

SAVE YOURSELF MONEY IN THE LONG HAUL

ELIMINATE MID-SPAN OPTICAL AMPLIFICATION &
REGENERATION FROM UTILITY
COMMUNICATION NETWORKS

REPEATERLESS OPTICAL DISTANCE
UP TO 250 MILES/400 KM FOR SONET/SDH
& LOW-LATENCY 1G/ 10G MPLS LINKS

I P G
PHOTONICS®

The Power to Transform®

Introduction

Critical infrastructure, such as oil and gas pipelines and electricity transmission, requires extremely reliable, real-time monitoring and control technology. Increasingly, the monitoring and control of critical networks is accomplished over fiber optic lines. In the case of electricity transmission, Optical Ground Wire (OPGW) is used. OPGW is a dual-function cable: it contains multiple optical fibers for optical communications and metallic ground wire which provides a path to ground in the event of an electrical fault. In these networks, OPGW connects each of the sub-stations and other locations with an optical fiber connection to a central monitoring and control location.

Renewable Energy Sources Result in Longer Electricity Transmission Distances

A key driver for the increase in ultra-long-haul (ULH) electricity transmission is the relatively recent increase in renewable energy investments. In the past, most electricity transmitted over the electrical grid was generated by burning fossil fuels. The electricity generation process was co-located in areas that had the greatest energy consumption. More recently, the generation of energy from renewable sources such as hydro, wind and solar often means that the generation of energy is separated over long distances from the areas of consumption.

The Ability to Eliminate Optical Regeneration is Enabled by Optical Amplification

Historically, these fiber optic lines were engineered to limit the optical transmission distance based on the specifications of the optical interfaces used in the telemetry equipment that monitors and controls the electricity transmission. The transmission distance was limited to approximately 100 km (60 miles). The design of an optical monitoring network required an optical regeneration station for each span >100 km.

Limited Optical Transmission Distance = Higher Cost

Optical regeneration is costly, from both a capital and operational expense perspective. In some applications, an optical regeneration station can cost ~\$1M USD. The optical regeneration site includes:

- Optical Regeneration Monitoring Equipment
- Environmentally-controlled Electronic Enclosure
- Electrical Supply
- Backup Electrical Source, Typically LP Emergency Generator
- Vehicle Access

Grid operators often budget another \$1M USD for the annual operations of the site. Optical amplification can completely eliminate an optical regeneration site.

Eliminating Optical Regeneration using Optical Amplification

Figure 1, (below) shows an electric grid connecting two sub-stations separated by ~400 km (250 miles). Due to optical transceivers limitations, the maximum distance for optical signal transmission is 100 km resulting in the need for three optical regeneration sites. Using optical amplification and high quality transmitter and receiver optics eliminates all intermediate optical regeneration locations. (Figure 2, below)

Components of Optical Amplification

Figure 3's graph (back cover) shows that a signal unaided by optical amplification can travel about 100 km (60 miles) before it must be regenerated. Using optical amplification techniques, that same signal can be transmitted 400 km before it must be regenerated or reamplified.

The diagram in Figure 3 illustrates various amplification techniques. Two basic optical techniques are used and are discussed in more detail:

- Erbium-doped Fiber Amplifier (EDFA)
- Distributed Raman Amplification.

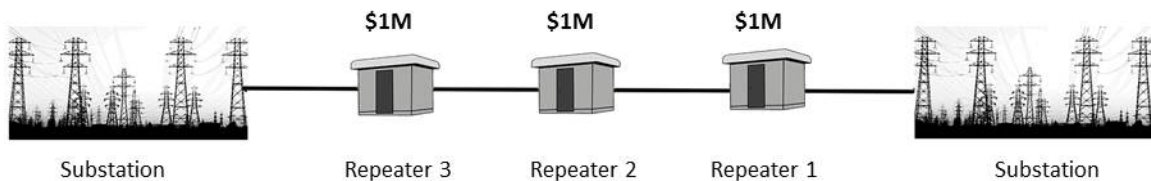


Figure 1: Application without Amplification

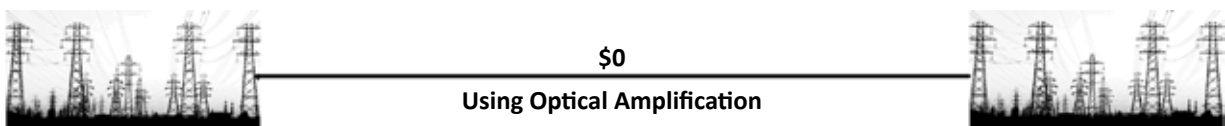


Figure 2: Application with Amplification

Erbium-doped Fiber Amplifier

All optical telecommunications extending over long distances transmit over single-mode fiber in the Optical “C”-band, between 1529-1563 nm. In single channel applications, a center wavelength around 1550 nm is typically used for the telemetry signal. DWDM applications can utilize many wavelengths with the C-band.

