

Dual Source Self-Calibration Method for the Fiber-Optic Raman DTS (Distributed Temperature Sensor)

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ABSTRACT

A method to improve the accuracy of distributed temperature measurements derived from the intensities of back scattered wavelengths along a sensing fiber in a Raman DTS instrument is presented. Optical attenuation profile along the optical fiber sensing cable can be empirically derived for the light wavelengths of interest and used to obtain an improved temperature calculation. This method utilizes two light sources with different wavelengths to determine and compensate the wavelength dependent local variation in attenuation. The wavelength values are chosen so that the anti-Stokes Raman return of the primary light source is approximately the same value as the Stokes Raman return of the secondary source. An alpha system is used in two case studies to validate the effectiveness of the new method, and the result is presented.

1. INTRODUCTION

One key factor in obtaining accurate and reliable temperature measurement using fiber optic DTS technology is the optical property of the fiber. DTS technology derives temperature information from two backscattered signals that are in different wavelength band, one being the Raman anti-Stokes signal, and the other being either Raman Stokes or Rayleigh signal (see figure 1). Since optical fiber has different attenuation characteristics as a function of wavelength, a proper correction needs to be made so that the two signals exhibit the same wavelength attenuation. With the assumption that the attenuation profile is exponentially decaying as a function of distance, an exponential function with the exponent called Differential Attenuation Factor (DAF) is multiplied to the Stokes or Rayleigh data as correction factor to match the attenuation profile to that of the Anti-Stokes signal, as shown in figure 2. Temperature is then derived by taking the ratio of the two signals. DAF is the difference in attenuation between two signal wavelengths and is typically determined by the fiber material. Further fine adjustment on actual DAF can be made during calibration process

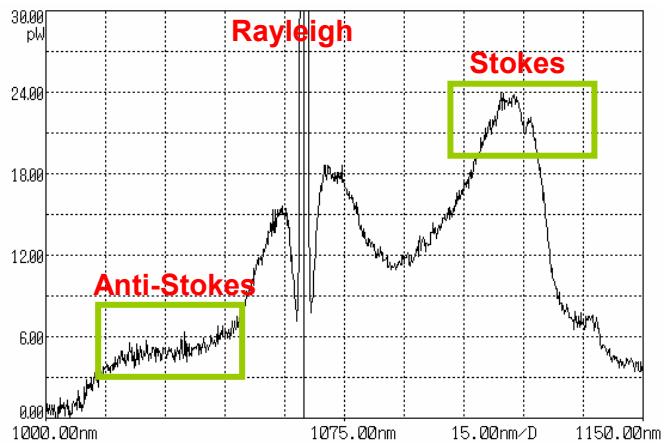


Figure 1. Spectrum of Raman and Rayleigh signals

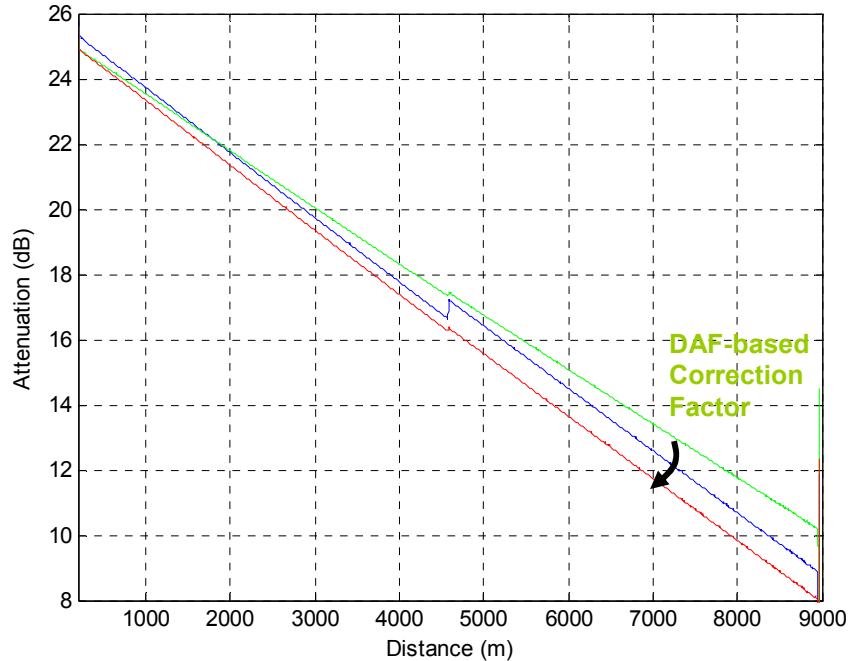


Figure 2. Typical DAF adjustment (anti-Stokes: blue, Stokes: green, DAF adjusted Stokes: red).

