Development of transmission fibre for Long-haul High-capacity Transmission

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Abstract

We review recent developments in the area of Dispersion Management of optical fiber transmission Lines (DMLs) and speculate as to future opportunities exploiting holey fiber technology.

1. Introduction

The optical characteristics of transmission fibre ultimately define the performance limits of long-haul high-capacity transmission systems. The limitations imposed by established fiber types such as SMF and DSF (as shown in Fig.1) have been overcome by the development of new fiber types to provide a new generation of dispersion managed lines (DMLs) capable of ever higher bandwidth operation.

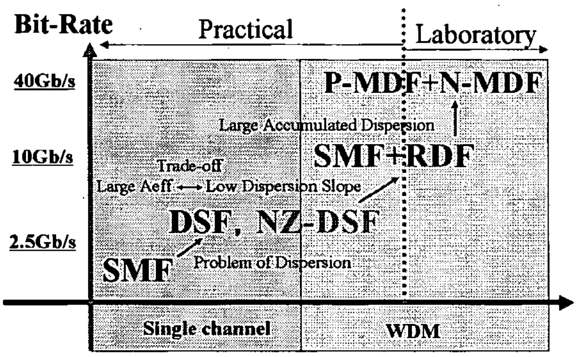

Fig.1 The flow of submarine transmission fibre development

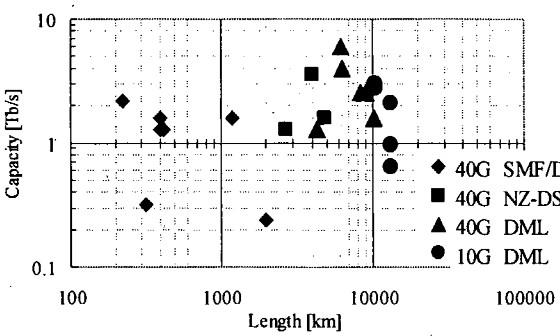

Fig.2 Transmission experimental results

Of these the use of 1.31-zero single mode fiber (SMF) plus reverse/inverse dispersion fiber (RDF/IDF) or Medial Dispersion Fibre (MDF) are of particular note leading to a range of new records for long haul transmission as summarized in terms of aggregate capacity in Fig. 2. We review the state of the art in terms of RDF and MDF fabrication in the following sections.

2. State-of-the-art SMF+RDF fiber fabrication

The first DML demonstrated comprised SMF with Aeff of 80μm^2 and attenuation of 0.19dB/km and RDF designed to have the opposite dispersion characteristics to SMF but with an Aeff of 24μm^2 and an attenuation of 0.24dB/km [1]. Further developments of these two fiber types have led to significant improvements as summarized in Tables1 & 2.

Table.1 Characteristics of various high performance SMFs @1550nm produced at Furukawa

No.		01	02	03
Attenuation	dB/km	0.185	0.169	0.173
Dispersion	ps/nm/km	20.0	19.5	21.9
Slope	ps/nm^2/km	0.060	0.064	0.058
Aeff	μm^2	107	104	153
Bend Loss	dB/m(20φ)	5.0	5.0	5.0
PMD	ps/rkm	0.04	0.04	0.07

Table.2 Characteristics of various high performance RDFs @1550nm produced at Furukawa

Reference		01	02	03
Attenuation	dB/km	0.235	0.255	0.205
Dispersion	ps/nm/km	-45.0	-60.0	-22.0
Slope	ps/nm^2/km	-0.150	-0.228	-0.077
DPS	nm	300	263	286
Aeff	μm^2	31.0	23.0	34.0
Bend Loss	dB/m(20φ)	10.0	3.0	0.6
PMD	ps/rkm	0.05	0.04	0.05

DMLs consisting of SMF plus RDF show very good optical properties. As an example combinations of the above fiber types can be used to design the two 50km DML spans shown in table 3. Both combinations show very flat dispersion, low nett-attenuations and an average Aeff larger than 70μm². Even lower nett-losses and Aeffs can be obtained by using other variants of SMF.

Table.3 Total characteristics of SMF+RDF@1550nm

	A. Disp	Slope	Aeff(*)	Loss
	ps/nm	$ps/nm^2/km$	μm^2	dB/km
+RDF01	650	0.00	79	0.203
+RDF03	520	0.00	72	0.197

*) Equivalent Aeff calculated by fiber NL and power density

3. The development of Medial Dispersion Fiber (MDF)

As previously mentioned DMLs consisting of SMF+RDF show very good performance in terms of overall nett-fiber properties. However the maximum accumulated dispersion along the span is too large to realize 40Gb/s transmission [2]. To suppress the maximum accumulated dispersion MDF has been developed [3-5]. The typical optical properties of initial MDFs produced at Furukawa are shown in table 4 [3].

