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OPTICAL AMPLIFIERS THAT BUILD BETTER NETWORKS

White Paper

UltraSpan Power Booster EDFA
Extending Single-Span Network Reach

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1 Introduction

Geography often limits the ability to provision repeater sites between two remote terminal locations. For example, submarine links (island hopping, oil rigs), links spanning over large unpopulated areas (deserts, jungles, mountain ranges), and single-span disaster recovery solutions for enterprise storage systems. Even when it is not imperative, a single-hop solution is often desired as it reduces operational expenses and increases security.

The optical networking industry is aligning itself to this growing need by searching for practical, realizable, and cost-effective solutions. These include using - advanced modulation techniques, improved FEC algorithms or advanced optical amplification techniques.

In this paper we focus on advanced optical amplification techniques, and show how they provide a cost-effective method for increasing single-span system reach without requiring significant system redesign.

2 Technology Alternatives for Increasing the Span Limit

Several technology alternatives exist to increase the span limit. Advanced modulation techniques are a common method for Ultra Long Haul (ULH) equipment manufacturers to increase fiber link length by improving the tolerance to Optical Signal to Noise Ratio (OSNR) and non-linear effects. The Non-Return to Zero (NRZ) data coding is still the most common and is a widely used coding technique in Metro to Regional optical networking applications. NRZ is the lowest cost technique, but in terms of OSNR and non-linear tolerance, it is inferior to options such as Return-to-Zero (RZ) or RZ - Differential Phase-Shift Keying (RZ-DPSK). However, these advanced modulation schemes are either still confined to the laboratory or implemented only in high-end ULH systems. Introducing even just RZ to an existing system will require a significant increase in capital expense.

Another method to realize greater transmission distances is Forward Error Correction codes (FEC). FEC significantly increases the system margin by embedding extra data that is used to correct errors, at the expense of a slight increase in signal bandwidth. The most common FEC algorithm is G.709 Reed-Solomon (RS-FEC). Reach can be further increased by implementing other FEC algorithms such as enhanced FEC, super FEC, or breakthrough algorithms such as soft decision turbo product code FEC[1]. FEC is an excellent low-cost method for increasing span lengths and is almost mandatory in today's competitive high-end optical networks.

Advanced optical amplification techniques can also improve span power budget, without significantly modifying existing terminal equipment. Amplification solutions may include simply increasing the available output power of the standard booster, adding Distributed Raman Amplification (DRA) or using Remote Optically-Pumped Amplifiers (ROPA). Optical amplifier solutions often require increased day-one CapEx, but on a cost per-channel basis they are a good cost effective alternative. Increasing the standard booster power may be easily achieved by using RED-C's Power Booster EDFA - a special low gain, high output power amplifier placed after any existing booster. This stand-alone Power Booster is an excellent alternative for increasing system margin without major modification to existing equipment. Reach can be further improved with the addition of a stand-alone DRA. ROPA can also significantly increase the span power budget, but may not always be an option for pre-deployed fiber links which commonly do not have adequate flexibility to optimize the EDF placement.

Since extending a single-span budget is an occasional but sometimes unavoidable requirement, it is advantageous for the system vendor to be able do this with existing equipment without system redesign and unnecessary additional capital expense to the terminal equipment. For today's systems, this can be easily done using a stand-alone Power Booster EDFA and DRA. In this article we will explore the design considerations of adding these modules to an existing system.

3 Increasing Span Limit Using Optical Amplifiers

To increase the span limit using optical amplifiers, three configurations will be discussed. First, we will explore the limitation of existing standard booster and pre-amp configuration, then we will see how adding a Power Booster EDFA can help in multi-channel systems, and finally, how a DRA can further improve the link budget.

3.1 Limited Booster Power

Typically, the limiting factor in long links is OSNR. When the signal power received at the end of the link is reduced due to high span attenuation, the OSNR is also reduced. However, every transmission system has its minimum OSNR tolerance. Typical 2.5Gb/s and 10Gb/s NRZ transmission systems without FEC will have an OSNR tolerance of about 16dB and 21dB, respectively. When FEC is implemented, the bit-rate is increased to 2.7Gb/s and 10.7Gb/s, but the resulting OSNR tolerance will reduce to approximately 10dB and 13dB, respectively. These figures are practical boundaries of OSNR tolerances in the majority of deployed systems.