The conventional approach of using DAF has an inherent limitation in many cases because of the assumption that the attenuation of the optical signal along the sensing fiber path is always exponentially decaying, whereas in reality, many different factors can cause the actual attenuation to deviate from the exponential form. For example, localized mechanical stress or strain applied to the sensing fiber can cause an increase in attenuation of which the magnitude can also be wavelength dependent. In another example, hydrogen gas ingression can cause the overall attenuation to be continuously fluctuating. One typical way to deal with such abnormality is dividing the entire fiber span into several sections and applying different DAF's for each section. However, as the condition of the fiber changes as a function of time, it will require re-sectioning and readjusting DAF's repeatedly, or in some cases, the attenuation change is continuously varying that sectioning may not be feasible at all. Furthermore, deriving accurate DAF's require knowledge of temperature at the end points of each section. Such requirement cannot be met in most cases once the sensing fiber is installed at the application sites.

A new self-calibration method has been developed by SensorTran to automatically adjust for the variations of attenuation. This method utilizes two light sources in which their wavelengths are selected such that the anti-Stokes signal of the primary light source coincides in wavelength with the Stokes signal of the secondary light source. Such method enables accurate and repeatable temperature measurement independent of the changes in the fiber condition.

A self-calibration alpha system is built from a commercially available DTS system (SensorTran DTS 5100). DTS 5100 is a DTS system based on 1064nm laser, and a 980nm laser is added for the self-calibration. Figure 3 shows a block diagram of the alpha unit. When self-calibration routine is activated 1064nm and 980nm laser sources are connected to the optical setup sequentially, and scattered Rayleigh and Stokes bands are collected. The 980nm Stokes signal is processed with both Rayleigh signals to produce a new Stokes signal that overlaps in wavelength with 1064nm anti-Stokes signal (1064nm propagating forward and ~1015nm propagating backward). The ratio between the processed 980nm Stokes signal and 1064nm Stokes signal produces the calibration factor that replaces DAF derived exponential correction factor. In subsequent temperature measurement, the DTS system uses 1064nm laser only to take Stokes and Anti-Stokes signals, apply the calibration factor to the Stokes signal, and then take the ratio to generate temperature information.

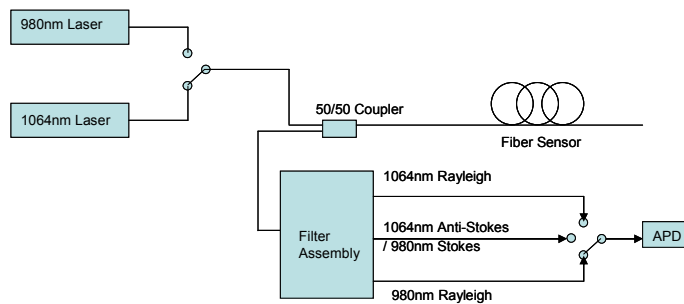


Fig. 3. Block diagram of self-calibration alpha system

The alpha unit has been tested with two cases of non-linear differential attenuation, a hydrogen darkened fiber, and a fiber with several strain points. In this paper we present the result of the self-calibration test in these two cases.

2. CASE 1: HYDROGEN DARKENED FIBER

A spool of hydrogen darkened fiber is obtained to verify the effectiveness of self-calibration method. The sample fiber (carbon and polyimide coated, ~800m long) deployed in an oil well for 3 months and was diagnosed to be no longer usable was used for the case. To be compared to normal fiber, the darkened fiber is spliced with 1.5km of fiber in normal condition (see figure 4). The normal fiber spool is placed in room temperature (~25°C) while the darkened fiber spool is placed in a 40°C oven. A self-calibration routine is initially used to generate the calibration factor, and subsequent measured data are processed with the calibration factor to produce temperature data.

Figure 4 shows typical attenuation profiles of 1064nm Stokes (Green) and Anti-Stokes signals (Blue). Application of conventional single DAF on Stokes signal (Red) effectively corrects the differential attenuation in normal fiber section to match in slope with Anti-Stokes signal. However, it fails to fully compensate the non-linear differential attenuation in the darkened fiber section, leaving some difference in slope between the two signals.

