DSMF FIBERS, A COMPARISON OF VARIOUS SOLUTIONS

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Abstract: Ultra long haul, high bit rate WDM transmission systems now require the use of a transmission media that precisely manages not only the chromatic dispersion in itself, but as well its variation across the window of operation i.e. its slope. To address this need a specific type of fiber or couple of fibers has been developed, called Dispersion Slope Matched Fibres (DSMF).

DSMF products from different suppliers have been investigated and compared in their transmission parameters and capability, cabling and splicing performances.

This presentation concludes on the possible applications, performances and advantages of these fibers for ultra long haul, high bit rate systems.

1 INTRODUCTION

For future systems using DSMF fibers in submarine transmission cables, critical parameters are not only chromatic dispersion and effective area, but also fiber attenuation performances in cable, as the new fibers have, for some of them a larger effective area and for the others a larger numerical aperture than NZDSF fibers.

A DSMF path consists in two types of fibers: a D+ fiber type with a positive chromatic dispersion, positive chromatic dispersion slope and a very high effective area, followed (in the optical signal transmission direction) by a D- fiber type with a negative chromatic dispersion, negative chromatic dispersion slope, a low effective area but a large numerical aperture.

	Effective Area at 1550nm	
	Range	**Average**
unit	**µm²**	**µm²**
Fibre A	95 - 109	102
Fibre B	24 -32	28
Fibre C	100-116	112
Fibre D	25 - 31	28
Fibre E	100 - 111	106
Fibre F	28 - 32	30

Table 1: Effective areas of DSMF fibers

Table 1 gives the effective area average values and ranges for the different DSMF fiber types.

Looking at table #1 values, it appears that the DSMF fibers combinations have a higher equivalent effective area than NZDSF spans, offering better performances against non linear effects.

Fibers from different suppliers have been investigated in two ALCATEL-LUCENT cable designs OALC4 and OALC7, through the following testing sequence: laboratory tests on bare fibers, sensitivity test to cabling, environmental tests including long term aging on cable prototypes, splicing tests.

In addition to the cabling aspects, the transmission performances of these DSMF fibers have been compared using a laboratory test bed in order to validate their transmission performances for ultra long haul systems, from a system design and a power budget standpoint.

2 BARE FIBER TESTING

2.1 Microbending

Fiber sensitivity to microbending has a strong impact on fiber attenuation losses in a cable when the fiber is submitted to stress.

We developed a laboratory microbending test that allows to identify fibers with a high microbending sensitivity, in comparison with other fiber types which behavior in our cables is well known through a long time and large volume experience.

This test is performed on long length samples. Low stress is applied on the fibers in order to be representative of what may happen in the cable under severe conditions. By experience, a microbending sensitivity limit has been defined, corresponding to fibers that have proven to be cabled with acceptable attenuation variations under all conditions. A cabling trial is required to confirm this limitation.

Several fibers selected to be representative of the optical parameters (MFD, cut-off) range have been tested. For each, one km of fiber is wound under stable tension on a drum having a well defined mesh on its surface. This test had already been conducted on several fiber types, already successfully deployed in large volumes in our cables. DSMF fiber results have been compared to these known fibers.

The micro bending results showed that the maximum attenuation increase is including between 0.5 and 2.0 dB/km at 1550nm and the average is in the range of 0.2 to 1.5dB/km at 1550nm

Obtained results demonstrate that tested DSMF fibers are as sensitive as and in some cases more sensitive than already qualified NZDSF fibers. For more sensitive fibers, a demonstration of their cable-ability has then to be proven through cabling tests.

2.2 Macro bending

Fiber sensitivity to macro bending may have a strong impact on fiber attenuation losses mainly when fibers are coiled in joint boxes.

Fibers representative of the optical parameters (MFD, cut-off) range have been tested using a coiling test on different diameters, and their attenuation increase monitored at 1550nm. Fiber attenuation increase for a 20mm diameter is deducted from fitted results. This diameter is defined as a reference and allows to identify fibers with high macro bending sensitivity. By experience a limit is applied by ASN beyond which the fiber is considered as very sensitive to macro bending.

The macro bending results showed that the maximum attenuation increase is including between 4 and 50 dB/m at 1550nm and the average is in the range of 2 to 15dB/m at 1550nm

All obtained results have been found equivalent to already qualified NZDSF fibers, proving their suitability with submarine applications in our cable designs.