For a single-span link containing a pre-amplifier and booster, as shown in Figure 1, the noise is mainly generated within the pre-amplifier.

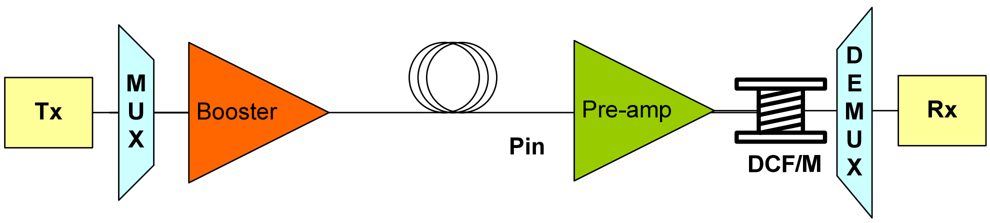


Figure 1: Single-Span with Booster and Pre-amplifier

In this configuration the OSNR at the end of the link can be increased by increasing the booster output power - every dB increase in booster power results in an immediate dB improvement in OSNR. However, this can be done only to a limit, as non-linear effects will start deteriorating the signal when the launch power increases beyond a certain point. For a single-span, single-channel applications, a standard booster with output power of up to 20dBm is usually sufficient for maximizing the output power and hence the OSNR, but vendors should be aware of the non-linear limits of their system. The influence of non-linear effects will be discussed shortly.

3.2 Power Extending Using a Power Booster EDFA

When the system includes more than one channel and the total output power is limited by the booster output power, the overall per-channel launch power is reduced by 10*log*N, where N is the number of channels. Therefore, to further increase the per-channel launch power to maximize link budget, a Power Booster EDFA can be added, as shown in Figure 2. This innovative amplifier can provide a desirable solution for many single-span applications, when designed from standard, mature and telecom-qualified single-clad EDF technology.

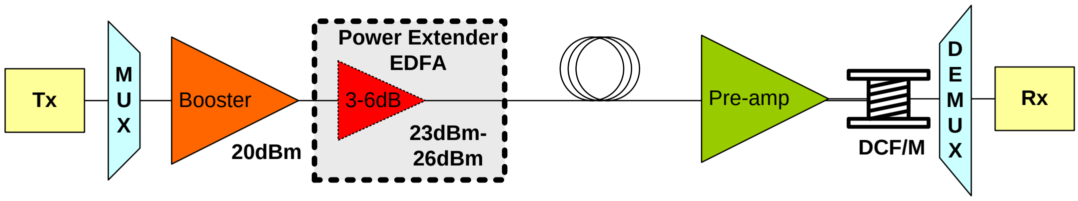


Figure 2: Single-Span link with Power Booster EDFA

A standard booster has output power of 17dBm-20dBm, a Power Booster can be used to boost the total output power to 26dB, thereby increasing the per-channel signal power. However, for these power levels, non-linear effects begin to deteriorate the signal. Therefore, it is important to determine the maximum launch power limit of the signal.

For a single-span transmission link containing few, broadly-spaced channels (up to 8), with 2.7Gb/s and 10.7Gb/s data rates, two non-linear effects are relevant: Stimulated Brillouin Scattering (SBS) and Self-Phase Modulation (SPM). The Four Wave Mixing (FWM) effect is usually negligible, and can be eliminated by avoiding low dispersive fiber or by distributing the signal wavelengths unevenly.

When increasing signal launch power, the first non-linear effect that needs to be dealt with is SBS[3]. In this effect, the optical signal interacts with density variations inside the optical fiber (caused by acoustic modes or temperature gradients) to create a reflected Stokes wave. This effect can add considerable noise to the signal, but is reduced significantly when the linewidth of the laser is broadened.