Erbium-doped fiber amplifiers are a reliable, stable amplification solution for optical signals transmitted in the C-band. The Erbium-doped fiber amplifier uses a doped optical fiber as the gain medium to amplify the optical signal(s). The optical signal is multiplexed with the energy from a 980 nm pump laser diode causing the Erbium ions to release photons that are absorbed by the coincident 1550 nm signal, thus producing gain.

Booster EDFA

A booster amplifier is an EDFA used to launch the signal into the transmission fiber. The power of the launched signal must be managed to minimize some non-linear effects such as Stimulated Brillouin Scattering (SBS). For lower rate signals (i.e. STM-1/OC-3 or STM-4/OC-12), the launch power can be as high as 20 dBm, assuming no co-propagating signals are transmitted. Higher bit rate signals cannot be boosted as high as lower bit rate signals. The use of ITU G.652 non-dispersion shifted fiber with a fiber core with larger effective area can support higher optical powers than those with lower effective core areas (i.e. 0.54 cm²) of some ITU G.655 dispersion shifted fiber types.

Pre-amplifier EDFA

A pre-amplifier is an EDFA designed to receive and amplify very low signals and is always used at the end of the link. A key measure of performance for a pre-amplifier is “receive sensitivity”. Those with the lowest sensitivity can detect and amplify the lowest signals. Another key figure of merit is Noise Figure. Noise figure is a ratio of the signal-to-noise at the input to the signal-to-noise at the output of the EDFA. Pre-amplifiers and ROPAs must contribute as little noise as possible to the signal and thus must have a very low Noise Figure. IPG’s advanced manufacturing production capability produces the pump laser diodes and the single-mode pumped EDFAs with extremely low noise figures.

Remote Optically Pumped Amplifiers (ROPAs)

ROPAs are EDFAs with a large distance between the pump energy source and the doped fiber gain medium. In addition to 980 nm, Erbium ions also respond to the pump energy from 1480 nm, so this wavelength is used to “pump” the remotely placed doped fiber. The 1480 nm pump source can be wave division multiplexed onto the same fiber as the C-band signal. If the distance where the ROPA must be deployed is large, then a dedicated fiber can be used to carry the 1480 nm pump signal to the ROPA

because the pump source must be launched at a very high level and would interfere with the signal if launched in the same fiber. A ROPA is typically located about 50 km from the end terminal and as far away as 100 km. ROPAs can be used both as a “booster” amplifier and as a “pre-amp” amplifier. It is common for ROPAs to provide approximately 10 dB of gain.

Raman Amplifiers

Raman pump lasers provide high optical power levels at a wavelength shorter than that of the signal wavelength at the start and/or end of the span. The non-linear effect of Stimulated Raman Scattering (SRS) transfers optical energy from the Raman laser pump to the signals, effectively turning the ordinarily passive span fiber with loss into a distributed optical amplifier with a region of gain. Many factors affect the amount of signal gain provided from Raman amplification, but 7 to 10 dB of OSNR gain is typical. IPG’s patented seedless 2nd- and 3rd-order Raman solutions provide an additional 2-3 dB of OSNR gain over traditional 1st order solutions.

Co-propagating (Forward) Raman Amplifiers

Co-propagating Raman amplification provides signal amplification in the same direction as the propagation of the signal. Use of Raman amplification in the forward direction is rare and only provides a few dB of gain. The high launch power of the signal must be carefully engineered to not interfere with the high launch power of the co-incident forward Raman pump.

Counter-propagating (Backward) Raman Amplifiers

Counter-propagating Raman amplification is more common than co-propagating. A Raman signal pump is multiplexed in the same fiber with the received signal. The direction of transmission of the counter-propagating Raman signal pump is opposite that of the approaching signal. The signal level of the Raman signal pump is much higher than the approaching signal, which has been attenuated as it has traveled through the lossy fiber. Thus, the SRS effect (and the level of gain) is much greater in the counter-propagating direction than the co-propagating direction.