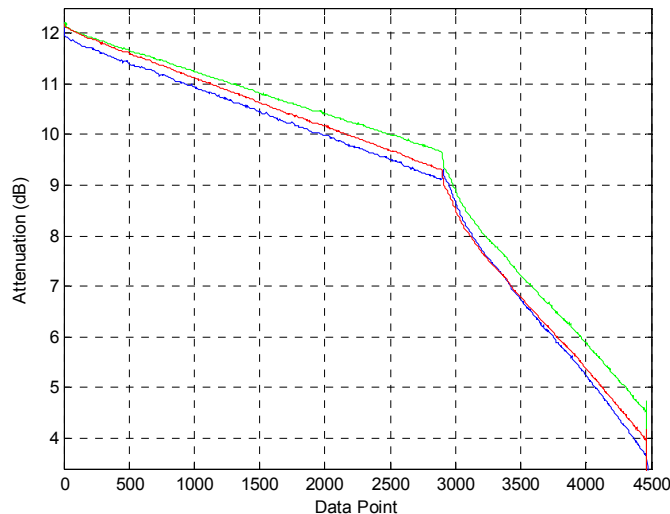


Figure 4. Conventional DTS analysis method - attenuation profiles of 1064nm Stokes (Green), Anti-Stokes (Blue), and DAF-adjusted Stokes signal (Red).

The calibration factor generated by self-calibration method is compared with DAF-based factor in figure 5. In addition to the single slope pattern in the normal fiber section, the self-calibration factor shows the effective compensation by the self-calibration method to the non-linear attenuation profile in the darkened fiber section. Figure 6 shows the attenuation profile of the same Stokes and Anti-Stokes signal along with self-calibrated Stokes signal. With the calibration factor generated by self-calibration method, the attenuation profile of the Stokes signal is closely matched with that of Anti-Stokes signal across the entire fiber span.

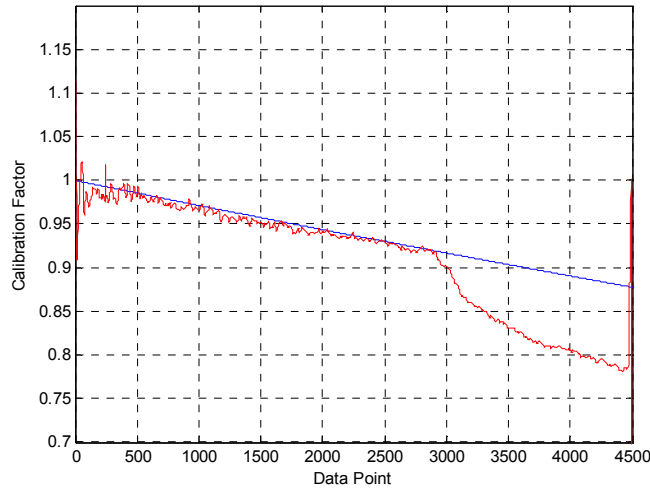


Figure 5. Comparison between the calibration factors: DAF generated (blue) vs. self-calibration generated (red).

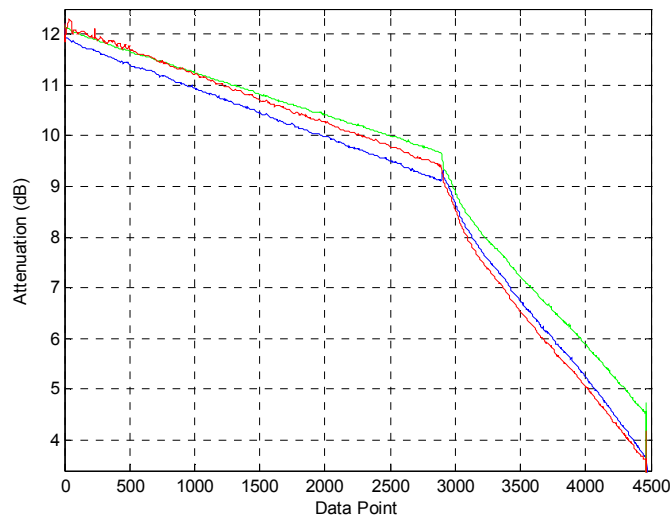


Figure 6. Attenuation profiles of 1064nm Stokes (Green), Anti-Stokes (Blue), & self-calibrated Stokes (Red) signals.

Figure 7 shows the resulting temperature profiles produced by both conventional method and self-calibration method. It is clearly shown that the self-calibrated temperature profile is not affected by the non-linear attenuation.

