Coriant

WHITE PAPER

LIGHTNING STRIKES AND 100G TRANSPORT

The Advantages of Coriant CloudWave™ Optics in Mitigating Aerial Fiber Perturbations

Fiber optic cables are the vital transmission medium for global communication – connecting cities, countries, and continents. Within the worldwide fiber infrastructure, aerial fiber plays an important role as it is substantially cheaper to deploy compared to buried fiber. An obvious challenge to aerial fiber is the exposure to potentially harsh environmental conditions including wind, rain, snow, and thunderstorms. While legacy direct detect transmission technology such as 10Gbps is inherently immune to the perturbations caused by severe weather, coherent 100Gbps technology was tested and discovered to be much more susceptible. This white paper discusses the physics of fiber perturbations due to lightning strikes, the resulting challenges for coherent transponders, and how Coriant CloudWave™ Optics technology delivers superior resilience in adverse conditions.

INTRODUCTION

The Internet has profoundly changed our lives by impacting the way we work, communicate, shop, listen to music, or view entertainment such as movies and TV shows. With the Internet more ubiquitous than ever and with anytime, anywhere access to content available through powerful smartphones and tablets, the typical broadband user rarely thinks about the backbone of this global infrastructure – a web of hundreds of thousands of kilometers of fiber optical cables spanning the globe. Submarine cables connect continents, while terrestrial cables, which can be co-located with pipelines or railroad tracks, as well as aerial fiber on overhead power lines, support the transmission of data within and across countries, until it reaches metropolitan areas where fiber is typically buried in ducts and (micro) trenches as shown in Figure 1.

FIGURE 1 – *Deployment of fiber cables in trenches (left) and overhead power lines including fiber cables (right)*

Aerial fiber is an eminently important building block of this worldwide fiber infrastructure because it is substantially cheaper to deploy compared to buried fiber. However, aerial fiber also faces exposure to the elements including wind, rain, snow, ice, and even thunderstorms. All of these weather-related phenomena can affect the integrity of optical signals on different timescales and to varying degrees. Fortunately, this was not a problem until now. The majority of channels to date were provided by direct detect transmission technology, such as 10Gbps on-off keying, which is inherently immune to perturbations. However, with ever-increasing traffic demands, operators are moving to state-of-the-art coherent transmission technology with bit rates of 100Gbps and beyond. These fast and spectrally efficient interfaces rely on combined phase and amplitude modulation and transmit two channels on orthogonal polarizations. Fast processors (DSPs) are used to recover the information from the deteriorated signal and allow compensation for a wide range of distortions such as chromatic dispersion and polarization mode dispersion (PMD). In particular, the processors are also able to revert changes of the polarization state, which are usually induced by mechanical perturbations, e.g., by trains cruising along tracks co-located with fiber.

Aerial fiber on power lines can be packaged into optical ground wire (OPGW) cables, as shown in Figure 2. OPGWs are designed to attract lightning and protect the current carrying cables from direct hits.

