Hydrogen Absorption and Losses Characterization of Submarine Fiber Optic Cable

K. Namsongnern[1] and P.P. Yupapin[2]
[1] Fiber Optic Research and Development Laboratory, Celestica (Thailand) Ltd., 49/18 Moo 5,Laem Chabang Industrial Estate, Tungsukla, Sriracha, Chon Buri 20230
[2]Lightwave Technology Research Center, Department of Applied Physics, Faculty of Science King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520

Abstract

The hydrogen induced attenuation increases in optical fiber cables has been tested and estimated. The increased spectrum attenuation of optical fiber cables is investigated by submersing the tested cables in ocean water tank for a period time. The increased attenuation in dB is characterized using monochromator and oscilloscope. The test procedure is intended to provide a test that is characterized the effect on fiber optic attenuation due to hydrogen generated by the cable components only, does not address the effect of hydrogen generated from sources exterior to the cable. The saturation of attenuation in dB is also determined.

Keyword: fiber optic cable, fiber optic standard

1. INTRODUCTION

The fiber optic systems with little or no system margin are most at risk in communication link. The attenuation of optical fiber is one of the most important parameter that limits the optical power within transmission window. Obviously, the lower attenuation the greater will be required repeater spacing and the lower will be the cost of the communication system. In fact, the attenuation of optical fiber is not stable. It can increase due to hydrogen that diffuses into the fiber core. In order to estimate system margin of optical power in communication system, the saturated value of attenuation [1-2] which increasing by hydrogen absorption is determined. In this research, The ocean water is heated for maintaining at the temperature of $60^{\circ}c \pm 1.5^{\circ}c$ and being circulated by the anti-corrosion [3] water pump. The source with wavelength between 1,292 and 1,328 nm from OTDR is launched in to the fiber optic cable. The fiber optic losses and hydrogen absorption of the tested fiber optic cable are characterized and discussed.

2. THEORY

There are three key component of insertion loss in an optical fiber, where one is the OH absorption, Rayleigh scattering and Urbach tail[7] as shown in the Figure 1. In the transmission windows, light sources wavelength of 0.85 and 1.66 μm are employed, the OH absorption produce such a high peak [8-10] within the first overtone at the wavelength of ~ 1.38 μm [8]. The lower peak is obtained at the wavelength of 1.2 μm and 0.95 μm. For the Rayleigh and Urbach losses have shown sum of them contribute the minimum limit of attenuation in transmission window, using SiO_2 glass, could not reduce less than the sum of Rayliegh and Urbach tail. But it can be increased by the hydrogen absorption. Since the first overtone of the OH stretching vibration is absorbed at the wavelength of ~ 1.38 μm, when long-hual communication wavelength around 1.30 and 1.55 μm are employed and affected by hydrogen absorption. There are two mechanisms of the increasing loss due to hydrogen, which is classified as following [5-6].

Table1 Parameter of the OH-Absorption using source between 1200 and 1550 nm.

n	Function	$\lambda_n(\mu m)$	A_n	$\sigma_n(\mu m^{-1})$
1	Lorentz	1.412	0.142	0.00883
2	Lorentz	1.391	0.606	0.00700
3	Gauss	1.381	0.542	0.00440
4	Lorentz	1.352	0.020	0.00615
5	Gauss	1.247	0.059	0.00663

2.1 Reversible optical loss increases due to the number of molecular hydrogen that diffuse into the fiber core and insert between SiO_2 configuration lattices, which is known as the interstitial hydrogen effect. Hydrogen molecule induced loss in this case is given by[5]

$$L_{H2} = AP_{H2} \exp(2.24/RT) \text{ dB/Km} \quad (1)$$

Where A is a constant that to be determined by source wavelength. A is 0.0102 and 0.0195 at a 1.3 and 1.5-μm wavelength respectively. P_{H2} is the partial pressure of hydrogen, R is gas constant ($R=1.986\times10^{-3}$ K cal / mol.K) and T is temperature.