2.3 Hydrogen sensitivity

Hydrogen is a well known cause of optical fiber loss increases. This loss increase is caused by two additive phenomenon:

- absorption by reacted Hydrogen – Not reversible,
- Interstitial penetration of molecular Hydrogen in the silica core – Reversible.

The test carried out verifies the impact of the non reversible phenomenon and the good reversibility of the second effect.

Long lengths of fibers are placed in a hydrogen environment under a partial pressure of 10,000ppm at 20°C (a higher hydrogen pressure than what in the cabled fiber will see during its lifetime) up to their 1240nm attenuation variation stabilization, corresponding to a partial pressure equilibrium reached between fiber core and environment. Then they are placed in a neutral environment up to their total hydrogen resorption (for the reversible part of the phenomenon – checked via 1240nm attenuation loss evolution). Attenuation variation in the C-band is then checked. DSMF fiber results are then compared to already qualified, well known NZDSF fibers.

Intrinsic protection against hydrogen effects for fibers selected for use in submarine cables must be sufficiently efficient so that it does not create any attenuation increase higher than 0.003 dB/km at 1550nm during cable lifetime.

The tests showed that the attenuation variation results after total hydrogen resorption (no variation at 1240nm) for all samples is less than 0.003dB/km at 1550nm which is within the measurement accuracy order of magnitude.

All obtained results are equivalent to those obtained on well known NZDSF, in full agreement with ASN requirements.

3 TESTS IN CABLE

3.1 Cabling

These fibers have been tested through manufacturing of long length cable prototypes in our two cable designs: an OALC-4 cable up to 12 fibers, and an OALC-7 cable up to 16 fibers, under the same conditions.

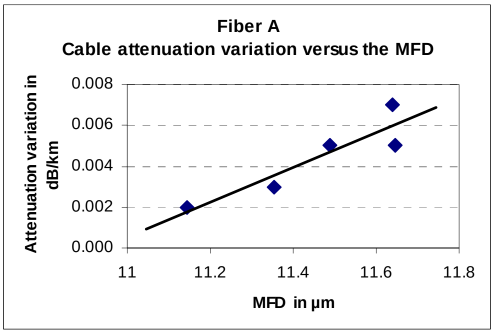
Fibers integrated in cable prototypes have been chosen so that to be representative of the optical parameters ranges, more particularly regarding MFD and cut-off wavelength.

Attenuation and PMD variations have been checked all along the cable manufacturing process up to insulation stage (light weight cable). Optical variations at this step are considered as references for the fiber qualification process. Results are compared to measurements performed on bare fibers before cable manufacturing.

Chromatic dispersion is not monitored, as this parameter is not impacted by cabling process.

The average attenuation increase and the average PMD variation compared to the measurement before cabling are less than 0.004dB/km at 1550nm for attenuation and less than 0.02ps/√km at 1550nm for the PMD at the end of the cabling process for all the fibers and the both cable types. No noticeable difference between fiber types have been detected, within the measurement accuracy order of magnitude.

One of the fiber main critical parameters impacting the attenuation is its mode field diameter. Graph #1 shows typical attenuation variations as a function of the fiber MFD.



Graph #1: attenuation variation versus fiber MFD

Cabling results demonstrated the cable-ability of DSMF fibers, without any noticeable degradation of the system optical parameters.

3.2 Ageing

Long lengths of insulated cable prototypes containing these various fiber types have been submitted to an accelerated ageing test designed to be equivalent to 25 years at 3°C. Attenuation variations on the C-band have been monitored all along the test.

The average attenuation increase compared to the measurement before ageing test is less than 0.003dB/km at 1550nm at the end of the test for all the tested fibers and for both cable types. No noticeable difference between fiber types have been detected, within the order of the magnitude of accuracy. No noticeable peak increasing at 1240nm has been detected during the test.

No attenuation variation higher than measurement accuracy (0.003 dB/km) has been measured on any of the tested cables.

3.3 Thermal cycling

More than 9 km of OALC4 prototype cable and more than 7km of OALC7 prototype cable lengths of have been submitted to a thermal cycling test between -30°C and +65°C to simulate the storage and laying temperature variation effects. The temperature range for the storage test was between -30°C and +65°C and for laying between 3°C to 35°C. Attenuation variations have been monitored all along the test.