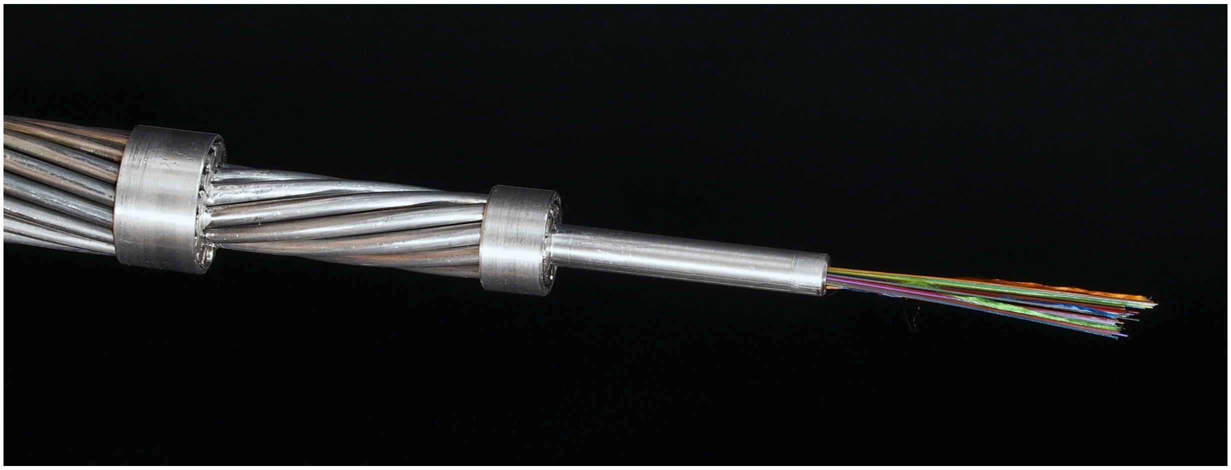

FIGURE 2 – *OPGW cable with integrated optical fiber*

The impact of lightning strikes on and around aerial fibers has not been fully understood and also, to a large degree, not considered when the first coherent 100Gbps transponders were deployed in the field. When unexpected bit errors occurred on aerial cables in two directions simultaneously (i.e., on different fibers within the same cable), this pointed to an external perturbation that could not be explained by previous operational experience with 10Gbps transmission in the same environment.

LIGHTNING STRIKES IN AERIAL FIBERS

Thunderstorms are subject to strong regional and seasonal variations. Outside the tropics, lightning strongly peaks around the summer months but happens throughout the year near the equator, as shown in Figure 3. The map displays the total number of ground and cloud-to-cloud strikes per square km and per year based on satellite data.

About one third of total strikes hit the ground. Note that lightning is particularly frequent in sparsely inhabited regions such as the Amazon or Central Africa where aerial fiber is most cost-effective. In central Europe, the statistics translate into about 30 direct OPGW hits per 100km per year and can be several times higher in the Americas.

Lightning strikes are fast and powerful events, where several discharges on the μs timescale carry tens or even hundreds of Coulombs with peak currents ranging from 30kA on average to hundreds of kiloamperes. These short and intense bursts can affect optical fiber in various ways, most importantly, mechanically, thermally, or by electromagnetic fields.

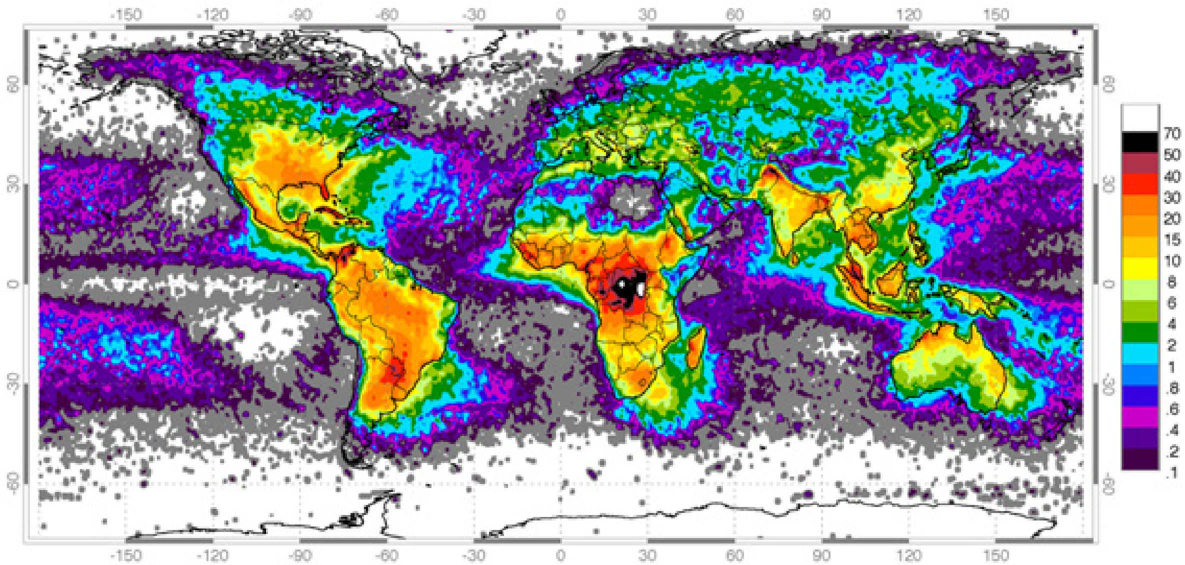

FIGURE 3 – *Global frequency of lightning strikes per square km and year* [1]

First, mechanical perturbations to the OPGW due to direct lightning strikes lead to a vibrational and thermal shock on the scale of a few milliseconds. This affects the fiber in the OPGW and can introduce a fast change of PMD within the fiber [Figure 4]. While 100G DSPs do not have issues dealing with slow-changing PMD distortions, a sudden PMD change is not something that was typically foreseen in legacy DSP designs, putting a lot of strain on the adaptive equalizers.

A second negative impact comes from magnetic fields induced by lightning bolts striking an OPGW directly or in its proximity. Because the conductor elements of OPGW are twisted like a wire cable, the current flows with a spiral component, which induces a magnetic field in the OPGW in the same direction as the optical fibers, causing a Faraday rotation of the propagating light.

