Advanced Fibers for Submarine and Long-Haul Applications

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Abstract: We discuss the development of advanced fibers for submarine and terrestrial long-haul applications and current trends in transmission technologies that will influence next generation fibers.

Advanced fiber development is strongly influenced by technological and economical environment of the telecommunications industry. At the end of the nineties, explosive growth of the Internet led to the requirements of >1 Tb/s capacity per fiber in the long-haul (LH) and submarine transmission systems. In addition, unique connection length pattern of the Internet traffic stimulated reach increase for the terrestrial LH systems [1]. Over the same period, a number of technological advances focused on the increase of system capacity were taking place. Use of dual bands (C and L) of Erbium doped fiber amplifier (EDFA) or Erbium bandwidth extension with Raman amplification made the entire low loss band from 1530 nm to 1620 nm usable for transmission [2]. Raman assisted transmission improves system margin up to 7 dB [3]. Finally, 10 Gb/s has become a default rate and a 40 Gb/s development starts.

In this environment, non-zero dispersion shifted fiber (NZDSF) developed in the mid-nineties became increasingly popular relative to standard single mode fiber due to lower local dispersion that requires less dispersion compensation. Further fiber optimization to extend reach and maximize capacity required precise broadband dispersion compensation, low nonlinearity and low accumulated dispersion led to the concept of dispersion managed fiber (DMF) – concatenation of two fibers types in a single span. DMF has different configurations for submarine and terrestrial applications (Fig. 1a and 1 b) due to the differences in the amplifiers employed in these systems. Submarine systems use highly efficient EDFAs due to electrical power constraints. Large effective area (A_{eff}>100 μm^2) positive dispersion fiber (D≈18 ps/nm-km) is at the beginning of the span (Fig. 1a) in order to minimize nonlinear effects. Dispersion slope compensating fiber (DSCF) is placed at the end of the span where signal power is low. DMF has proven to be a mature technology and 0.96 Tb/s trans-Pacific transmission has been demonstrated over installed cable [4].

DMF for terrestrial applications is optimized for Raman amplification with DSCF placed in the middle of the span (Fig. 1b). This configuration improves Raman NF while minimizing nonlinearity and double Raleigh backscattering crosstalk [5]. Terrestrial DMF must be capable of supporting 40 Gb/s transmission and be compatible with various amplification schemes, thus precise dispersion compensation is required in the entire C+L bands. Since terrestrial cable will undergo seasonal variations in temperature, very low DMF's dispersion sensitivity to temperature [6] is a useful feature that reduces the need for dynamic dispersion compensation at 40 Gb/s. A DMF field trial experiment [7] confirms that a high precision dispersion map can be achieved in industrial production and installation, and 40x40 Gb/s transmission over 2160 km was demonstrated. A review of hero transmission experiments reported in the literature shows that DMF enables higher capacity distance product than any NZDSF (Fig. 1 c).

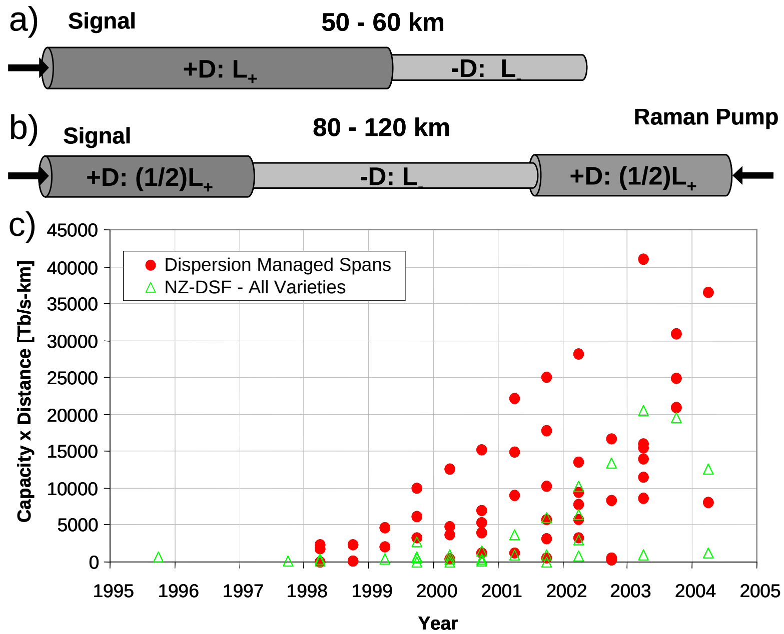

Figure 1. Configurations for submarine (a) and terrestrial DMF (b) and capacity reach product for DMF and other NZDSFs including medium dispersion fiber reported in OFC and ECOC hero experiments (c).

The current technology trends present an interesting change in assumptions for advanced fiber design. The main theme is the sophistication of transmitter and receiver to achieve higher performance of the transmission link. For instance, progress in modulation formats, especially the development of Differential Phase Shift Keying (DPSK), enables better receiver sensitivity and better tolerance to fiber nonlinearities [8]. Progress in forward error correction brings its performance within 1 dB of the Shannon limit [9]. Steady development of the signal processing at the receiver promises to compensate for accumulated chromatic dispersion and PMD [10]. Next generation advanced fibers will have to take advantage of these trends by using vast experience in fiber design and advancements in fiber manufacturing technology to deliver superior performance and financial attractiveness to the network operators.

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