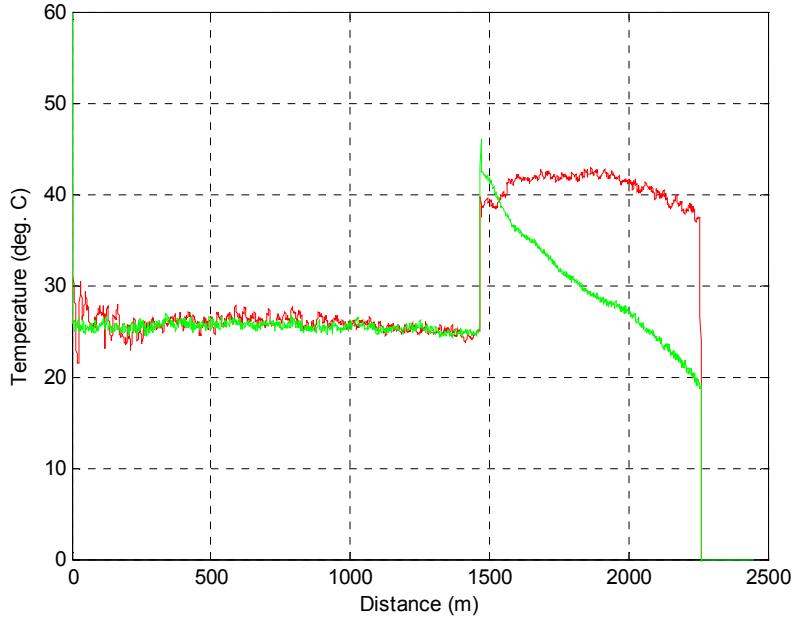


Fig. 7. Temperature profiles calculated by conventional method (green) vs. self-calibration method (red). Self calibration result shows correct temperature reading.

3. CASE 2: PRESSURE INDUCED LOCAL ATTENUATIONS

The self-calibration alpha system is also tried in a gas well downhole application. A sensing fiber of 6km length is blown into a tube and 4km of it is inserted downhole to monitor the temperature while the well is being serviced. It was noticed after the insertion of the fiber into the tube that there appeared to be several locations where attenuation of the Stokes signal show visible increase. Using conventional DTS, such change in attenuation profile resulted in step-up in temperature profile while in ambient temperature in spool (see figure 8).

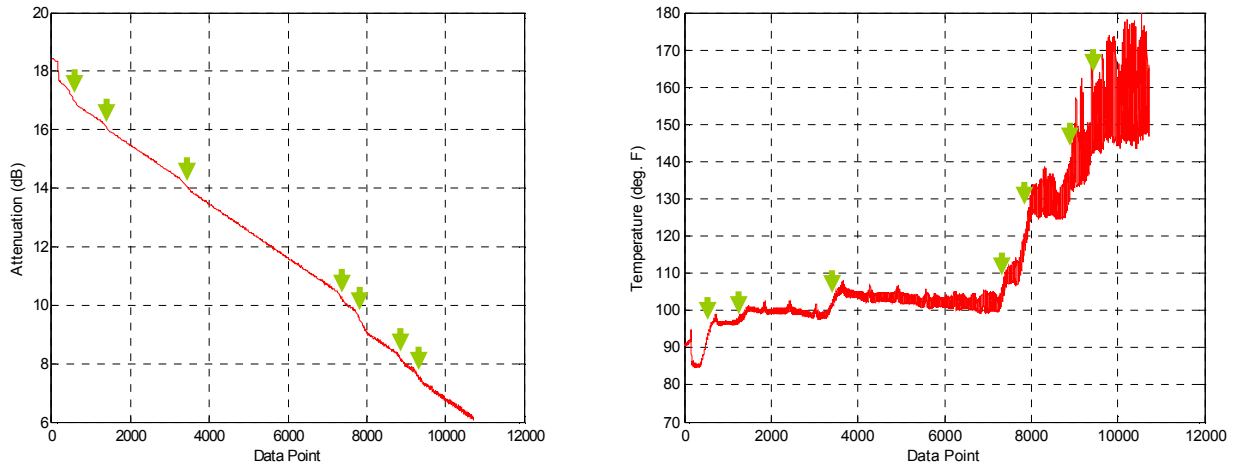


Figure 8. Left: Attenuation profiles of local stresses, Right : temperature profile of conventional DAF correction.