A limited field measurement of lightning strikes around a short 40km OPGW link in Japan has shown angular rotational polarization speeds of up to 100krad/s[2], although no direct lightning strikes into the OPGW were observed. Experiments on OPGW were replicated in the laboratory as well, where with a 16kA current pulse, polarization rotation speeds of more than 200krad/s have been observed. Natural lightning strikes, however, are even stronger with 50% having peak currents of more than 30kA and 1% of more than 150kA. Therefore, it is estimated that an average 30kA lightning strike can cause 400krad/s rotations while the strongest strikes can exceed 2Mrad/s.

To put these numbers in perspective, in terrestrial fibers, polarization rotations of up to 20krad/s have been observed in year-long trials, significantly less than even an average direct hit on an aerial fiber. Most legacy 100Gbps transponders in the industry have been designed to or below a specification of 300krad/s, which was deemed sufficient to mitigate worst case vibration impact (a.k.a. the screwdriver test on dispersion compensating fiber spools).

1 NASA Lightning Team
2 Lightning Field Measurements

FIGURE 4 – *Lightning strike close to an overhead transmission line*

CORIANT CLOUDWAVE™ OPTICS

Can state-of-the-art coherent transponders with data rates of 100Gbps and beyond mitigate such severe perturbations and give the service provider the look and feel of a classic 10Gbps appliance? Coriant CloudWave™ Optics offers a 100Gbps solution as close as it gets. Figure 5 compares the requirements for polarization rotation speed with a typical third-party 100Gbps, as well as the Coriant CloudWave™ Optics 100Gbps solution. The Coriant CloudWave™ Optics solution can follow an impressive 3Mrad/s in the presence of optical amplifier noise, chromatic dispersion, PMD, and PDL and thus offers superior resilience against polarization perturbations.

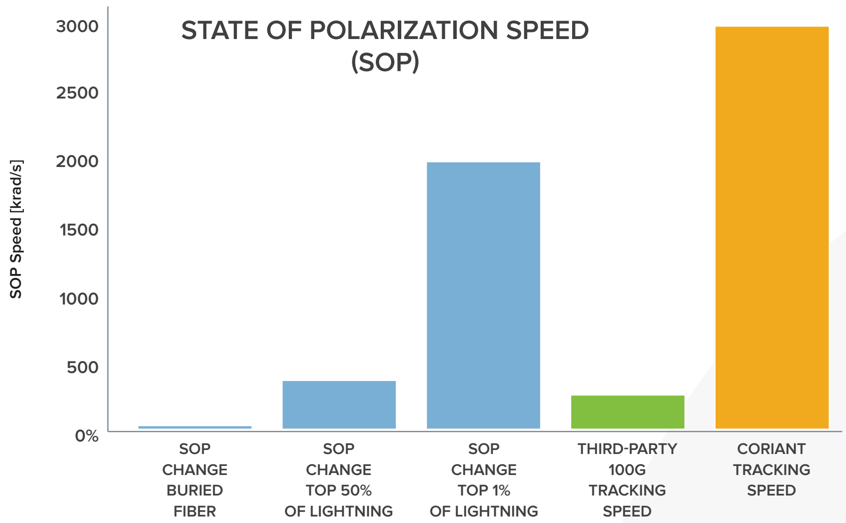

FIGURE 5 – *Superior robustness of Coriant CloudWave™ Optics against ultra-fast polarization rotations*

Where does technology go from here? With the lightning issue mitigated for 100Gbps transport, research will focus on 400Gbps, 1Tbps, and beyond. Advances in signal processing will be required to make transport robust against lightning strikes for various higher order modulation schemes, such as 32QAM or 64QAM.

ABOUT CORIANT

Coriant delivers innovative, dynamic networking solutions for a fast-changing and cloud-centric business world. The Coriant portfolio of SDN-enabled, edge-to-core transport solutions enables network operators to reduce operational complexity, improve utilization of multi-layer network resources, and create new revenue opportunities. Coriant serves leading network operators around the world, including mobile and fixed line service providers, cloud and data center operators, content providers, cable MSOs, large enterprises, government agencies, financial institutions, and utility companies. With a distinguished heritage of technology innovation and service excellence, forged by over 35 years of experience and expertise in Tier 1 carrier networks, Coriant is helping its global customers maximize the value of their network infrastructure as demand for bandwidth explodes and the communications needs of businesses and consumers continue to evolve. Learn more at www.coriant.com.