Long-Term Monitoring of Local Temperature and Stress Changes in a Buried Fiber-Optic Cable Using a BOTDA

J. A. Nagel and S. L. Woodward
AT&T Labs – Research, 200 Laurel Avenue South, Middletown, NJ 07748
L. Zou
OZ Optics Ltd, 219 Westbrook Drive, Ottawa, Ontario K0A1L0 Canada

Abstract:
We present the initial results from a continuing long-term field measurement of the local Brillouin spectra in a fiber in a 70-km buried cable using a BOTDA. The use of these results to estimate local temperature and stress changes in the fiber is discussed.

OCIS codes: (060.2270) Fiber Characterization and (060.2300) Fiber Measurements.

1. Introduction

Brillouin Optical Time-Domain Reflectomers (BOTDR) or Brillouin Optical Time-Domain Analyzers (BOTDA) have been used for many years as a means to perform distributed temperature sensing using optical fibers as a sensor [1,2]. Both methods measure the local Brillouin spectrum of the fiber, and use the dependence of the Brillouin spectrum on temperature and stress to measure either temperature or stress. A reflectometer (BOTDR) operates with a pump at one end and measures the backscattered Brillouin light at the same end, relying on spontaneous emission to generate the backward-propagating signal. An analyzer (BOTDA) requires access at both ends of the fiber, allowing a probe signal to be introduced at the opposite end from the pump. Through the process of stimulated emission, the signal-to-noise ratio of a BOTDA signal is larger than that of a BOTDR.

2. Experimental Setup

A map of the fiber cable's location is shown in Figure 1, and the experimental setup is shown in Figure 2. The cable route runs along a river valley in Northern California, crossing the river twice, before ascending a mountain at the far end. The cable is in two sections, one 34.5 km and the other 32.2 km. In the middle is a repeater station (Node 2) used to house most of our experimental equipment.

The BOTDA requires access at both ends of the fiber, so we used loopbacks at Node 1 and Node 3 to create 68.9 km and 64.3 km continuous fibers with access to both ends at Node 2. We took BOTDA scans on one pair of fibers to Node 1 and to Node 3 as often as once every 24 hours starting in August 2008 and continuing to the present time. The fiber pairs under test were were connected to the BOTDA through optical switches. The measurements were controlled with computers at all three nodes, connected via a LAN connecting the three nodes using two of the other fibers on the cable. The measurements were controlled remotely from our lab in New Jersey. In addition to BOTDA measurements, we also took bi-directional OTDR measurements of 14 fibers within the cable, including the pairs used by the BOTDA. In this talk we will focus on the BOTDA results.

3. Data Analysis

The BOTDA uses a CW pump signal launched from the far end and a pulsed probe signal launched from the near end. The probe pulse propagates down the fiber, extracting power from the counter-propagating CW pump signal at each point in the fiber. By viewing a time-resolved measurement of the received pump signal, one can detect the pump depletion as a function of distance along the fiber. The frequency of the pump signal is then shifted slightly, and the process is repeated. In this way a map of the Brillouin spectra for each location in the fiber can be extracted. The fiber length that can be resolved in this way depends on the pulsewidth.

The Brillouin spectra in the buried fiber showed evidence of 1, 2 or 3 acoustic modes, and we measured all modes that could be resolved. The frequency at the center of each mode is determined by

$$\nu_B = \frac{2n\nu_L c_A}{c_L} \tag{1}$$

Here υ_L is the frequency of the pump light, c_A is speed of the acoustic mode, n is the index of refraction and c_L is the speed of light. Since the Brillouin frequency shift is dependent on both temperature and stress in the fiber, the temperature or the stress in the fiber can be monitored as a function of distance by measuring the local Brillouin frequency along the fiber.

4. Results

The calibration factor for determining either temperature or stress from the main Brillouin mode is different from fiber to fiber. The relative proportionality constants between Brillouin frequency and temperature or stress changes are unknown. Normally, one calibrates a fiber to be used as a distributed sensor by making measurements in the lab before deployment. This option is clearly not available for fiber buried the 1980's. However the surface air temperature over the buried cable at the time of our measurements is available from weather reports, and by using a simple heat-transfer model, the temperature in the ground can be estimated from this data. There is a single parameter in the heat-transfer model that is determined by the depth of the fiber and the heat-transfer characteristics of the insulating ground. The mean surface temperature varies rapidly from day-to-day, but the variations at a given depth in the ground are filtered out considerably until only the long-term seasonal variations remain. The data shows that the Brillouin frequency shift at each point in the fiber appears to be similar to a sinusoidal function with a period of one year. We then use a two parameter fit (calibration factor and thermal constant) of the filtered surface temperature data to the measured local Brillouin shift as a function of time. In this way the calibration factor for determining temperature from the Brillouin frequency shift as a function of distance along the fiber can be determined. The second fitting parameter gives a picture of the local variation in heat-transfer characteristics of the ground over the cable.

The fiber is in a loose-tube cable, and the cable itself is deployed in a conduit with slack, so in most cases there is no stress on the fiber. However, there are cases where the cable can be locally stressed, for example by a shift in the earth or other intrusion that does not break the cable. The Brillouin shift from stress is much larger than the Brillouin shift from temperature changes. Therefore we look for departures from the simple ground-temperature pattern discussed above to determine if fiber stress is present.

5. Conclusions

A buried cable can be used as a distributed temperature and stress sensor, even though the fiber has not been pre-calibrated. In our presentation we will show the results of a two-year ongoing study of the temperature and stress changes in a buried fiber-optic cable.

References

1. K. Shimizu. T. Horiguchi, Y. Koyamada, and T. Kurashima, "Coherent Self-Heterdyne Brillouin OTDR for Measurement of Brillouin Frequency Shift Distributions in Optical Fibers", *IEEE Journal of Lightwave Technology.,* **vol. LT-12,** pp. 730-736, 1994.
2. T. Horiguchi and M. Tateda, "Non-Destructive Measurement of Single-Mode Optical Fiber Attenuation Characteristics Using Brillouin Interaction," *IEEE Journal of Lightwave Technology.,* **vol. LT-7,** pp. 1179-1176, 1989

Figure 1: Satelite map of the cable route in California showing the 3 nodes.

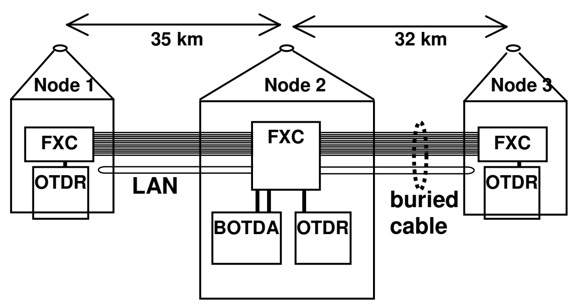

Figure 2: Experimental setup showing the three nodes connected by the fiber and LAN. FXC = fiber cross connect