Ultra-Large Effective Area Fibre Performances in High Fibre Count Cables and Joints, A New Technical Challenge

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Abstract: Ultra long haul, very high bit rate WDM transmission systems now require the use of optical fibres with extra large effective area and very low attenuation levels (Coherent Submarine Fibres, CSF). This paper presents the comprehensive testing program performed to accurately measure attenuation variations of several CSF fibre types and validate their qualification in ASN cables and joints for full +D system applications. It also presents the good performances reached in high fibre count cables, thanks to the optimization of cable design and well managed cabling processes. Integration in joints and design optimization to guarantee low attenuation is detailed too.

1. INTRODUCTION

Full +D systems require the use of large effective areas and ultra low loss optical fibres (CSF, G.654 type) to guarantee very high bit rate WDM transmission on ultra-long haul systems.

Ensuring a fibre low attenuation level once integrated in the cable and jointing equipment is one of the key factors for good system transmission performances and economical design.

But it is also a real challenge, as high effective area also implies very high fibre sensitivity bending constraints. The challenge is even stronger, when the cable includes a large quantity of fibre pairs, which seems to be one of the market trends.

A comprehensive testing program has been performed in order to accurately measure attenuation variations of several CSF fibre types and validate their qualification in ASN cables and joints for full +D system applications. Adequate joint design optimizations have been done, as well as cable optimized design definition for high fibre counts.

Optimized optical performances can thus be obtained with these ultra-large effective area fibres in high fibre counts systems.

2. CSF QUALIFICATION IN CABLE

To validate fibre optical behaviour in a cable, a comprehensive qualification program is performed, including lab tests and tests on fibres in cable. This program is based on ASN standard protocol for the qualification of new fibres that has been validated through successful deployment of more than 1,000,000km of fibres in ASN cables.

4 fibre types have been tested:

- Fibre type A & B: G.654, 110µm² effective area, low loss fibres from 2 different suppliers
- Fibre type C : G654, 130µm² effective area, low loss fibre

- Fibre type D: G654, 150µm² effective area, low loss fibre

In order to evaluate fibre compatibility with cabling, microbending sensitivity lab tests are performed. Fibre loss is measured while being wound under tension on a specially designed spool, which has a mesh on the surface of its barrel, and compared to fibre loss when wound at free (near 0) tension on a spool which has a soft barrel surface.

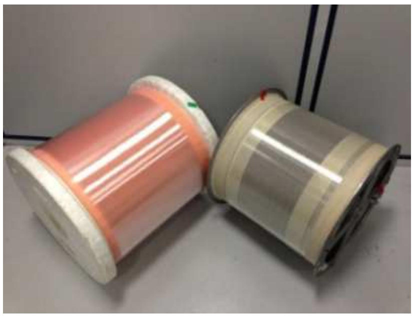
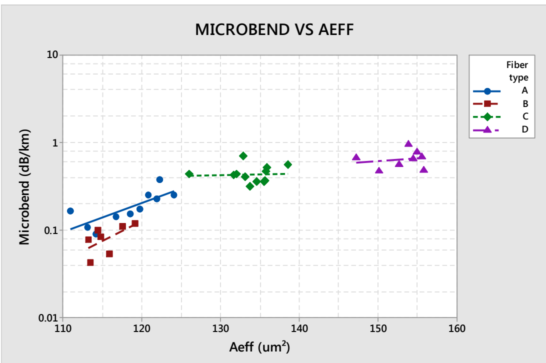


Figure 1: Microbending test spools

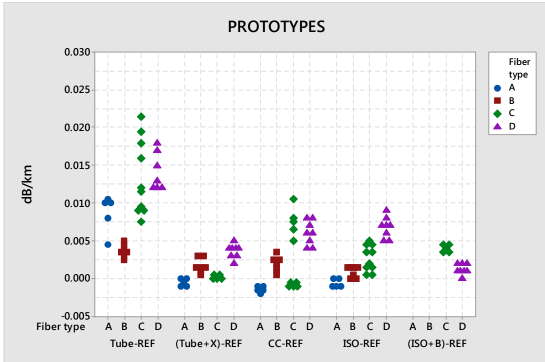
The following graph presents the microbending sensitivity results of CSF fibres with different effective areas, from 110 to 150µm².



