A classification of optical fiber types on the spectrum profile of the Mandelstam – Brillouin backscattering

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Abstract. The investigation deals with the type classification of optical fibers on the reflectogram obtained by the Brillouin reflectometer. The program for determination of optical fiber type by the Brillouin reflectogram is presented. The values of Brillouin frequency shift for some optical fiber types are given. The possibility to classify optical fibers on types and manufacturers using reflectogram is of practical interest.

1. Introduction
The principal aim of monitoring and early diagnostics of fiber optical communication lines (FOCL) is to detect and eliminate the “problem” sections in the OF: sections with temperature variation and strain, sections with bends, etc. [1, 2].

The Brillouin optical time-domain reflectometers (BOTDR) are utilized to detect FOCL sections with high OF strain and temperature variations. The distribution of the Mandelstam – Brillouin backscatter spectrum (MBBS) along the OF is recorded and examined in BOTDR [1 – 3].

The BOTDR can provide the distribution of MBBS in the OF. We can estimate the value of the \( f_B \) – Brillouin frequency shift, and then the strain along the OF by determining the position of a maximum (peak) in the MBBS profile [4 – 6].

The study of MBBS in the OF of different manufacturers with diverse dispersion laws and structure of the OF core is of importance in that the Brillouin reflectometry has significant levels of signal power introduced into the OF.

2. The theory
As shown by theoretical and experimental investigations [6 – 12], the shapes of frequency MBBS profiles [4 – 6] as well as the “bars of zero-level” \( (f_{B0}) \) for standard conditions, for various OF types and manufacturers, differ [1, 2].

To measure the temperature and strain of the OF it is necessary to determine the \( f_{B0} \) “zero-level” and coefficients for the \( f_B \) for each OF type [8 – 12].

To detect the sections with temperature variations and strain it is desirable to have a reference BOTDR-reflectogram for the testable OF under normal conditions (without of mechanical strains and at room temperature). This reflectogram simplifies the timely detection of a “problem” section in an OF, consequently eliminates a problem situation in FOCL before the OF accident [1, 2].

The evidence from practice shows, even the same-type OF of different manufacturers with similar optical characteristics have diverse shapes of MBBS profile [5 – 7].
The database of MBBS profiles of different fiber types and companies permits one to classify the OF in FOCL, as well as detects the problem sections [1, 5].

3. Statement of the problem
Experimental investigations with BOTDR “AQ 8603” with the cooperation of CJSC “Moskabel–Fujikura” were made to analyze the MBBS profiles in OF of various types and manufacturers.

The analysis of MBBS behaviour of different OF types and manufacturers was carried out in previous works [6 – 12] depending on external mechanical influences and temperature.

Special attention was given to the frequency characteristics of OF MBBS.

4. The research results
The program described below was developed to determine the reflectogram type quickly, accurately and conveniently. The program is written in C#-language by using the development environment Microsoft Visual Studio 2017 [13].

The process of program consists of image (width of 800 pixels and height of 600 pixels) loading by the user as a bmp-file, taken from the BOTDR output files.

The necessary image part is cropped by the program manually for the analysis, and then the profile of OF MBBS is formed. Whereat it can be save as a separate file for further analysis.

After forming the MBBS profile image, program reads pixels of the reflectogram.

Figure 1 shows the program screen, where a standard single-mode OF (G. 652) is identified by the program [1, 2], and Figure 2 shows classified erbium-doped fiber (EDF) [1, 12].

Figure 1. A program screen upon detection of G. 652 sample.
Figure 2. A program screen upon detection of erbium-doped fiber.

There are two kinds of chart design to be studied by the program. We can choose the black or blue colors of the lines and white or black colors of the background for visually presenting (Figure 1 – Figure 3).

Besides, we can identify the chart kind without secondary actions (chart feature selection). Since the first chart design has auxiliary points along the “x”-axis every 10 pixels, the difficulty appeared in considering the reflectograms at pixel by pixel reading the chart. To solve this difficulty, we need to eliminate each tenth pixel.

As a result of the eliminating point, the MBBS chart can be rebuilt using the linear interpolation formula.

Figure 3 shows that the program identified a MBBS profile of the non-zero dispersion-shifted fiber (NZDSF – G. 655) [1, 10].