2.2 Irreversible optical loss increase due to the chemical reaction between hydrogen atom and fiber constituent materials, which is further classified into the following two sub mechanisms of loss increase. i) Loss increase due to OH formation or OH absorption, and ii) Loss increase affected by short wavelength loss edge (SLE)

The result of OH attenuation spectrum, after normalization of the individual spectra yielded nearly identical results, which can be fitted with high accuracy to sum of four Lorentzian components and one Gaussian component. Table1 gives the averages of the fitted values at the center wavelengths with the intensity ratios, and widths of the components. Each measurement of OH spectrum could be fitted with intensity parameter varying by less than 15% and 10% of mean value and width parameters respectively.

The applied Gaussian function is expressed as[4]:

$$ATT_n = \alpha_{OH} A_n e^{\left(-\left(\frac{1/\lambda - 1/\lambda_n}{\sigma_n}\right)^2\right)} \quad (2)$$

where the Applied Lorentzian function is given as :

$$ATT_n = \frac{\alpha_{OH} A_n}{1 + \left(\frac{1/\lambda - 1/\lambda_n}{\sigma_n}\right)^2} \quad (3)$$

Total OH-absorption is written by

$$A_{OH} = \sum_{n=1}^{5} ATT_n \quad (4)$$

where σ_{OH} = peak intensity dB/km .

3. EXPERIMENT

The experimental system is as shown in Figure 1, a cylindrical plastic tank with 60cm diameter and 40 cm height is used as a water tank. The sample fiber optic cable under test (CUT) that exposed 24 cores at all ends and splice each other except two ends, for launching propose providing the connection as shown in Figure 1. The FC/PC connector is used at the end of CUT without any splicing connection, the another end is cut by a fine cleaver. The CUT is protected by the PVC matting sleeves, around 10 cm long in each length, for load protection from upper portion as shown in Figure 1. Bend and position CUT in plastic tank, then the water thank is filled with the instant ocean water to completely immerse the CUT.

Set up all equipment as Figure 1, where all parts of equipment in the direction of water flow that is made from the anti- corrosion materials. The water is heated by electrical heat source outside the water tank and temperature is controlled to maintain at $60^\circ c \pm 1.5^\circ c$ with temperature controller.

Circulate the water to maintain a homogeneous mixture of the test solution by the anti-corrosion water pump. The CUT ends are terminated securely outside the tank providing the connection FC/PC end with OTDR source, where the another end is connected to the monochromator with a photo-detector and oscilloscope respectively, as shown in Figure 2. The line-width of OTDR source is measured with experimental set up as shown in Figure 3 before connecting the CUT to OTDR. Elevate the temperature of the water to the test temperature of 60 ° C for 4 hours.

Establish baseline of output voltage which to be measured at wavelength of 1292 nm to 1328 nm, after elevate to test temperature. Discharge the salt crystals into the sea water tank after completing the baseline measurement. Every 24 hours after establishing the baseline measurement at 1292nm to 1328 nm, continue to take this measurements at 24 hour intervals until the attenuation has stabilized within 0.15 dB/km of the previous day's measurement. Calculate attenuation that increasing after finish the test and determine saturated attenuation values that affect by Hydrogen.

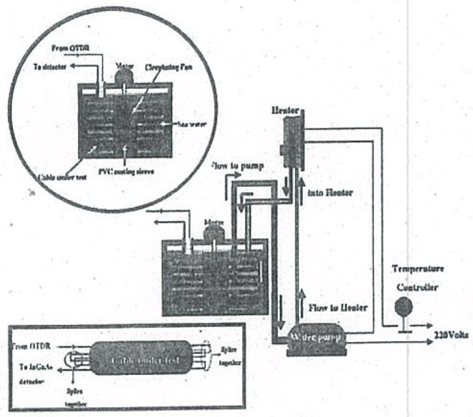


Figure 1 Illustrate set up diagram of control environment section.