For direct laser modulation, typically employed in 2.7Gb/s transmission systems, the optical linewidth is inherently broadened by the adiabatic chirp induced via the RF modulation. The SBS threshold in this case is above 16dBm launch power. For externally modulated transmission (2.7Gb/s and 10.7Gb/s), SBS back-reflection occurs at relatively low powers since about half of the modulated signal power remains contained within the narrowband carrier signal. The maximum launch power in this case is limited to about 11dBm, but can be easily improved by increasing the laser linewidth using a low-frequency dither of the laser bias current. Laser dithering is common and can increase the SBS threshold for Distributed Feedback (DFB) lasers to approximately 18-19dBm launch power. For other types of lasers, even if dithering is used, the SBS threshold can still be significantly lower.

The second effect to limit transmission is SPM. SPM occurs when the power modulation of the on-off keying signal, self-modulates the phase of the signal, thereby causing signal distortion. For 10.7Gb/s single-span transmission, SPM limits the launch power to roughly 21dBm, and for 2.7Gb/s, the SPM limit is well above this[4]. In both cases, the maximum power in a single-span system is limited by SBS, and not by SPM.

Therefore, the use of a Power Booster in single-span applications should be considered using the following criterion:

- For single-channel links - employ a standard booster without a Power Booster.
- For 2-6 channels links - employ Power Booster designed with output power of 18dBm+10*log*N, where N is the number of channels.
- For more channels and/or for additional link budget - employ a DRA in addition to the Power Booster, as described in the next section.

3.3 Further Increasing the Limit using a DRA

If the link budget is high, or the link uses a large number of channels, an "extra push" may be required. This push can employ a counter-propagating DRA[5] at the receiving end as shown in Figure 3.

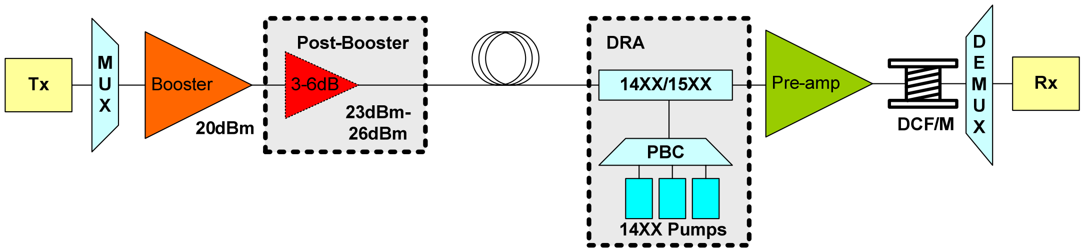


Figure 3: Single-span link with booster, Power Booster EDFA and DRA and pre-amp

Most the noise in the single-span configuration is generated within the DRA and pre-amplifier at the end of the link. To calculate the OSNR, a link-model is used, as shown in Figure 4. This model shows a link (see Figure 3), containing a booster, Power Booster, DRA, and pre-amp, in a schematic way.

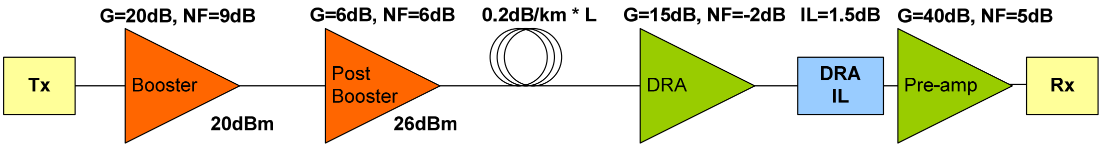


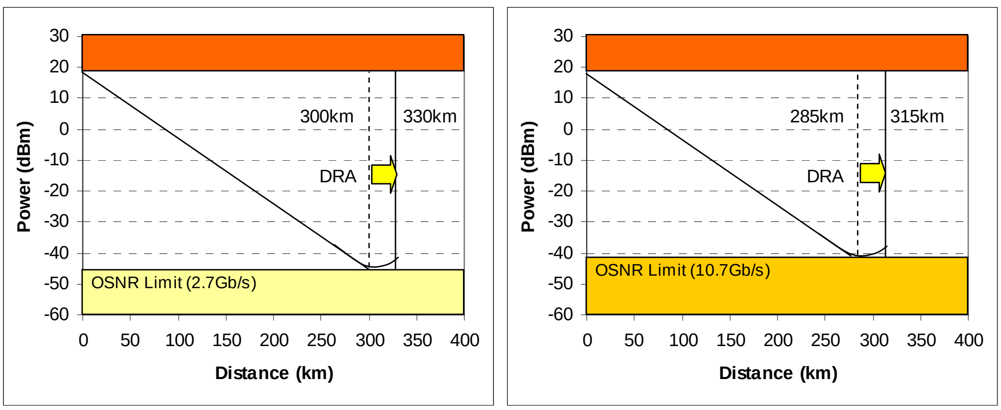
Figure 4: Model for calculating the link budget and OSNR

