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White Paper

Optical Fiber Optimized for Long Haul Transmission at 400 Gb/s and Beyond

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Abstract

Long Haul transmission systems operating at 400 Gb/s data rates will move from the lab to the field in the next few years to meet bandwidth demand that is increasing by 40% or more annually. The details of these systems are still being finalized but one concern is evident: network operators are nearing the capacity limit of standard single-mode fiber and will likely need to consider new types of optical fiber to support cost effective solutions at higher data rates. New optical fiber designs have been suggested to improve 400 Gb/s and higher speed system performance. In this paper the options are compared and it is shown why optimum large effective area G.654 fibers, such as OFS TeraWave^{TM} Fiber, will likely play an important role in the modern long haul network.

Introduction

The past five years have seen explosive growth in broadband connections around the world. Further, these connections require more bandwidth to support content such as streaming video and video file transfers. A large portion of the traffic on the access network requires information to be retrieved from or uploaded to data centers around the world. The net result is that the traffic on the long haul network is growing as well. This annual bandwidth demand has been estimated to be growing at rates anywhere from 40% to 100%[i] annually. Growing capacity to meet this demand has traditionally been supported by either adding DWDM wavelengths to an existing optical fiber link or increasing the transmission speed of existing wavelengths by using more complex modulation formats.

One challenge in the not-so-distant future is the limit of how much information can be transmitted on a standard single-mode optical fiber. Once this limit is reached, the only way to continue growing capacity is to add more optical fibers to the given link. As a result it is likely that installing new fiber plant will be required in the foreseeable future. This raises an important question: what kind of fiber should be deployed to support today’s data rates of 100 Gb/s, and future data rates beyond 100 Gb/s? Understanding the trends in electronics, data rates, modulation formats, and the capabilities of available fiber types is essential to help service providers make this important choice.

Bandwidth Growth

Globally, data rates are estimated to be growing about 40% per year and some carriers have seen growth rates at 100% annually. Even with compression, emerging super high definition 4K video will require three times the data rates of current 2K (1080P) video. The next step is 8K video, which will again increase data rates by three times[ii]. With the trend toward higher definition and higher data rate video, along with increasing use of video based communications and applications, there is reason to believe a 40% growth rate in data rates will continue for the foreseeable future. That works out to the amount of data being transported increasing at least ten times every seven years. If one looks at the impact of this growth on optical networks, that means that if we are running 50 channels at 10 Gb/s today for a given route, we can assume that that same route will need 50 channels at 100 Gb/s in less than seven years and 50 channels at 1 Tb/s in less than 14 years to support the growth rate. Looking out 14 years may seem so far into the future that it hardly seems worth the worry, but because it is expensive to deploy new optical cables, service providers typically assume a 20 year lifetime for new optical plant. If the fiber deployed today is not ready for the future, significant added costs could be required to keep pace with bandwidth demand.

Challenges with 400 Gb/s and Beyond:

Future transmission at 400 Gb/s and beyond will employ higher-order modulation formats such as polarization-division multiplexed (PDM) 16-QAM and coherent digital detection. In such systems, the chromatic dispersion and PMD can be digitally compensated in the electrical domain. However, these systems are susceptible to fiber nonlinear limits. In addition, these 400 Gb/s and beyond systems require much higher optical signal to noise ratio (OSNR). It is believed that about 10 dB improvement in the OSNR will likely be needed for 400 Gb/s systems to have comparable performance to 100 Gb/s systems. The design of the optical system including transmitters, receivers and amplifiers all play an important role improving the signal to noise ratio. An additional approach is to use new optical fibers that mitigate non-linear impairments to improve OSNR of the transmission systems. Each of these will be addressed separately.

Hut Spacing, Amplifiers and Transmission Distances

When designing an optical link in a long haul system there are several considerations. Equipment to transmit, receive and amplify is placed along the length of the link. Placing amplifiers closer together improves the signal to noise ratio but this option increases cost as there are more amplification sites that must be installed and maintained along the link. An alternative is to use Raman amplifiers (in addition to, or instead of EDFA amplifiers) to improve the OSNR of each amplifier span. Raman amplification can improve the overall system performance by more than 3 dB and will likely be considered for many 400 Gb/s deployments, but this will fall well short of what can be accomplished in 100 Gb/s systems. The net result is that 400 Gb/s systems will have roughly 4 times *less* reach than 100 Gb/s systems, requiring very expensive signal regeneration to support the long haul distances required by service providers. Another option is to choose a fiber that both improves the nonlinear impact on coherent systems, and improves OSNR, to retain un-regenerated long-haul reach when scaling up the spectral efficiency (SE) and the channel data rate to 400 Gb/s and beyond.

What is the Best Fiber for 400 Gb/s?

Currently 100 Gb/s systems are being deployed using a multilevel transmission format with a coherent receiver. One great advantage of this transmission strategy is that the electronics correct for dispersion, unlike 10 Gb/s direct-detection systems where this must be done optically. With dispersion no longer a concern, controlling nonlinearity becomes the dominant challenge. In order to reduce the fiber nonlinearity which is proportional to n_2/A_{eff}, where n_2 is the nonlinear refractive index and A_{eff} is the fiber effective area, it is necessary to increase A_{eff} while not jeopardizing bending performance. While reducing fiber attenuation also improves system OSNR, it causes an increase of accumulated nonlinear effects and has diluted benefit when paired with Raman amplification. There are two fiber designs that can improve the signal to noise ratio. The first is an optimized large area fiber design such as TeraWave Fiber that allows for more optical power, and the second is a fiber with a very low attenuation such as an ultra-low loss G.652 fiber.