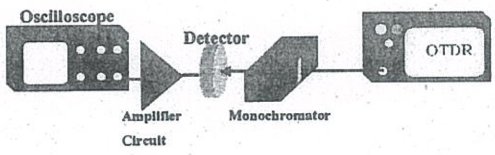


Figure 2 Illustrates the experimental set up of the loss increasing measurement.

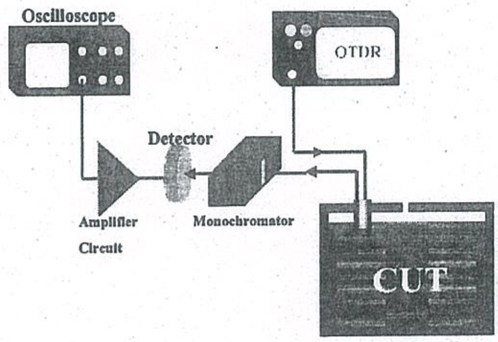


Figure 3 Illustrates the experimental set up of the OTDR line-width measurement.

4. RESULTS

The decreased voltage output is observed after the 48th hour after the baseline measurement. Where the voltage decreased to minimum values at the 180th hour after the baseline measurement. The output voltage value is stable after the 180th hour until to 216th hour or the ninth day. α is the Insertion loss parameter in dB/km

$$\alpha = -\frac{10}{L}\log\frac{P_{out}}{P_{in}} \qquad (5)$$

where P_{out} is total optical power output in mW unit that is going out of fiber optics, P_{in} is optical power input in mW unit that is going to be launched in fiber optic cable, L is a length of fiber optic cable in kilometer that is measured from input to output end of the tested cable.

Optical power (P), which to be focused on junction of InGaAs photodetector causes proportional current to flow across the junction, which is expressed as $P \propto i$. As simplified amplifier circuit in Figure 2, the current proportional with voltage difference (V) across the ends of resistance or $i \propto V$. Then

$$P \propto V \tag{6}$$

Consider equation (1) and (2), yield

$$\alpha = -\frac{10}{L}\log\frac{V_{out}}{V_{in}} \tag{7}$$

If initial measurement of optical power output is V_o and consecutive optical power outputs are V_1, V_2,...,V_n , determine loss values as equation (4)

$$\alpha_n = -\frac{10}{L}\log\frac{V_n}{V_{in}} \tag{8}$$

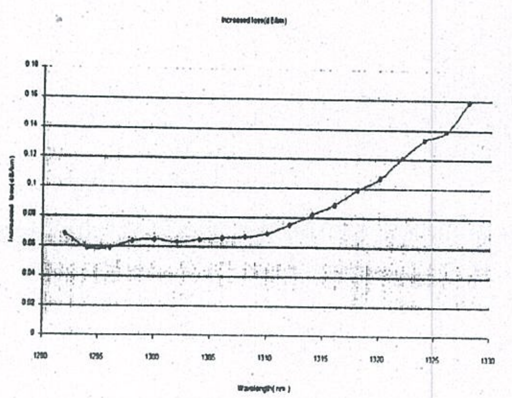
Difference between equation (7) with (8) is the increased loss values.

$$\alpha_n - \alpha_o = \Delta\alpha = \frac{-10}{L}\left(\log\frac{V_n}{V_{in}} - \log\frac{V_o}{V_{in}}\right) \tag{9}$$

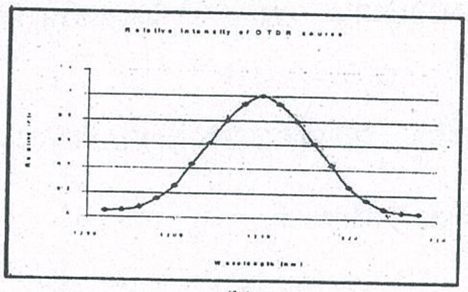
and thus

$$\Delta\alpha = \frac{-10}{L}\log\frac{V_n}{V_o} \text{ dB/km} \tag{10}$$

From equation (10) calculate loss values that increasing from the initial values and tabulated in table 3. The results are shown in Figure 4.



(a)



(b)

Figure 4 (a) Shows the fiber loss characterization of the tested fiber , and (b) shows to the estimate line-width of OTDR.

