Optical Fiber Spectral Attenuation Measurement by Using Tunable Laser Sources to Improve Accuracy and Uncertainty

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ABSTRACT

The attenuation in optical fibre is a critical factor affecting all optical fibre applications. Usually, the current optical fibre spectral attenuation standard is calibrated using a broadband source, modulated by a mechanical chopper with a monochromator as the wavelength selector. With reference to the IEC 60793-1-140 international standard of optical fibre measurement methods and test procedures in attenuation, we studied the optical fibre attenuation measurement by cut-back method using tuneable lasers source.

1. INTRODUCTION

By using a power stabilised laser source, we measured the fibre attenuation in the wavelength range from 1270 nm to 1350nm and from 1520 nm to 1620 nm using ‘cut-back’ technique. The power measurement before and after cut-back have better repeatability. Besides, the evaluation of the splicing losses before and after cut-back as well as the evaluation of effective refractive index (N_{eff}) will improve the accuracy in calculating the fibre attenuation. Our method will improve accuracy and reduce uncertainties in the measurement and thus enable us to establish our own optical fibre spectral attenuation standard.

2. STUDY OF TUNEABLE LASER SOURCE

Tuneable Laser Source Power Stability Check

The tuneable laser will be on continuously for 60 mins with each power measurement taken at every 2 mins interval at a selected wavelength of 1550nm. This is to study whether the power of the laser source will vary largely. The variation will provide information about the stability of the power in the tuneable laser source. The tuneable laser is then tuned to different wavelengths and tuned back to 1550nm to check the repeatability of the power measurement.

Tuneable Laser Source Wavelengths Accuracy

In the above setup, the tuneable laser will be on continuously for 60 mins with each power measurement taken at every 2 mins interval at a selected wavelength of 1550nm. This is to study whether the power of the laser source will vary largely. The variation will provide information about the stability of the power in the tuneable laser source. The tuneable laser is then tuned to different wavelengths and tuned back to 1550nm to check the repeatability of the power measurement.
The wavelengths generated by the tuneable laser are checked using an optical spectrum analyser (OSA). The wavelengths are tuned with readings taken at intervals of 5nm from 1520nm to 1620nm. The process is repeated two times to obtain 3 sets of readings. This is to check the accuracy of the selected wavelength tune by the tuneable laser. The variation from 3 sets of reading will provide information on the repeatability of the selected wavelengths.

**Power Stability Results**

<table>
<thead>
<tr>
<th>Time / min</th>
<th>PM / dBM</th>
<th>Time / min</th>
<th>PM / dBM</th>
<th>Time / min</th>
<th>PM / dBM</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>0.917</td>
<td>22</td>
<td>0.918</td>
<td>44</td>
<td>0.924</td>
</tr>
<tr>
<td>6</td>
<td>0.916</td>
<td>26</td>
<td>0.919</td>
<td>46</td>
<td>0.925</td>
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<td>8</td>
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<td>0.923</td>
<td>48</td>
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<tr>
<td>10</td>
<td>0.919</td>
<td>30</td>
<td>0.923</td>
<td>50</td>
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</tr>
<tr>
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<td>0.914</td>
<td>32</td>
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</tr>
<tr>
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<td>0.919</td>
<td>54</td>
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<tr>
<td>16</td>
<td>0.919</td>
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</tr>
<tr>
<td>20</td>
<td>0.922</td>
<td>40</td>
<td>0.919</td>
<td>60</td>
<td>0.924</td>
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</table>

Average = 0.9210

U / dBM = 0.0011

**Table 1: Power Variation Table**

The above table shown that the power measurement uncertainty based on standard deviation calculation is 0.0011 dBm or approximately 0.12% with a coverage factor of 2. This result has shown that the power produced by the tuneable laser source is stable. The tune back power measurement also achieved within the same range as shown in above table which also proved good repeatability.