Table.4 Characteristics of typical MDF@1550nm

		P-MDF	N-MDF
Attenuation	dB/km	0.195	0.225
Dispersion	ps/nm/km	13.0	-13.0
Slope	$ps/nm^2/km$	0.070	-0.070
Aeff	μm^2	95	32
Bend Loss	dB/m(20ϕ)	10.0	5.0
PMD	ps/rkm	0.05	0.06

Both P-MDF and N-MDF have smaller local dispersion than both SMF and RDF, so the maximum accumulated dispersion in a 50km span is reduced about 320ps/nm. The major current goal of R&D in MDF is to obtain larger Aeff whilst keeping the small dispersion. P-MDF with a ring profile and new N-MDFs including MM Designs and SM Transmission N-MDF (N-MDF MDST) have been proposed [4,5] as shown in Table5.

Table.5 Characteristics of new types of MDF@1550nm

Reference		P 01	P 02	N 01
Attenuation	dB/km	0.237	0.210	0.220
Dispersion	ps/nm/km	10.2	13.5	-10.0
Slope	$ps/nm^2/km$	0.071	0.068	-0.030
Aeff	μm^2	146	125	54
Bend Loss	dB/m(20ϕ)	3.0	6.0	2.0
PMD	ps/rkm	0.06	0.05	0.10

The development of these MDFs is still in the research phase and some problems such as the relatively high attenuation loss, influence of HOMs, and optimization of the dispersion properties remain to be fully solved however such fibers appear to be very attractive for use in long haul systems. The N-MDF MDST in particular has the potential to break the conventional N-MDF limitations (maximum Aeff of 40μm² [4]), and to realize new optical properties.

4. Conclusion and future directions

Various types of dispersion management schemes and associated fibers have been realized for use in future long haul systems. SMF/ RDF lines have already installed into real submarine systems and the installation of MDF lines is expected in the relatively near term future. These new fibers are also ultimately likely to find application in terrestrial system as for previous fibers improved for submarine applications such as SMF and NZ-DSF. P-MDF seems the most suitable candidate however some modification to the current P-MDF design in likely to be required to make it adaptable with terrestrial systems.

It is interesting to speculate as to what the future holds for the development of new transmission fibers. Clearly improvements in existing fiber types and concepts remain to be made using conventional fabrication approaches. However, the design possibilities provided by microstructured holey and photonic band-gap fibres mean that these new fiber type could emerge as one of the biggest candidates for next generation submarine (or terrestrial) transmission fiber development. These fiber types have the potential to offer radical improvements in fiber properties including: reduced losses, increased mode areas and increased operational bandwidths. For example, Fig.3 shows the relationship between the key parameters for PCF, namely hole pitch (Λ) and hole diameter divided by Λ (d/Λ) vs. Aeff. The limits due to bend loss and endlessly single mode guidance are also shown in the Fig.3. As can be seen SMF designs offering large Aeff are possible which offer single mode guidance over a far broader wavelength range than is possible within conventional SMF providing possible opportunities for ultra wide-bandwidth transmission. It is however to be appreciated that many fabrication/practical challenges will need to be addressed if such technology is ever to achieve real world deployment.

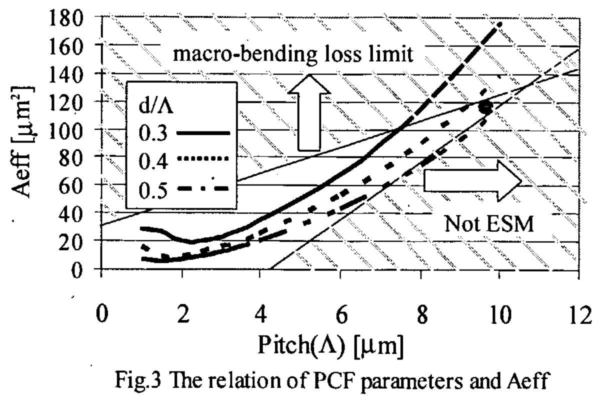

Fig.3 The relation of PCF parameters and Aeff

5. Reference

[1] K.Mukasa et al., Proceeding of ECOC'97, MO3C-27
[2] H.Sugahara et al., Post-deadline paper of OFC2002, FC6
[3] K.Mukasa et al., Proceeding of OECC'01, THA3
[4] K.Mukasa et al., Proceeding of ECOC'02, 5.1.2
[5] K.Mukasa et al., Proceeding of ECOC'04, We3.3.3