Table 2 gives thermal cycling test results obtained on DSMF fiber prototypes.

	Thermal Cycling Results			
	OALC-4		**OALC-7**	
	Max attenuation variation between 3-35°C	**Attenuation variation at the end of the test between -30 and 65°C**	**Max attenuation variation between 3-35°C**	**Attenuation variation at the end of the test between -30 and 65°C**
	1550nm	**1550nm**	**1550nm**	**1550nm**
units	**dB/km**	**dB/km**	**dB/km**	**dB/km**
Fibre A	-0.001 to 0.000	0.001	$	$
Fibre B	-0.003 to 0.000	0.001	$	$
Fibre C	-0.004 to -0.002	-0.002	0.001 to 0.003	-0.001
Fibre D	-0.002 to +0.002	-0.001	+/-0.003	+0.002

$: test not necessary

Table 2: DSMF fibers thermal cycling results

3.4 Laying effect:

The attenuation variations at 1550nm monitored during the test for all temperature steps are within the measurement accuracy order of magnitude for both OALC4 and OALC7 cable types, when compared to the values before the test at 20°C. No noticeable difference between fiber types has been detected

3.5 Storage effect:

The attenuation variations at 1550nm before and after test at 20°C are within the measurement accuracy order of magnitude for both OALC4 and OALC7 cable types. No noticeable difference between fiber types has been detected

3.6 Long length tensile tests

Long length (550 m) of OALC optical core (stainless steel tube) containing DSMF fibers has been submitted to a tensile test up to a load causing an elongation corresponding to cable elongation at NTTS, in order to check the fiber behavior in the most severe laying / recovery conditions the cable can encounter during its lifetime. Attenuation, PMD and chromatic dispersion were measured and compared before and after test. This test is conducted as a complement to the cable mechanical tests, conducted over lengths of cable too short (typically 30 to 50m) to allow high precision measurement of optical parameters variations.

Table 3 describes the DSMF prototype long length tensile tests results.

Unit: dB	**DSMF Type A**	**Bridge Fiber**	**DSMF Type B**	**Repeater Fiber**
DSMF Type A	0.02	0.1	0.3*	0.1
Bridge Fiber		#	0.1	0.15
DSMF Type B			0.05	0.3*
Repeater Fiber				#

*: These splices are not direct, i.e. there is a bridge between the two fibers

#: Not applicable for DSMF systems

Table 3: DSMF fibers long length tensile test results

No noticeable permanent attenuation at 1550nm, any CD variation and any PMD variation within the order of the magnitude of the measurement accuracy were detected after complete relaxation of the load for all fiber types in the both cable type OALC4 and OALC7.

4 SPLICING INVESTIGATIONS

Several splicing techniques have been evaluated to investigate how the impact of the large mismatch between D+ and D- fibers could be minimized with regard to the splice loss. Among them, the arc fusion splicing has been found to be the most industrial one, that also gives acceptable both mechanical performances and optical losses.

We concluded as well from this evaluation that the use of a bridge for the splice between the large core fiber of the DSMF and the small core one was offering the best compromise in terms of industrial tool and attenuation/strength. The bridge fiber is a fiber with an intermediate effective area between the DSMF D+ and D- fibers.

Qualification tests have been performed for matching fiber splices made before cabling, and for fiber splices made during cable jointing as part of SAT operations.

Unit: N	**DSMF Type A**	**Bridge Fiber**	**DSMF Type B**	**Repeater Fiber**
DSMF Type A	31 (32)	34 (30)	#	(18)
Bridge Fiber		#	32 (32)	(31)
DSMF Type B			34 (32)	(32) and (31)
Repeater Fiber				#

#: Not applicable for DSMF systems

First value: for matching and tube repair splices - Second one ( ): for cable jointing splices

Table 4: Typical splice values at 1550 nm obtained during type A and type B splicing qualification program

Table 4 describes as an example the splice typical losses found for DSMF type A and type B splice combinations.

Table 5 describes the splice typical mechanical strength found for these DSMF type A and type B splice combinations.

Unit: N	**DSMF Type A**	**Bridge Fiber**	**DSMF Type B**	**Repeater Fiber**
DSMF Type A	31 (32)	34 (30)	#	(18)
Bridge Fiber		#	32 (32)	(31)
DSMF Type B			34 (32)	(32) and (31)
Repeater Fiber				#

#: Not applicable for DSMF systems

First value: for matching and tube repair splices - Second one ( ): for cable jointing splices

Table5: Typical splice mechanical strength obtained during type A and type B splicing qualification program

Obtained mechanical results are compatible with constraints applied to splices in our cables and joints.

