Longitudinal measurement of chromatic dispersion along an optical fiber transmission system with a new correction factor

Madiha Abbasi¹, Mirza Imran Baig² and Muhammad Shafique Shaikh³

¹ Dept. of Telecommunication Engineering, Sir Syed University of Engineering and Technology, Karachi, Pakistan (madihaabbasi2@hotmail.com)
² Dept. of Telecommunication Engineering, Sir Syed University of Engineering and Technology, Karachi, Pakistan (imran101b@yahoo.com)
³ Dept. of Electrical and Computer Engineering, King Abdulaziz University, Jeddah, Saudi Arabia (msmuhammad@kau.edu.sa)

Abstract. At present existence OTDR based techniques have become a standard practice for measuring chromatic dispersion distribution along an optical fiber transmission link. A constructive measurement technique has been offered in this paper, in which a four wavelength bidirectional optical time domain reflectometer (OTDR) has been used to compute the chromatic dispersion allocation beside an optical fiber transmission system. To improve the correction factor a novel formulation has been developed, which leads to an enhanced and defined measurement. The investigational outcomes obtained are in good harmony.

1. Introduction
As the fiber optic networks increases rapidly, the responsibilities for monitoring different characteristics of fiber also increases and creating hurdles for telecommunication companies. Various experiment setups for this purpose have been made but actually that are time-taking and costly. For locating breaks and other anomalies, optical time domain reflectometers (OTDR) have been used (1).

Some performance parameters like transmission length and bit rate are badly affected by Chromatic Dispersion (CD). It is produce when different wavelength of light propagates with different velocities in fiber. It raises the pulse broadening effect in transmission systems (1). In dispersion management transmission system, the need for accurate measurement of chromatic dispersion is obvious. By this technique, the chromatic dispersion can be compensated at the wavelength of interest which is helpful in optical networking.

2. Background and theory
2.1. Backscattered Power:
As in (1), the following steps have been carrying out for longitudinal Chromatic Dispersion measurement:
1. Accusation of bi-directional OTDR backscattered power;
2. Estimation of longitudinal mode field diameter (MFD).
3. Estimation of the Waveguide and Material dispersion contribution.

Light which is move all along a fiber with wavelength $\lambda$, is backscattered from a generic section $z$, that backscattered portion is captured by OTDR (1). To know the information about scattered light intensity, the light pulse is taken shorter than the fiber length. The optical power $P(\lambda, z)$ of backscattered light for a single mode fiber can be expressed as (1), (2) and (3) at time $t=0$,

$$P(\lambda, z) = P_0 \alpha_s(z)WB(\lambda, z) \frac{c}{N} \exp\left(-\frac{2z}{\gamma(x)}dx\right)$$ (2.1)

where

- $P_0$ = input power
- $\alpha_s(z)$ = local scattering coefficient
- $W$ = pulse width
- $B(\lambda, z)$ = backscatter capture fraction
- $z = \text{position beside the fiber } z = ct/N^2$
- $N = \text{group refractive index}$
- $\gamma(x)$ = local attenuation coefficient

Backscattered power has two parts; one is an exponential decay due to absorption in the glass and scattering. Second signal component is due to the changes in mode field diameter and $\alpha_s$ which is sensitive to local imperfections (1). The resulting trace of OTDR is the summation of these two components. In (4) and (5), separated results of these two OTDR signals have been described.

2.2. MFD Evaluation:
As in (1), $S_1(z)$ is the backscattering trace from the origin and $S_2(L-z)$ is the backscattering trace read from the end of the fiber, which are defined as follows:

$$S_1(\lambda, z) = 10\log[P(\lambda, z)]$$

$$S_2(\lambda, L-z) = 10\log[P(\lambda, L-z)]$$ (2.2) (2.3)

Using equation (2.2) and (2.3), the waveguide imperfection contribution $I(\lambda, z)$ can be expressed as (1)

$$I(\lambda, z) = \frac{S_1(\lambda, z) + S_2(\lambda, L-z)}{2}$$ (2.4)

It is defined in (3) and (6), the mode field diameter $2W(\lambda, z)$ has significance as compare to the variation in the local scattering coefficient $\alpha_s$. Thus, the normalized imperfection contribution $I_n(\lambda, z)$ at $z = z_o$ is as follow

$$I_n(\lambda, z) = I(\lambda, z) - I(\lambda, z_o) = 20\log\left[\frac{W(\lambda, z_o)}{W(\lambda, z)}\right]$$ (2.5)
As in (1) and (6), when the mode field diameter $2W(\lambda, z_0)$ at $z = z_0$ is given, the mode field diameter distribution $2W(\lambda, z)$ can be obtained

$$W(\lambda, z) = W(\lambda, z_0) \prod_{0}^{I_x(\lambda, z)} \left[ \frac{I_x(\lambda, z)}{20} \right]$$

(2.6)

