

Long-distance vision

Ian Davis explains how ultra-low loss and large effective area designs for optical fibre can enhance the operation of long-haul optical transmission in modern optical networks

Often attention is focused on the penetration of fibre closer to the subscriber; however, it is important to not lose sight of how the global demand for data-rich applications also impacts further upstream in the long-haul section of the network. Links between cities must support the ever-increasing volume of data traffic to ensure that transmission bottlenecks do not occur.

Increases in per-channel data rates up to 400G are grabbing headlines and fibre makers must continue to innovate to allow such speeds to be installed efficiently.

An aversion to dispersion

In the late 1990s, optical fibre makers developed a new design of optical fibre in response to the emergence of dense wave division multiplexing (DWDM) in the C-band from 1530 to 1565nm. With network reach extended by the use of erbium-doped fibre amplifiers (EDFAs), advantage could be derived by shifting the zero-dispersion wavelength of the fibre from 1310nm to just outside the C-band. With chromatic dispersion around 1550nm reduced by around 75 per cent from that of standard ITU-T G.652 singlemode fibre, this design allowed long-haul networks to operate with a much reduced need for dispersion-compensating modules (DCMs) at amplifier stations, serving both to lower the total network cost and to extend reach. This new class of non-zero dispersion shifted (NZDS) fibres was standardised by ITU-T G.655 and dominated the vigorous market for long-haul deployments in Europe and North America around the turn of the century.

In recent years, advances in long-haul transponder technology have seen channel speeds increase far beyond 10G, such that 100G operation in the long haul is now widespread and 200G operation is becoming increasingly common. New modulation formats have been developed for transmission at 100G and above, such as PM-QPSK and PM-16QAM. These formats use polarisation



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● In challenging terrain, building and powering remote amplifier or repeater sites can be expensive. An installation in the Amazon included 13 spans longer than 100km and five spans longer than 200km

What does become more critical is the optical signal-to-noise ratio

and phase – and in the case of PM-16QAM also amplitude – to encode bits of data in a more spectrally efficient manner. The adoption of such modulation formats is enabled through coherent detection. Using coherent detection and subsequent digital system processing, dispersion compensation of the signal can be performed electronically at the receiver rather than optically using in-line modules, greatly reducing the benefits conferred by the low dispersion of NZDS fibres.

What does become more critical, however, is the optical signal-to-noise ratio (OSNR). Since QAM-based modulation formats use multi-level amplitudes in the signal to convey more bits per symbol, attenuation or deterioration in the signal power levels can adversely impact system performance. For error-free decoding of the

complex signal at the receiver, noise accumulation must not be allowed to approach the received signal strength. This requirement can result in severely limited reach for operation exceeding 100G.

Optical fibre design can assist in mitigating this limitation. Selecting a fibre with lower attenuation ensures that the signal power remains stronger for longer distances, thus enhancing the OSNR. Two classes of lower attenuation fibre are available for network operators to consider. Low-loss fibre delivers attenuation to 0.18 dB/km at 1550nm (compared to above 0.20 dB/km for conventional G.652.D singlemode fibre).

For the most demanding installations, an ultra-low-loss fibre featuring attenuation to 0.16 dB/km at 1550nm should be considered. Through use of high-purity silica core designs, ultra-low-loss fibre not only delivers the lowest possible attenuation, it also features a lower refractive index than a conventionally doped silica-core fibre to provide a modest improvement in signal latency. Over a 100km span, ultra-low-loss fibre can provide around 4dB of OSNR advantage over conventional G.652.D singlemode fibre.

Experiments featuring the use of ultra-low-loss singlemode fibre have demonstrated the advantages of the new fibre types. In a laboratory experiment, Corning collaborated with Cisco to demonstrate how much additional reach can be achieved in a multi-span link through the use of ultra-low loss fibre complying to ITU-T G.652 with conventional EDFA amplification only. Error-free operation over 24 spans of 125km was achieved for a total reach of 3,000km. This represented an improvement of around 35 per cent compared to operation with conventional singlemode fibre.

Since then, a live demonstration at OFC 2014 showed just how far a span can be extended when using all the benefits of low attenuation and various advanced amplification techniques. Corning and Xtera combined ultra-low-loss optical fibre with transmission equipment featuring forward and reverse Raman amplification as well as dual remote optically pumped amplification (ROPA) modules, to achieve error-free 100G transmission over a single 500km span.

According to research by CRU, some 90 per cent of new long-haul routes are being built outside North American and Europe with regions such as China, India, Middle East and Africa being some of the largest. Many of these new deployments are being built through hostile environments such as desert, tropical rain forest, mountains, etc. Placing amplification in these areas, probably not well served by either the transport network or electricity grids, adds considerable expense to build, power, secure and maintain the sites. The increased reach enabled by ultra-low-loss fibre can provide the network designer with flexibility to minimise the number of sites located in such hostile territory.