Graph 1: Microbend vs. Effective Area

Fibres with 110µm² effective areas (A and B) are less sensitive to microbending than fibres with larger effective areas. A coating change is necessary to contain sensitivity level into acceptable limits for fibres with 150µm² effective areas.

Once cabling compatibility is evaluated through lab tests, cable prototypes are manufactured, enabling us to define more precisely attenuation variation levels of the different fibre types, and associated power budgets. Several OALC-4 cable prototypes, containing 12 fibres, have been manufactured to check the behaviour of the different fibre types inside cables.

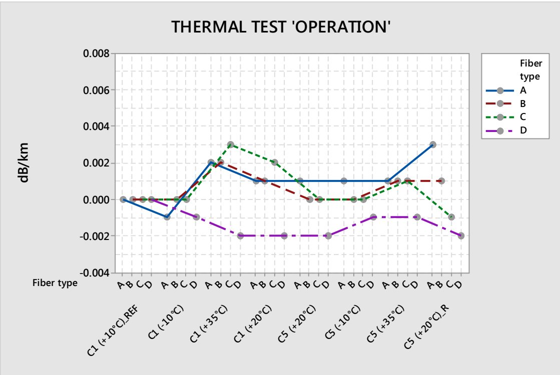


Graph 2: Cabling effect

Depending on their microbending sensitivity and effective areas, attenuation variations during the cabling process (and more especially after tubing) are variable. Nevertheless, all fibre types have attenuation variations below 0.003dB/km (measurement accuracy) at 1550nm at the final manufacturing stage, thus they are all compatible with the cabling process.

Once cabling compatibility is verified, additional qualification tests have to be done to check fibre behaviour in the cable under specific environmental conditions, and to simulate a 25 year lifetime.

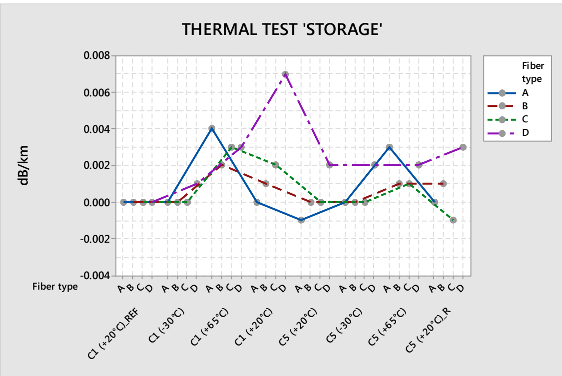
The following graph shows attenuation variations observed on concatenated cabled fibres during thermal cycles simulating a cable in operation.



Graph 3: Thermal cycles - Operation

Attenuation variations remain below test measurement accuracy during the cycles for all types of CSF tested.

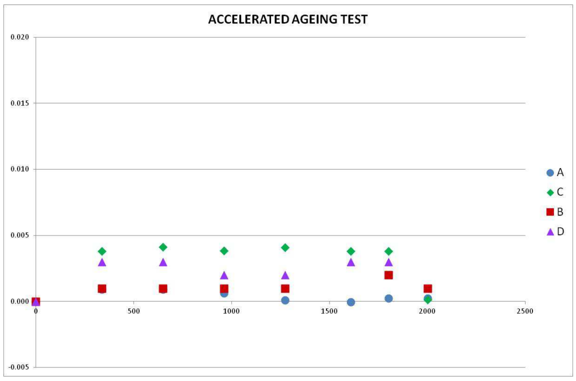
The following graph shows attenuation variations observed on cabled fibre loops after thermal cycles simulating cable storage environment.



Graph 4: Thermal cycles - Storage

Attenuation variations remain below test measurement accuracy after the storage cycles for all types of CSF tested.

In order to guarantee good fibre performances during the system lifetime, an accelerated ageing test is performed, exposing a length of cable to high temperatures in order to accelerate ageing physical phenomena and evaluate attenuation variations the cable life on the sea-bed. The following graph shows attenuation variations measured on different CSF cabled in various prototypes.



Graph 5: Accelerated ageing

Attenuation variations after test, on fibre loops inside the cable are below test measurement accuracy.

One possible solution to limit the microbending sensitivity for very large effective area fibres, is to design a specific coating, offering a better protection of the fibre glass against external microconstraints.