**Wavelength Accuracy and Repeatability Results**

<table>
<thead>
<tr>
<th>λ / nm</th>
<th>1st Read</th>
<th>2nd Read</th>
<th>3rd Read</th>
<th>U / nm</th>
<th>λ / nm</th>
<th>1st Read</th>
<th>2nd Read</th>
<th>3rd Read</th>
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<tbody>
<tr>
<td>1520</td>
<td>1520.003</td>
<td>1520.007</td>
<td>1520.005</td>
<td>0.002</td>
<td>1575.000</td>
<td>1575.005</td>
<td>1575.007</td>
<td>1575.008</td>
<td>0.002</td>
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<tr>
<td>1525</td>
<td>1525.005</td>
<td>1524.999</td>
<td>1524.996</td>
<td>0.006</td>
<td>1580.000</td>
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<tr>
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<td>1585.000</td>
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<td>1590.006</td>
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<tr>
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<td>1595.001</td>
<td>1595.004</td>
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<td>1600.009</td>
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<td>0.002</td>
<td>1605.000</td>
<td>1605.004</td>
<td>1605.006</td>
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<td>1565.003</td>
<td>0.002</td>
<td>1620.000</td>
<td>1619.999</td>
<td>1620.000</td>
<td>1620.002</td>
<td>0.002</td>
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<tr>
<td>1570</td>
<td>1569.999</td>
<td>1570.001</td>
<td>1570.003</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2: Wavelength Variation Table**

The above table shown that the highest wavelength uncertainty based on standard deviation calculation is only 0.006nm or approximately 0.0002% with a coverage factor of 2. This result has shown that the wavelengths tuned and produced by the tuneable laser source are accurate as the variations only occur in the range of picometre. The 3 readings from each wavelength also proved the good repeatability.

From these two measurement results, it is proven that that tuneable laser source can be used for optical fibre spectral attenuation measurement which supports the purpose of using tuneable laser source as the light source for spectral attenuation measurement.
3. SPLICE LOSS EVALUATION

The accuracy of the measurement equipment is the first important criterion in this study. Optical Time-Domain Reflectometers (OTDR) is used to measure splicing loss. In order to improving measurement accuracy of a typical splicing loss, we use the reference of a well-calibrated power meter and a tuneable attenuator to calibrate OTDR splice loss measurement.

![Figure 1: Attenuator act as connector joint](image1)

Firstly OTDR was used to measure the ‘connector’ loss in the variable attenuator in increasing steps of 0.1 dB interval from 1.2 dB to 5 dB. A linear relationship was developed between OTDR and variable attenuator.

![Figure 2: Linear relationship between OTDR and attenuator](image2)

\[ y = 1.02268x + 0.99797 \]

Next, the OTDR was replaced by tuneable laser. Power measurements were taken in increasing steps of 0.1 dB interval from 1.2 dB to 5 dB. A linear relationship was developed between tuneable and variable attenuator.

![Figure 3: Tuneable Laser to measure the interval step-up attenuation in attenuator](image3)

\[ y = 1.00473x + 2.06038 \]

![Figure 4: Linear relationship between tuneable laser and attenuator](image4)
By combining the two linear relationships,

\[ y = 0.98238x \]

Figure 5: OTDR VS Power Measurement

We have developed a relationship between OTDR based splice loss measurement and power meter based loss measurement and the linearity of both results will enable us to correct/calibrate the OTDR. This will help us to refine the splicing loss measurement between the test fibre (fibre 1) and receiving fibre (fibre 2) before and after cut-back.

### 4. CUT-BACK MEASUREMENT

Cutback Measurement is the most common technique used in measurement of the spectral attenuation of optical fibre and will be used in this study to establish the attenuation coefficients.

The fibre under-test (fibre 1) was spliced with a pigtail connected with the laser source so that the fibre launching condition was never changed before & after cut-back. At the receiver end, to avoid any variation due to the fibre coupling with the power meter before and after cut-back, we decided to splice the output end of another fibre (fibre 2) with a fibre pigtail fixed with the power meter. The two fibres were spliced using a fusion splicing method. The splice loss before and after cut-back may vary, hence they were measured and used to adjust the cutback fibre attenuation calculation via the splice loss evaluation.
After the ‘cut-back’ was performed, the centre splice point was removed and a new splice was created by splicing the 260m fibre #1 with fibre #2. Next, power measurement #2 (P₂) was performed in steps of 5 nm interval wavelength from 1520nm to 1620nm. Below figure is an illustration for power measurement #2 (P₂) after ‘cut-back’.

5. **Nₐ₀ EVALUATION**

Different materials’ refractive indices are different which means different fibre cables may have difference refractive indices due to different specifications, manufacturers and etc. However, most optical fibre spectral attenuation standards use a common group of refractive index of 1.46. In this section, pulse technique experiment is conducted to evaluate the true refractive index of the Corning SNIF-28e+LL single-mode optical bare fibre cable.