Two aspects of these fiber types are compared to a conventional G.652.D fiber in Table 1. Exemplary cabled attenuations are used here. The effective area for TeraWave fiber (ITU-T G.654.B) is 50% larger than the standard single-mode fiber (ITU-T G.652.D), increasing the optimum launch power by ~2 dB, depending on link length. The ultra-low loss fiber has the same effective area as the standard single-mode fiber, but it also increases the non-linear effective length resulting in a penalty that partially offsets the benefit of lower loss. Both fibers give improved performance with coherent receivers. The result for a 100 km span is that the G.654 fiber with optimized large effective area shows the greatest overall system benefit, especially when paired Raman amplification, which will likely be standard with 400G. Commercial hybrid EDFA-Raman amplifiers are already on the market which can take advantage of the large effective area of TeraWave Fiber.

Table 1. 100 km span performance comparison for three fiber types at 1550 nm.

	Low loss G.652.D	Optimized large area G.654 fiber	Ultra low loss G.652 fiber
Effective Area (square microns)	83	125	83
100 km fiber loss (dB)*	19	19	17
% of reach benefit, above G.652 with co/counter pumped all Raman amplifiers**	N/A	40%	16%

*Values given are illustrative of fiber plus basic cable margin. Precise budgeting values vary by carrier and depend on allowance for splicing, environmental variation, end-of-life, etc.

**Calculated using the Gaussian Noise model for coherent transport, pioneered by Poggiolini and co-workers Ref. iii.

Performance of TeraWave Fiber in the Field

One key aspect of any new fiber is how it performs in the field. TeraWave fiber has been fully tested in standard outside plant cable designs and is able to meet the full battery of GR-20 cable testing. One of the reasons for this is that the bend performance is designed to match that of a G.652.D fiber to handle the rigorous conditions to which an outside plant cable is exposed.

In addition, TeraWave fiber uses a well understood material system that has been deployed in optical fibers for over 30 years. The net result is that the fiber can perform reliably terrestrial cables.

Pulling all this Together in System Performance

Transmitting at 400 Gb/s will be challenging. Current models show that the distance between regeneration sites for 400 Gb/s networks will be about one quarter of the distance that can be achieved for a 100 Gb/s system. An optical regenerator is a receiver and transmitter combination that is placed along an optical link to clean up the optical noise that is generated. Regeneration involves optical-electrical-optical conversion and needs to be done for each channel that is being transmitted on the fiber. If one assumes that there are 50 channels (note that estimates range from 50 to 80 channels for this technology) and the cost of a 400 Gb/s transceiver is approximately $50,000 per channel, the total would be $2.5 million per fiber for regenerators.

Other regeneration costs that need to be considered include the wider footprint of a regenerator in the hut as compared to an amplifier, as well as higher utility costs in operating the additional equipment. The exact cost of a regenerator is somewhat uncertain and will depend on when the technology is deployed but it is apparent from this simple example that optical amplifiers will likely be far less expensive than regenerators. In short, if regenerators can be avoided in an optical link the overall system costs can be reduced considerably.

The figure below compares two examples: one uses TeraWave fiber and the second uses standard single-mode fiber. The link is 2000 km and the hut spacing is 100 km. The TeraWave fiber link can transmit the entire distance without a regenerator while the one using standard single-mode fiber requires regeneration for distances greater than 1400 km. The figure shows that when 400 Gb/s electronics are deployed on this link, TeraWave fiber will not require the costly optical regeneration electronics. Not needing the regeneration site will dramatically reduce the cost of this future upgrade to the system.

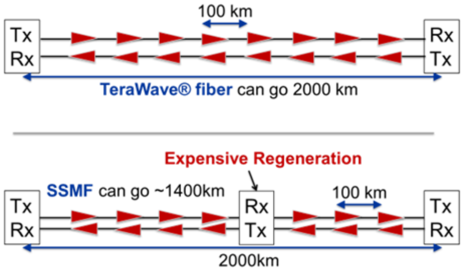

Figure 1. The figure compares two 2000 km optical links operating at 400 Gb/s using reach estimates shown in the table below. The top example using TeraWave Fiber requires a hybrid Raman amplifier every 100 kms. The lower example using standard single-mode fiber requires the addition of a costly regenerator to make the link operational.

Lowering the OSNR in an amplifier span improves the margin. In optically amplified systems, noise and distortion in one span is passed to the next and accumulates in the link. With better span OSNR, the OSNR of the entire system is increased adding system margin so the signal can propagate a greater distance before regeneration is required.

As an example we can compare published results of transmission experiments for several fiber types using 100 km amplifier spacing and 400 Gb/s transmission. All these examples shown in Table 2 below use Raman amplifiers to take advantage of the 3 to 5 dB improvement in OSNR that they provide allowing overall transmission distances that are greater than 900 kms. For the amplifier spacing (60 – 120 km) used in terrestrial networks, the added margin provided by TeraWave fiber allows longer distances between regeneration sites. The net impact of this to the service provider is a lower overall cost to deploy 400 Gb/s systems.

Fiber	Reach from published Experiments, 50 GHz channels, with 2 dB Q margin
G.652 fiber	~1400 km, Counter-pumped Raman, Ref. iv
Ultra low loss G.652 fiber	~1750 km, Counter-pumped Raman, Ref. iv
TeraWave G.654 fiber	~2000 km, Hybrid-Raman, Ref. v

Summary and Conclusions

Fibers being deployed in the long haul network today will likely be required to operate at 400 Gb/s per channel during their lifetime to meet continuously increasing video driven bandwidth demand. The choice of optical fiber made today can have a dramatic impact on the cost of 400 Gb/s electronics in the not too distant future. This paper explains why OFS' TeraWave fiber, with its optimized large effective area and low loss, is a good choice for 100 and 400 Gb/s networks and should be considered for overlays that are underway today and tomorrow.

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