2.3. Evaluation of MFD with Correction Factor:
In the MFD Evaluation, the fluctuation in scattering co-efficient $\alpha_s(z)$ across the fiber is assumed negligible in comparison with fluctuation in MFD, from equation (2.6) longitudinal MFD can be obtained. But it is important to take in consideration the length dependency of the fiber when the scattering coefficient differs greatly along a fiber. By considering the change in refractive index and scattering coefficient, the imperfection contribution $I(\lambda, z)$ expressed in (1), (3) and the normalized imperfection contribution $I_n(\lambda, z)$ at $z = z_0$ can be rewritten as

$$I_x(\lambda, z) = 10 \log \left[ \frac{\alpha_s(z)}{\alpha_s(z_0)} \cdot n^2(z_0) \right] + 20 \log \left[ \frac{W(\lambda, z_0)}{W(\lambda, z)} \right]$$

(2.7)

The first expression on the right in above equation is considered as correction factor $K$.
It is defined in (1) that by using the relative refractive index $\Delta$ and the Rayleigh scattering coefficient $R$ for GeO$_2$ doped core fiber, the correction factor $K$ is rewritten as

$$K = 10 \log \left[ \frac{1 + 0.62\Delta(z)}{1 + 0.62\Delta(z_0)} \cdot \left( \frac{50 - \Delta(z_0)}{50 - \Delta(z)} \right) \right]$$

(2.8)

Thus, the distribution of mode field diameter $2W(\lambda, z)$ can be acquired as (1)

$$W(\lambda, z) = W(\lambda, z_0) \prod_{0}^{I_x(\lambda, z) - K} \left[ \frac{I_x(\lambda, z) - K}{20} \right]$$

(2.9)

2.4. New Correction Factor $K$:
The group refractive index of fiber under testing conditions also influenced the received OTDR backscattered power. Therefore by taking in account, it can be figured out from (2.1). The group refractive index expressed as in (7)

$$N = n - \lambda \frac{dn}{d\lambda}$$

(2.10)

Where,
$n =$ fiber refractive index
$\lambda =$ operating wavelength
In (1), an assumption has been made by ignoring the second term in the equation (2.10). By taking into account this neglected factor, a new correction factor has been formulated. Therefore, equation (2.7) can be amended as

$$I_n(\lambda, z) = 10 \log \left[ \frac{\alpha_s(z)n^2(z_o)(2n(z_o)-1)}{\alpha_s(z_o)n^2(z)(2n(z)-1)} \right] + 20 \log \left[ \frac{W(\lambda, z_o)}{W(\lambda, z)} \right]$$

and the correction factor $K$ has to be changed as

$$K = 10 \log \left[ \frac{\alpha_s(z)n^2(z_o)(2n(z_o)-1)}{\alpha_s(z_o)n^2(z)(2n(z)-1)} \right]$$

Consequently, we get a new correction factor $K$, which has an effect on the measurement of MFD and chromatic dispersion (CD).

2.5. Evaluation of Chromatic Dispersion (CD):

The CD $\sigma$ is a summation of the material dispersion $\sigma_m$ and waveguide dispersion $\sigma_w$. $\sigma_m$ and $\sigma_w$ calculations and estimations are well defined in (2) and (8) and (9).

$$\sigma_w = \frac{\lambda}{2\pi^2cn} \frac{d}{d\lambda} \left( \frac{\lambda}{W^2} \right)$$

The experiential relationship between the MFD $2W$ and the normalized frequency $V$ has been presented in (10). By substituting the equation of wavelength dependency of mode field diameter $2W$ expressed in (1), in equation (2.13) then the waveguide dispersion $\sigma_w$ taken from

$$\sigma_w(\lambda, z) = \frac{\lambda}{2\pi^2cnW^2(\lambda, z)} \times \left\{ 1 - \frac{2\lambda}{W(\lambda, z)} \left( \frac{3}{2} g_1(z) \lambda^{0.5} + 6g_2(z) \lambda^2 \right) \right\}$$

3. Results

3.1. Experimental Setup:

With the OTDR the backscattered signal power is measure by using four wavelengths of 1.31, 1.45, 1.55 and 1.625 $\mu$m. The transmission link composed of 2km single mode fiber (SMF), 10 km of SMF, 10 km of SMF and 20 km long dispersion compensation fiber (DCF).

3.2. Measurement of Mode Field Diameter:

Figure.1 shows the results for the MFD distribution. The difference between prior and our intended new correction factor $K$ can be observed. Our new results are shown with the red line which is superimposed on previous result which is indicated by blue line. A significant enhancement in the MFD measurements is clear.
3.3. Measurement of Chromatic Dispersion:
The results of longitudinal CD measurement are shown in figure 2. In this paper the both previous and recent result of proposed correction factor K are presented. Result of new correction factor is shown with red color line where as result of old correction factor is represented by blue color line.

4. Conclusion
With our projected new correction factor K, the chromatic dispersion measurement along optical fiber transmission system become clearer. As compared with the previous technique with old correction factor, this constructive OTDR based technique with new correction factor gives improved results. The chromatic dispersion measurements are now turning out to be more accurate and precise.

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