The chart details are brought into a linear array, where a comparison with a pre-loaded chart sampler into the program takes place; a particular procedure taken from an electronic resource is applied to determine the reflectogram kind with high precision.

A correlation characterization of the chart with samplers is carried out using the procedure:
1) The sum of every position on an “y”-axis is found.
2) This sum is divisible by the number of these positions.
3) The amount of every array member is shifted to the value gotten in subsection 2 toward a lower position. Therefore, the average value of the obtained array will be null.
4) Since an assembly average in modulus of an occurrence of the following position is different for every sampler, an adjustment of calculations is made by \( \frac{M_g}{M_0} \), where \( M_g \) – is the assembly average in modulus of the sampler, and \( M_0 \) – is the assembly average in modulus of the next samplers.
5) The correlation characterization is evaluated and the summation is adjusted over the array of the chart positions [2, 13].
Figure 3. A program screen upon detection of G.655 sample (NZDSF).

The charts of all loadedsamplers are shown to the operator. As a result of a comparison of a sampler and a loaded chart, the sampler more similar to the loaded chart is shined in green and its title is presented for the operator (Figure 1 – Figure 3), the samplers that have less commonality are shined, for example, in yellow and orange colors.

For a more accurate classification of OF varieties and evaluation of \( f_{B_0} \), \( f_B \) and then the strain, the estimation algorithm should be improved to eliminate the scaling effect of the graphs along the axes, as well as the displacement of the \( f_B \).

This can be done by approximation the data array using a high order polynomial. In this case, the estimation of profile matches can be performed with the correction of the scale and the shift of the MBBS maximum (\( f_B \)).

5. Conclusion

The numerous experimental investigations of particularities of the MBBS for various OF kinds or companies made with BOTDR “AQ 8603” enabled us to determine the basis level of Brillouin frequency shift (\( f_{B_0} \)) for each OF type.

Table 1 shows the \( f_{B_0} \) values for every examined OF kinds.
Table 1.

| OF kind        | $f_{B0}$ values, GHz | recommended value of $f_{B0}$, GHz | $v_A$, km/s ($n = 1.468$) | $n_e$ ($v_A = 5.7$ km/s) |
|----------------|----------------------|-----------------------------------|---------------------------|-------------------------|
| G.652          | 10.82 ... 10.86      | 10.84                             | 5.71                      | 1.468                   |
| G.653 (DSF)    | 10.47 ... 10.49      | 10.47                             | 5.53                      | 1.42                    |
| G.655          | 10.61 ... 10.64      | 10.63                             | 5.61                      | 1.443                   |
| G.655 (LEAF)   | 10.66 ... 10.67      | 10.66                             | 5.63                      | 1.447                   |
| G.657          | 10.77 ... 10.80      | 10.79                             | 5.70                      | 1.466                   |
| EDF            | 10.68 ... 10.70      | 10.70                             | 5.64                      | 1.450                   |
| ECDF           | 10.38 ... 10.39      | 10.38                             | 5.48                      | 1.409                   |
| “Panda”        | 10.40 ... 10.43      | 10.42                             | 5.50                      | 1.414                   |
| “Panda PS-887” | 10.55 ... 10.56      | 10.55                             | 5.57                      | 1.432                   |

In addition to the previous OF (G. 652 [1], G. 653 (DSF – a dispersion-shifted fiber) [10] and EDF [12], table 1 also presents the characteristics of G.655 (NZDSF) [11], G.657 – a single mode OF with high immunity to bends [5, 7], “Panda” is kind of polarization maintaining fiber [12], “Panda PS-887” – PS887-A270318 fiber, ECDF – erbium and cerium doped fiber (CeEr008-B270418). The values $v_A$ are obtained for the amount $f_{B0}$ in case of $n = 1.468$. Amounts $n_e$ (counterpart values of $n$) are estimated for the amount $f_{B0}$ in case of $v_A = 5.7$ km/s (table 1) [1]. The strain characteristics on temperature for OF are almost analogous in use of values $f_{B0}$ from table 1 [1, 9].

The attained profiles of the MBBS and frequencies of maximums are of practical effect, as they allow structure and formation of the layers making the OF core to be measured. This is because of the fact that a velocity of hyper-acoustic wave in OF and a powerful refractive index depend of an impurity material and a variation in its strength.

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