In this configuration, and assuming the insertion loss and NF of the DRA are 1.5 dB and -2dB, respectively, the overall OSNR improvement using a 450mW DRA is approximately 5dB, and using a 700mW DRA, the improvement is more than 6dB.

4 Single Channel Transmission Example

As the maximum launch power of one channel is limited to roughly 18dBm due to SBS, the use of a Power Booster for single-channel transmission is not required. The maximum link budget for 2.7Gb/s and 10.7Gb/s systems can be seen in Figure 5 (a) and (b), respectively. Without DRA, the maximum distance of a 2.7Gb/s and a 10.7Gb/s system is 300km and 285km, respectively. When a DRA is used, the distance can be extended to 330km and 315km, respectively. The assumptions in these calculations are:

- System margin is not accounted for and will be added as required by the designer.
- Fiber attenuation is roughly 0.2dB/km, suitable for pure silicon core (PSC)-type fiber (0.18dB/km) + 0.1dB splice every 5km.
- Raman amplifier gain is 15dB. Higher gain values can be achieved with other types of fibers or higher Raman pump power.
- To reduce dispersion penalty, the dispersion is optimally compensated.
- Transmission is NRZ with FEC.



(a) **(b)**

Figure 5: Single-channel maximum transmission without Power Booster EDFA:
a) 2.7Gb/s transmission, extended using DRA b) 10.7Gb/s transmission, extended using DRA

5 Multi-Channel Transmission Example

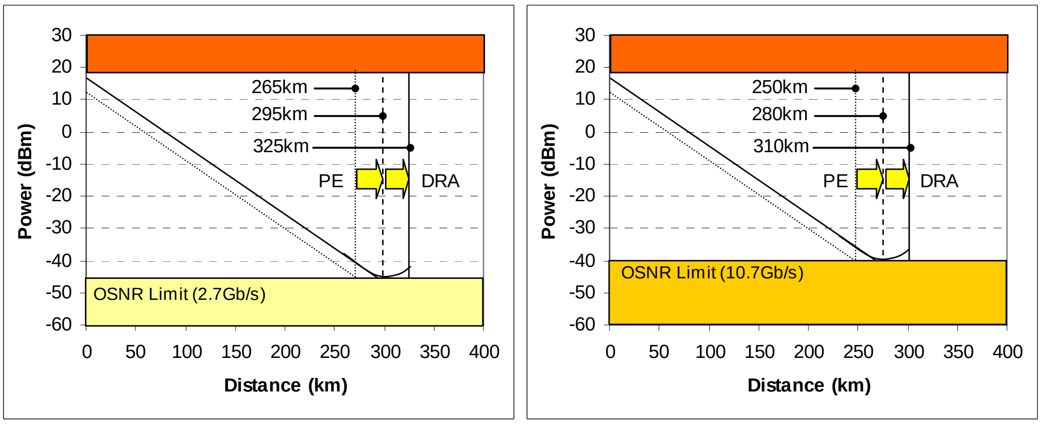
For systems containing 2-6 channels, an additional Power Booster with 3-6dB gain and DRA can be used to achieve similar reach improvement performance, as shown in Figure 5. The assumptions here are that:

- The transmit power per-channel is 18dBm (similar to the one-channel case)
- There is no non-linear interaction between the channels
- The amplifier gain tilt is corrected via pre-emphasis to achieve optimal OSNR per channel.

Over 6 channels, non-linear effects do not limit the ability to use the maximum available gain of the Power Booster EDFA (PE), 6dB, since the power per-channel is below 18dBm. Therefore, the overall reach of a multi-channel system can be significantly improved by adding the Power Booster EDFA.

Figure 6 shows the benefit of using the Power Booster EDFA in an 8-channel transmission system – a typical channel-count limit for disaster recovery WDM storage area networks.