In particular, 150µm² fibres need a high-level protective coating to be compatible with cabling constraints and reach very low attenuation levels inside the cable. This is the case for fibre type D tested in ASN qualification program, fitted with a specially designed coating.

This new fibre coating requires a series of additional qualification tests linked to coating compatibility with some of the cable raw materials.

Corresponding tests conducted on D type fibres are described here below:
Coating compatibility with colouring ink and tube internal filling jelly has been checked, through accelerated ageing tests, mechanical tests after ageing and electronic microscope observations.

Compatibility of a new coating with fibre splice protections (micromolded recoat and heatshrink) has been validated through mechanical tests on splices, microscope observations, thermal test, accelerated ageing with mechanical control after test.

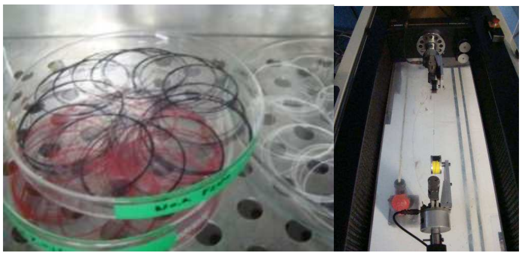


Figure 2: Fibre coating qualification

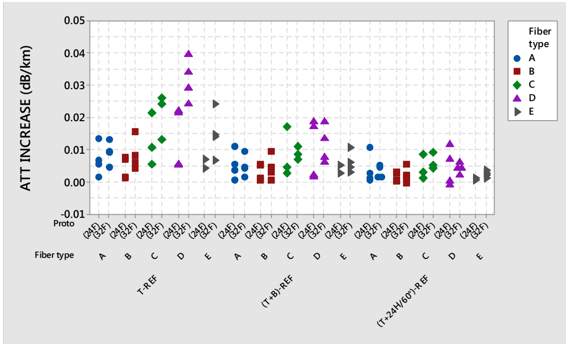
Thanks to this comprehensive testing program, 4 fibre types from 2 different fibre suppliers, including fibres from 110µm² to 150µm², one of them having a specifically designed coating, have been successfully qualified in ASN cables, containing up to 12 fibres.

3. CABLE DESIGN OPTIMIZATION FOR HIGH FIBRE COUNTS

For systems which require more and more capacity, an efficient solution is to increase fibre quantities inside the cable. To investigate this, we reviewed the design of the well-known OALC-4 cable, to increase the maximum fibre quantity, also keeping in mind the objective which is to guarantee very low attenuation variations inside the cable and to minimize OALC-4 cable design changes, in order to optimize cable product cost.

Optical module diameter has been increased, vault structure and vault wires dimensions have been reworked, to enable the housing of up to 32 fibres inside the optical module.

To evaluate the attenuation variations on CSF fibres inside such cable, 2 tube prototypes have been manufactured with the new optical module dimensions, one including 24 fibres, the other one including 32 fibres. Some of the fibres have been ring-marked, so that each fibre can be identified inside the tubes.



Graph 6: Attenuation variations in 24/32 fibres optical modules

Attenuation variations inside both high fibre count optical module are low, especially for fibers without ring markings (+0.005dB/km max).

Ring marked fibres have higher attenuation variations but still limited. Fibres type E are fibres with very high effective area (150 to 160µm²) and new coating developed for these high effective area. Thanks to the efficiency of the new coating, ring markings have no detrimental effect on attenuation of these fibres, for which final attenuation variations in high fibre count optical module is very low.

4. CSF PERFORMANCES IN JOINTS

In order to evaluate the compatibility of fibres with different joint designs (ASN jointing box, ASN extremity box, ASN land joint, Universal Joint, Universal Quick Joint), macrobending sensitivity lab tests have been performed.

Fibre optical loss is measured versus bending radius, applying this radius on half a loop, following the 2-point bending method.