FEC, Low Chirp Transmitters, ASE Filtering

The longest links require the most demanding optical transmission components. IPG has implemented Forward Error Correction in our SoC and ASIC designs for all rates up to 10Gbps. This enables signal recovery with a lower Optical Signal to Noise Ratio (OSNR) and effectively extends the optical budget by 6-9 dB.

IPG’s low-jitter transmitters have highly accurate wavelength-stability control, narrow spectral line widths and low chirp to enable transmission over extremely long distances, eliminating dispersion compensation and signal

regeneration from many links. IPG's unique 10G OTN SFP+ Transceiver is the only 10G transceiver in the world incorporating an OTN wrapper with FEC supporting 10G transmission over >100 km without additional amplification or dispersion compensation.

Another technique used in IPG's systems is ASE filtering, further lowering the required minimum OSNR. A 100 GHz filter matching the ITU-grid transmitter wavelength is used prior to the receiver to eliminate amplified spontaneous emission generated as the signal propagates along the transmission path.

Summary

Utility operators must monitor and control their networks and many are using fiber optic communication to accomplish this. Oil pipelines and electricity transmission networks typically extend over extremely long distances; as renewable energy sources are increasingly relied on, the generation of electricity is typically in a remote location from the users. Optical amplification can eliminate optical regeneration of telemetry communication signals and save costly capital and operational expenditures for the owners

and operators of these critical infrastructures.

IPG's vertically integrated manufacturing process is unique among optical amplifier suppliers as IPG controls the performance, cost and yield of both active fibers and semiconductor pump diodes- the core technology of our fiber laser and amplifier products. This enables IPG to produce some of the **highest power optical amplifiers** in the world with very low Noise Figures.

About IPG Photonics

IPG Photonics is the world leader in high power fiber lasers and amplifiers. Founded in 1990, IPG pioneered the development and commercialization of optical fiber-based lasers for use in a wide range of venues such as materials processing, telecommunications, medical, scientific and other advanced applications. Fiber lasers have revolutionized the industry by delivering superior performance, reliability and usability at a lower total cost of ownership compared with conventional lasers, allowing end users to increase productivity and decrease operating costs. IPG is headquartered in Oxford, MA with manufacturing plants, sales & service offices throughout the world.

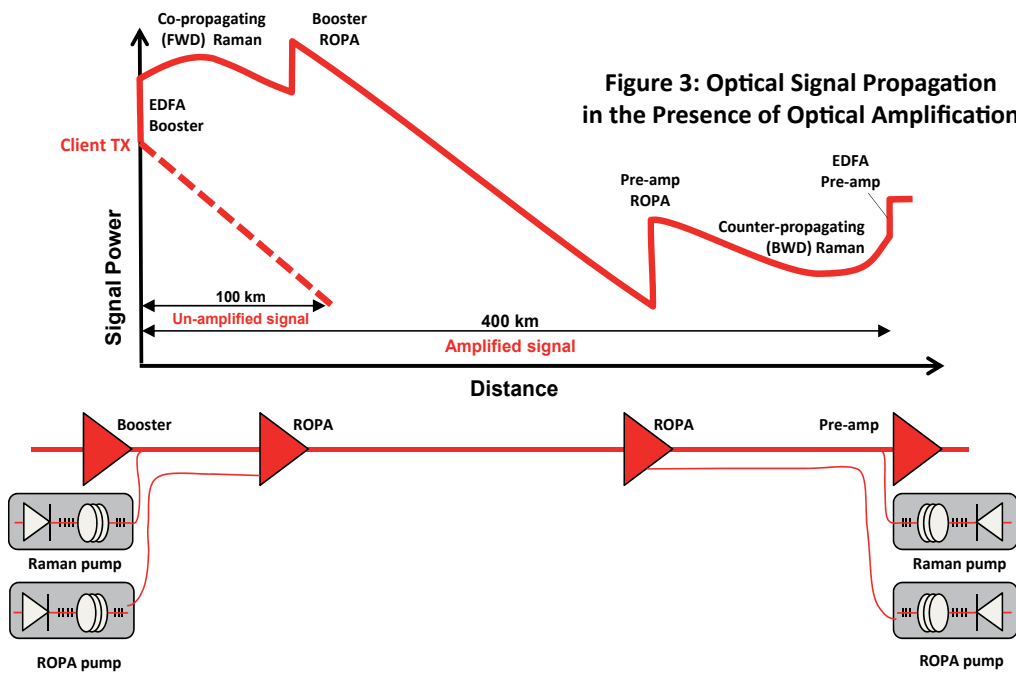


Figure 3: Optical Signal Propagation in the Presence of Optical Amplification

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