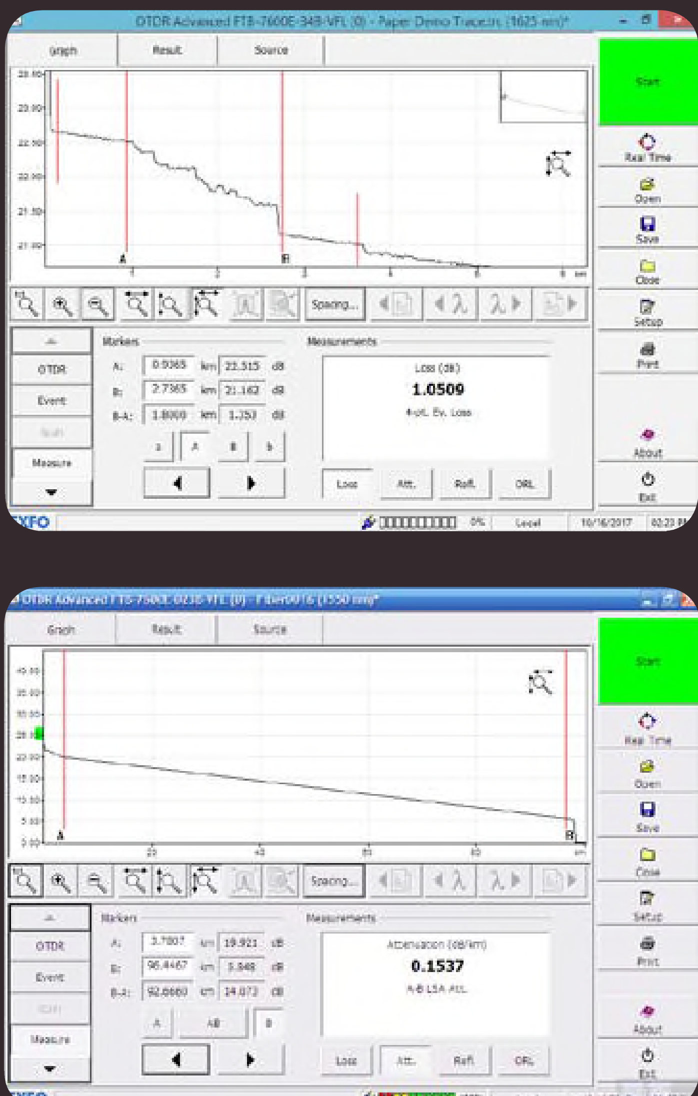

Figure 2. (a) shows overall low C-band (1550 nm) attenuation over the 97-km span, (b) shows a detailed loss view of the twenty transits through the cable coils and the 24 splices at L-band (1625 nm).

CONCLUSIONS

Flexibility in terminating submarine cables in datacenters can be greatly aided by deploying a state-of-the-art G.654.E terrestrial fiber or – with careful engineering – a submarine fiber itself. These fibers have ultra-low loss and large effective areas to help make terrestrial link engineering as similar as possible to the submarine link engineering. Properly designed large mode-field fibers can handle the bends and stresses normally incurred when deployed in terrestrial hand holes and splice enclosures. This flexibility allows network owners to consider alternative places to terminate their submarine links and forward traffic on to the terrestrial network with improved efficiency, simplified network control, higher reliability and lower cost.

REFERENCES

[1] M. Enright et al., "Open cables and integration with terrestrial networks," SubOptic 2016.

[2] M. R. Lingampalli and F. Salley, "Integrated submarine and terrestrial network architectures for emerging subsea cables," SubOptic 2016

BIOGRAPHIES

Alan McCurdy is a Distinguished Member of Technical Staff at OFS. He does technical business case development and support for new fiber products, marketing of the same, and, when time allows, works on advanced noise and fiber measurement problems in optical communications. Alan has worked in telecommunications since joining the Enterprise Networks Group at Lucent Technologies twenty years ago. Prior to that, he spent nine years on the Electrical Engineering faculty of the University of Southern California. He earned B.S. degrees in Chemical Engineering and Physics from Carnegie Mellon University, and a Ph.D. from Yale University.

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