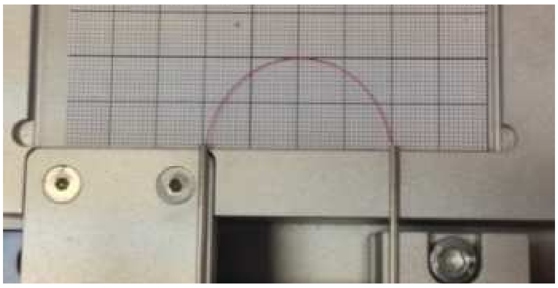
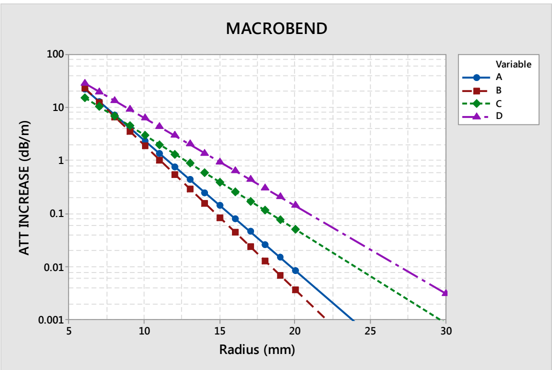


Figure 3: Macrobending measurement

The following graph presents the typical evolution of fibre loss versus applied radius, for the different CSF fibres tested for qualification:



Graph 7: Macrobend sensitivity evaluation

CSF fibres with effective areas around 110µm² (types A and B) have a macrobend sensitivity that is dramatically reduced when radius increases, and that give negligible attenuation variations for radius >18mm.

CSF fibres with higher effective areas (type C, 130µm² and type D, 150µm²) have a macrobend sensitivity that decreases slowly with radius, and attenuation variations remain significant for radius up to around 25mm. This may lead to some attenuation increases once these fibre types are coiled inside joints.

In order to better assess the risk of having a loss inside the jointing equipment, several joint designs have been tested during the qualification of 130/150µm² fibres (type C and D).

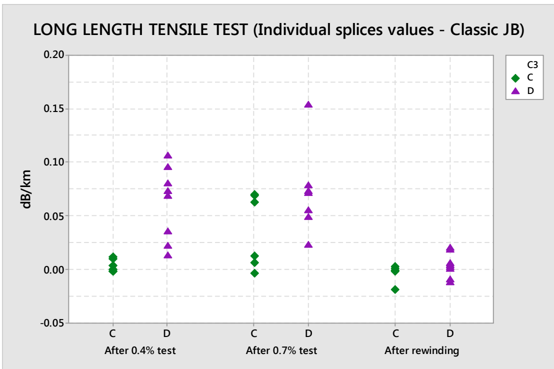
The first ones are the ASN standard jointing box and the extremity box, used to connect ASN cables to themselves (JB) or to ASN submerged equipment (EB).

The integration test in ASN joints gave conforming results for both fibre types C and D. Thanks to the relatively large coiling radius of the fibres in ASN standard joints, no significant loss variation is observed.

Fibres being free to move (no fibre blocking device) in ASN standard joint designs (JB and EB), another test has been done, to check the fibre behaviour when fibre movement occurs inside the joint, e.g. when the cable is submitted to axial strength.

A long length tensile test on optical module with joint in the middle has been performed, including fibre types C (130µm²) and D (150µm²) in the optical module and in the joint.

The following graphs present the results of the long length tensile tests performed.



Graph 8: Long length tensile tests in ASN standard joint with 130µm² and 150µm² fibres

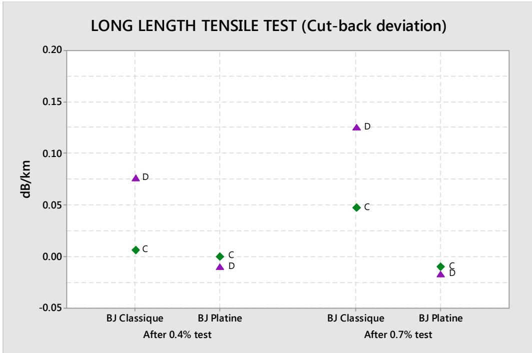
Attenuation variations are observed during the test, especially after the test's second step (tensile up to 0.7% of tube elongation). Fibre uncoiling operation and associated loss decrease confirms the correlation between fibre movement, decrease of fibre bending radius inside the joint, and attenuation variations measured during the test.

Figure 4: Standard ASN joint, long length tensile test

Such tensile test is part of ASN's qualification program for all new fibres, and gives conforming results for all fibres with effective areas up to 110µm². High bending sensitivity of new generation fibres with extra large effective areas necessitates the use of adequate joint design, with fibre tray and fibre blocking devices.