Self-calibration system is used to collect backscattered signals profiles with dual sources, and an generated array of calibration factor clearly shows the compensation for those attenuation variations in several locations (see

figure 9). Application of the calibration factor to the measured Stokes signal resulted in a corrected attenuation profile, which resulted in correct temperature measurement, is shown in figure 10.

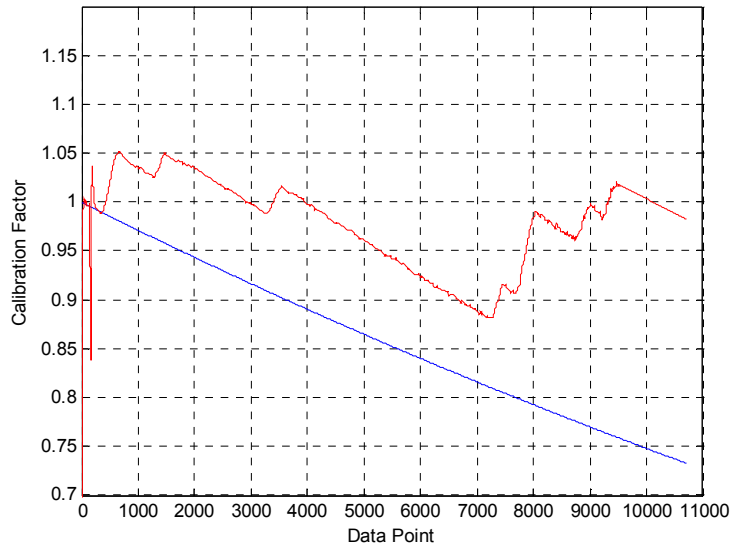


Figure 9. Calibration Factor array derived with Self-Calibration method (red) vs. conventional DAF (blue).

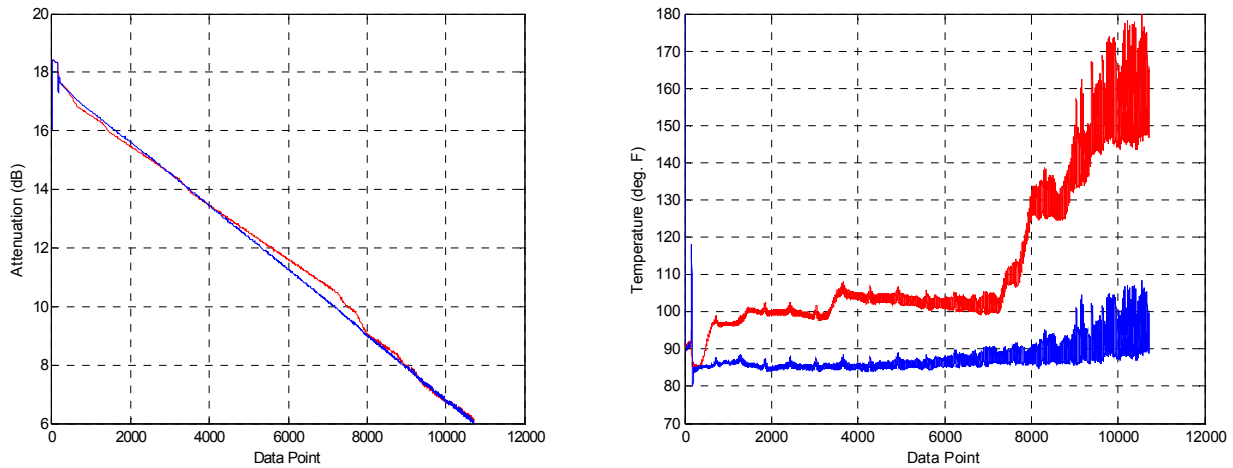


Figure 10. Left : Attenuation profiles of 1064nm Stokes signal , Right :resulting temperature profile made by Conventional DTS (red) vs. Self-Calibrated DTS (blue).

4. CONCLUSION

In this white paper, we described the use of new self-calibration method in DTS to effectively compensate for non-linear differential attenuation characteristics of fiber sensor with test results of two cases. As clearly presented, the self-calibration method calculates accurately temperature information from sensor fiber independent of local attenuations. This will enable the DTS system to be effectively used with any sensor fiber without priori knowledge of its optical characteristics such as DAF or any local variation in attenuation due to mechanical stress/strain or hydrogen ingress. Also, this method shows the potential of accurate and repeatable measurement with a sensor fiber under extreme temperatures.