If a standard booster with 20dBm output is used, the average launch power per-channel is roughly 11dBm. Without PE and DRA, the maximum distance for 2.7Gb/s and 10.7Gb/s transmission is 265km and 250km, respectively. When PE and DRA are added, the span length may be increased to 325km and 310km, respectively. This is an increase of 60km over the conventional booster-preamp configuration.



(a) **(b)**

Figure 6: 8-channel maximum transmission with (solid line) and without (dashed line) Power Booster EDFA: a) 2.7Gb/s transmission. b) 10.7Gb/s transmission.

Any link designs containing regular SMF fibers (typically 0.22dB/km) and a 3dB span margin, must adjust these span limits by roughly 50km downwards. Therefore, typical applications of Power Booster EDFA and DRA begin at approximately 200km.

6 Deployment Issues

DRA amplifiers are already deployed all over the world, and provide a good solution for difficult spans. Deployment issues of DRA have been discussed in previous articles[5]. Here we will discuss the new issues surrounding the Power Booster EDFA solution. As this amplifier operates at high power levels, there are three technical issues that need to be solved:

1. Eye safety – similarly to Raman amplifiers operating with similar output powers, this amplifier must shut down in case of fiber cut.
2. Line quality – similarly to Raman amplifiers, the line quality must be monitored to ensure connectors are not damaged due to the high signal power.
3. Non-linear effects – one needs to know the boundaries of launch power for linear transmission to ensure that this amplifier does not introduce non-linear signal degradation.

The first and second challenges can be dealt with in the same way as with Raman amplifiers[5]. Without eye safety mechanisms the IEC 60825 standard[6] defines the 26dBm Power Booster amplifier as a Class 3B laser product. If designed with reliable eye safety mechanisms, this amplifier can be compliant as a Class 1M hazard level as required for optical communication. This is achieved by reducing the power output of the amplifiers within 150ms after a connector is opened or a fiber break occurs

Since the output power of the Power Booster is very high, damage can occur in faulty lines. Any undesired attenuated, bent or pressed fiber, dirty connectors, or connectors with air gaps in-between can cause damage which is difficult to detect and repair. The fiber line has to be monitored continuously to ensure such damage does not occur. This amplifier will therefore require line monitoring mechanisms, similar to Raman amplifiers.

The third challenge, regarding knowing the non-linear limits of the link, was discussed previously in a general way but must be reconsidered individually for each specific system.

7 Summary

RED-C's UltraSpan Power Booster uses standard and mature, telecom-qualified, single-clad EDF technology specially designed to achieve a high output power of up to 26dBm. This innovative product also features state–of-the-art transient suppression, patent-pending line monitoring and eye safety mechanisms, and a Class 1M laser product classification according to IEC 60825-1. The Power Booster is a stand-alone 1RU rack-mountable network element that can be used as a power extender for any booster in any system.

The need to cater to applications where a single-span link is unavoidable or has significant operational or cost advantages has already driven the industry to move towards DRA solutions, such as RED-C's Raman amplifier. The Power Booster solution adds an additional margin which is comparable to DRA. These specialized products cater to the growing need to extend the reach of existing links. The combination of these two products can increase single-span distances by up to 60 additional kilometers, which could prove critical for certain applications.

Studying the economics of fiber amplifiers, one can conclude that system upgrades for single-span links of 200km and above and containing few channels are best performed in the following logical steps: The system vendor must first consider RED-C's UltraSpan Power Booster EDFA for extending the limit by roughly 30km; and then if an additional 30km are required, upgrading the system using RED-C's UltraSpan Raman amplifier. If longer links are needed, the vendor should consider ROPA or advanced modulation techniques.

Although this article covers the specific application of single-span networks, RED-C's Power Booster EDFA can be used to achieve margin improvement and reach extension also in multi-span networks.

8 Further Reading

1. T. Mizuochi et. al., OFC 2003, ThN1, pp. 527-8.
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3. D. A. Fishman et al. J. Light. Tech., 11, Nov. 93.
4. J. P. Elbers et al. IEEE J. of Selected Topics in Quantum Electronics, 6, 276-281, 2000.
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6. "Safety of laser products – part 1 – Safety of laser products", IEC International Standard 60825-1.