A dedicated ASN joint design adaptation has been developed and qualified, in order to manage 130µm² and 150µm² fibres sensitivity. This design has been applied to both JB and EB. It includes a fibre blocking device, with fibre gluing inside polycarbonate tubes, and fibre tray, maintaining very low bending radius in all situations all along fibre paths in these boxes.

Once the new joint design was finalized, new long length tensile tests have been done on optical module with new joint, including 130µm² (type C) and 150µm² (type D) fibres. The following graph presents associated results.



Graph 9: Long length tensile tests in ASN new joint with 130µm² and 150µm² fibres, compared to results in standard JB

As fibres are blocked during the test, no attenuation variations are observed after each step of the test.

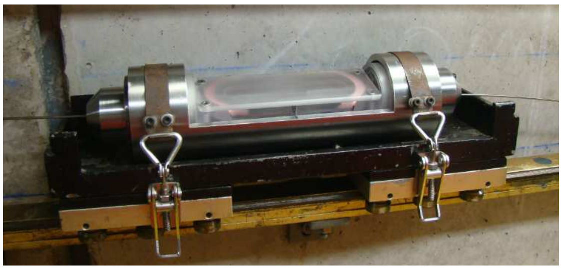


Figure 5: New ASN joint design, long length tensile test

Other joint types are also used on submarine systems: Beach/land joints, and universal joints (UJ or UQJ).

Results of the lab tests demonstrating the high sensitivity of ultra large effective area fibres to bending, it is absolutely necessary to test these fibres inside all the joint types to check their potential loss variations.

UJ and UQJ joints have been assembled with fibre type C (130µm²) and D (150µm²).

The integration test in UJ gave attenuation variations conforming to system design requirements (≤0.05dB). But integration test in UQJ gave much higher loss increases, due to the very compact design of UQJ and low bending radius applied on fibres.

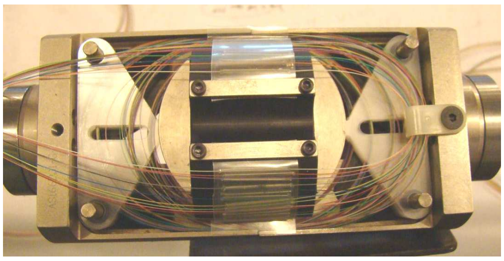


Figure 6: UJ integration test

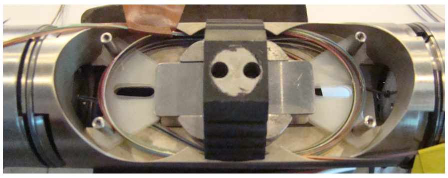


Figure 7: UQJ integration test

The last joint to be tested is the beach/land joint. ASN tested integration of extra large effective area fibres inside ASN land joint. This test demonstrated attenuation variations manageable with system design needs.

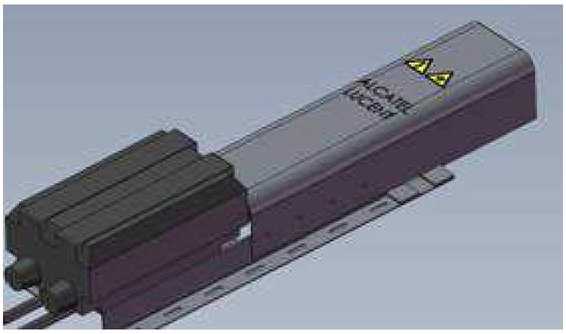


Figure 8: ASN Land Joint

5. CONCLUSION

Thanks to a comprehensive qualification test program, ASN fully characterized the performances of large (110µm²) and ultra large (130 to 150µm²) CSF fibres inside cables up to 32 fibres, and joints (ASN jointing box and extremity box, UJ, UQJ and ASN Land Joint).

Thanks to optimized product designs, attenuation variations have been maintained to very low levels, despite high sensitivity of ultra large effective area fibres. New fibre coatings are also really helpful in limiting fibre sensitivity to microbending.

6. GLOSSARY

CSF: Coherent submarine fibre
+D: High positive chromatic dispersion fibre
OALC: Optically Amplified Line Cable
JB: Jointing Box
EB: Extremity Box
UJ: Universal Joint
UQJ: Universal Quick Joint

7. REFERENCES

[1] ITU-T G.654: Characteristics of Cut-Off Shifted Single-Mode Optical Fibre and Cable