5 TRANSMISSION TESTS

Recent years have been characterised by the capacity increase request and therefore the improvement of fibre maps, replacing NZDSF fibres by new fibres called +D and –D, the combination of both being named DSMF. Such fibres have been tested and adopted in laboratory during the last six years to achieve very high capacity systems (> 3 Tbit/s) over transoceanic distances (> 6500 km) [1] & [2] with NRZ modulation format.

Today, these fibres, combined with Differential Phase Shift Keying (DPSK) modulation format, are also of interest for Terabit/s systems over transpacific distances. Recent experiments were performed with the +D/-D fibres from the three suppliers (A, B, C, D, E and F fibre types) in laboratory on a re-circulating loop to evaluate the performance over more than 12000 km transmission length.

The results demonstrate that the six +D/-D fibres are well adapted for such an application with industrial performance margins compared to the Q limit before correction with Forward Error Correction (FEC) and could be installed on real deployed systems.

As an example, experiments have been carried out with 75 km +D/-D span length from two different suppliers over 12400 km transmission with 124 wavelengths operating at 10 Gbit/s [3]. The measured performance margin is almost wavelength independent thanks to the very low CD slope and therefore very low cumulated CD difference between extreme channels. More than 3 dB industrial margins compared to the FEC limit is recorded for the 124 channels, which is compatible with a transpacific system from a power budget standpoint.

Therefore the feasibility of the Terabit/s capacity over 12000 km transmission length has been demonstrated with the +D/-D fibre types from three different suppliers.

6 CONCLUSION

The overall tested DSMF fibres fully meet the requirements for use in our cables on ultra long haul, high bit rate systems and could be deployed from now on. Tests have been performed to cover the worst case conditions fibres can encounter in cable during its life time.

These +D/-D fibre solutions offer the possibility to increase the repeater spacing and the transmitted capacity on long haul distances [4] & [5]. Typically, the transmission of 1 Tbit/s over transatlantic distances could be implemented with 80 km span length and +D/-D fibres combined with DPSK modulation format, compared to 50 km span length with NZDSF fibres and RZ modulation. The benefit brought by +D/-D fibres compared to NZDSF fibres is about half of the total benefit brought by both the fibre types and the modulation format (typically,15 km span length increase is obtained between +D/-D and NZDSF fibres over 6500 km length).

Finally, systems up to 12000 km long and up to 126 channels operating at 10 Gbit/s could be implemented with such fibres.

7 REFERENCES

[1] 3.65 Tbits (365 x 11.6 Gbit/s) transmission experiment over 6850 km using 22.2 GHz channel spacing in NRZ format – G. Vareille et al.- ECOC'01.

[2] 3 Tbit/s (300 x 11.6 Gbit/s) transmission over 7380 km using C+L band with 25 GHz channel spacing and NRZ format – G. Vareille et al.– OFC'01.

[3] 124 x 10 Gbit/s RZ-DPSK transmission over 12380 km without channelized chromatic dispersion management – Laurent Du Mouza et al.– OFC'07.

[4] 8370 km with 22 dB spans ULH transmission of 185 x 10.709 Gbit/s RZ-DPSK channels – G. Vareille et al., OFC'03.

[5] Multi terabit per second transoceanic systems – G. Vareille – ECOC'02.

8 GLOSSARY

ASN: Alcatel Submarine Networks

WDM: Wavelength-Division Multiplexing

DSMF: Dispersion Shifted Matched Fibers

NZDSF: Non Zero Dispersion Shifted Fiber

OALC: Optically Amplified Line Cable

PMD: Polarization Mode Dispersion

MFD: Mode Field Diameter

NTTS: Nominal Transient Tensile Strength - maximum tension that can be applied to the cable during a cumulative period of one hour, without significant reduction of NPTS/NOTS

NOTS: Nominal Operating Tensile Strength: maximum tension that can be applied to the cable during the time necessary to make cable joints, without significant reduction of NPTS

NPTS: Nominal Permanent Tensile Strength: maximum tension that the cable can withstand during the system lifetime without any impairment of fibers nor degradation of the overall cable performance