Long-haul in 2015 – a mixed environment

While 100G+ transponders are taking an increasingly large share of the market, 10G devices still account for around half of sales revenues, a level that is expected to be broadly maintained, according to market research by IHS Infonetics.

Where 10G is still used, dispersion remains a limiting attribute and DCMs are still required to extend reach. NZDS fibre continues to be an attractive option in this case. Hybrid cables, part filled with ITU-T G.655 fibre and part with ITU-T G.652.D fibre, are a good solution to address different traffic requirements on a route.

For example, local traffic between nearby cities can be run at 10G over NZDS fibre while express traffic running at 100G can be directed over low-loss standard singlemode fibre. An interesting example of such a hybrid cable solution is provided by the Fibreco Telecommunications network which links together the major cities of South Africa. The network, which stretches over a total distance of 12,000km, includes a 2,000-km link between Johannesburg and Cape Town connecting Bloemfontein, East London and Port Elizabeth.

It should also be noted that low loss and low dispersion are not mutually exclusive properties. Although the attenuation of these products is generally slightly higher than their ITU-T G.652.D counterparts, NZDS fibre specified at ≤ 0.19 dB/km at 1550nm is commercially available.

Beyond low loss – larger effective area

Further improvements in OSNR are possible if operators are prepared to look beyond the established ITU-T G.652 and G.655 standards. Increasing the effective area of the fibre, which is essentially the light-carrying core of the glass, is an approach that allows higher optical power to be launched without introducing reach limiting, non-linear signal distortions.

If the effective area of an ultra-low-loss singlemode fibre is allowed to increase, further OSNR advantage is achievable compared to standard singlemode fibre. A fibre that has been used extensively in submarine networks features ultra-low-loss and a nominal effective area of $112\mu\text{m}^2$ and complies with the less familiar (to terrestrial operators at least) ITU-T G.654.B standard.

At the recent OFC 2015 event in Los Angeles, California, Corning and Xtera held a live demonstration showing how 100G single-span reach could be extended to over 600km using this fibre type with a combination of advanced amplification techniques. The larger effective area of this fibre delivers around 1.5dB OSNR advantage compared with an ultra-low-loss fibre whose effective area is constrained by the G.652 standard.

Compression and the bends

In determining which larger effective area fibres are suitable for operation in terrestrial long-haul networks, attention must be given to the increased bend sensitivity of such products. Fibres with larger cores tend to carry a higher proportion of light around the core-cladding interface where it is more susceptible to loss if the axis of the core deviates

Low loss and low dispersion are not mutually exclusive properties

from a straight line. The construction of terrestrial cables typically provide a more constrained, tightly-packed environment for the fibre than the submarine cables for which larger effective area fibres were originally developed. This can result in increased loss due to microbending, which could potentially negate the OSNR advantage provided by the large effective area.

The suitability of a $112\mu\text{m}^2$ effective area fibre in a terrestrial cable has been recently demonstrated. Fibres for submarine cables are now available with effective area above $145\mu\text{m}^2$ as reported in a post-deadline paper at OFC 2015. Further study is required to establish where the limits exist to ensure the suitability of such fibre for terrestrial applications as well.

In conclusion, a mix of different types of fibre are relevant and available to deploy in long and ultra-long haul optical systems. NZDS fibre remains advantaged where direct detection systems are deployed and may be suitable as part of a hybrid cable design. Low-loss and ultra-low-loss fibres are optimised to support higher data rate protocols that rely on coherent detection. Further advantage may be delivered by ultra-low-loss fibre with a larger core, but first the compatibility and reliability of these fibres in terrestrial cable designs and applications needs to be demonstrated.

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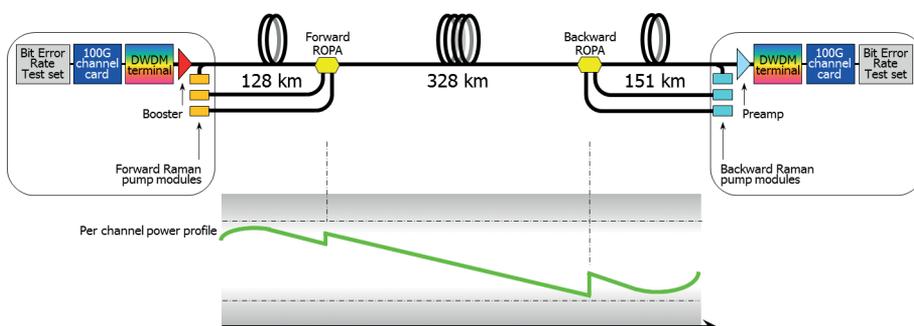


Figure 1. Corning and Xtera demonstrated 100G transmission over a distance of 607km at OFC 2015