Therefore, the cables that is which produced by Thai Fiber Optics, have the saturated Hydrogen absorption less than 0.1 dB/km. FOTP-183 is designed to make the critical environment as if the test cable to be installed in the normal environment for 15-20 years. As thus, it can be estimated maximum system margin that induced by hydrogen is less than 0.1 dB/km at 1310.00 nm. Photographs of the laboratory set up are shown in Figure 5.

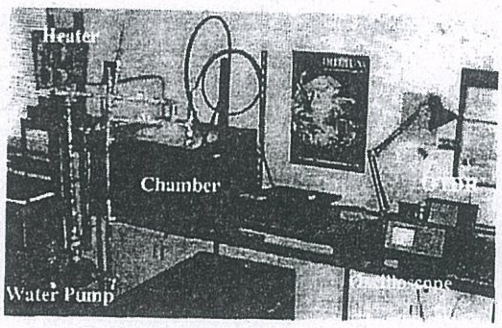


Figure 5 A photograph of the laboratory equipment.

5. CONCLUSION

This test is modified from FOTP-183. All equipment in this test is economical prices. Although the measurement is not high accuracy but it can show the maximum limit of increased losses that affected from hydrogen absorption. The test result is shown the at 1310 nm the loss is no more increased than 0.2 dB/km, which is the worst case. In this test is shown the result of using source wavelength at 1310 dB/km, the loss is increased to saturated values around 0.07 dB/km.

6. ACKNOWLEDGEMENTS

The authors are very please to acknowledge to the Department of Applied Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang (**KMITL**) and Celestica (Thailand) Ltd. for their financial support of the project research at Lightwave Technology Research Center (**LTRC**), KMITL.

REFERENCES

[1] B. Wiltshire and M.H. Reeve," A Review of the Environmental Factors Affecting Optical Cable Design", *J. Lightwave Technol.*, **Vol.6**, No.2, Feb.1988, pp. 179-185.

[2] D. Mercurse, "Principles of Optical Fiber Measurements", Academic Press, New York, 1981

[3] TIA/EIA Standard,"FOTP-183: Hydrogen Effects on Optical Fiber Cable", TIA/EIA Standard of optical fiber test procedure series.

[4] M. Bredol, D. Leers, L. Bosselaar and M. Hutjens,"Improved Model for OH Absorption in Optical fibers", *J. Lightwave Technol.*, **Vol. 8**, No.10, Oct.1990, pp.1536-1540.

[5] M. Ohnishi and et al.,"Loss Stability Assurance Against Hydrogen for Submarine Optical Fiber Cable", *J. Lightwave Technol.*, **Vol. 6**, No.2, Feb.1988, pp.203-209.

[6] M. Kuwazuru and et al.,"Estimation of Long-Term Transmission loss Increase in Silica-Based Optical Fiber Under Hydrogen Atmosphere", *J. Lightwave Technol.*, **Vol.6**, No.2, Feb.1988, pp.218-225.

[7] J. stone and G.E. Walrafen,"Overtone Vibrations of OH Groups in Fused Silica Optical Fibers", *J.Chem. Phys.*, **Vol. 69**, p.493, 1978.

[8] N. Uesugi, Y. Murakami, C.Tanaka, Y. Ishida, Y. Mitsunaga, Y. Negishi and N. Uchida, "Infared Optical Loss Increase for Silica Fiber Cable Filled with Water", *Electron. Lett.*, **Vol. 19**, pp.762-764,1983.

[9] K. Mochizuki, Y. Namihira, M. Kuwazuru and Y. Iwamoto, "Behavior of Hydrogen Molecules Absorped on Silica in Optical Fibers", *IEEE J. Quantum Electron.*, Vol. QE-**20**, pp.694- 697,1984.

[10] J. Stone, "Interactions of Hydrogen and Deuterium with Silica Optical Fibers:A Review", *J. Lightwave Technol.*, **Vol. LT-5**, pp.712-733, 1987.