![Pulse Technique Experiment Diagram](image)

**Figure 8: Power Measurement after ‘cut-back’**

**Figure 9: Schematic Diagram of Pulse Technique Experiment**

The pulse technique experiment uses a modulator to modulate the 1550nm wavelength light to create laser pulses into the test fibre. The laser pulses were then converted to optical waveforms and send to the oscilloscope. Two lengths of 5m and 10m approximately were removed from one 5km pool corning single-mode fibre and used as the test fibres for the experiment. Three measurements were taken in following sequence:

1. Default setup without any test fibre
   - Direct connection between modulator and photo detector
2. Setup with 5m test fibre
3. Setup with 10m test fibre

The two test fibre will then go through a physical length measurement using a metre long ruler to calculate the true $N_{eff}$ and comparison will done with refractive index of 1.46.
Default Setup W/O test fibre

Setup with 10m Test Fibre

A delay in the time arrival for the same pulse is expected after inserting the 10m test fibre. By adjusting the period of generated pulse, the same pulse can be located in the same display window.

Next, optical distance of 10m test fibre can be calculated:

\[
\text{Optical Distance} = 299792458 \text{m} \times [(49.3 \pm 0.08) \times 10^{-9}] \text{s} = (14.780 \pm 0.03) \text{m}
\]

Setup with 5m Test Fibre

Due to the resolution of the oscilloscope, the phase delay could not be displayed on the same window accurately since the difference was only 5m from the default setup. However, the time delay of the same pulse could still be measured using same peaks.

\[
\text{Time of flight (5m fibre)} = (74.6 \pm 0.06) \text{ns}
\]

\[
\text{Time Delay} = 74.8 - 49.9 = (24.9 \pm 0.08) \text{ns}
\]

Next, optical distance of 5m test fibre can be calculated:

\[
\text{Optical Distance} = 299792458 \text{m} \times [(24.9 \pm 0.08) \times 10^{-9}] \text{s} = (7.465 \pm 0.03) \text{m}
\]

Physical Length Measurement and \( N_{\text{eff}} \)

Metre ruler used: \((1 \pm 0.001) \text{ m}\). Additional of 2 mm in uncertainty was added due to human error in measurement. With every metre measured, there is an uncertainty of 2.24 mm.

Total length measured physically:
- 10 m test fibre: actual length = \((10.098 \pm 0.023)\text{m}\)
- 5 m test fibre: actual length = \((5.0875 \pm 0.011)\text{m}\)

Hence, we can calculate the true refractive index of the test fibre using equation 2:
- 10 m test fibre: \(N_{\text{eff}} = (14.780 \pm 0.03) \div (10.098 \pm 0.023) = (1.4636 \pm 0.0047)\)
- 5 m test fibre: \(N_{\text{eff}} = (7.465 \pm 0.03) \div (5.0875 \pm 0.011) = (1.4673 \pm 0.0067)\)

Taking the average of both \( N_{\text{eff}} \) as the true refractive index,
Comparison between True $N_{\text{eff}}$ and assumed index of 1.46

The physical length was calculated based on the refractive index of 1.46 and true $N_{\text{eff}}$. A comparison was done in the table below.

<table>
<thead>
<tr>
<th>Refractive Index</th>
<th>Physical Length for 5 m (m)</th>
<th>Physical Length for 10 m (m)</th>
<th>Uncertainty (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4600</td>
<td>5.092</td>
<td>10.123</td>
<td>0.041</td>
</tr>
<tr>
<td>1.4655</td>
<td>5.094</td>
<td>10.085</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Table 3: True Neff VS Refractive Index of 1.46

From table 1, we can conclude that even though the difference in true $N_{\text{eff}}$ and assumed index of 1.46 is very small, it can still affect the physical length measurement by 40 mm approximately for the 10m fibre. The actual length measurement in fibre attenuation standard can be corrected.

6. CONCLUSION

The study of the stability and repeatability of the tuneable laser source had proven that the tuneable laser source can be used in spectral attenuation measurement. In addition, the splice loss and $N_{\text{eff}}$ evaluation will help refine the measurement results in optical fibre attenuation measurement and together with a stabilised power laser source, we can establish a set of optical fibre spectral attenuation standard with better power and length measurements.

7. ACKNOWLEDGEMENT

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8. REFERENCES