Bi-Lateral Comparison between NIS-Egypt and NMISA-South Africa for the Calibration of an Optical Time Domain Reflectometer

Osama Terra, Mariesa Nel, Hatem Hussein

Abstract—Calibration of Optical Time Domain Reflectometer (OTDR) has a crucial role for the accurate determination of fault locations and the accurate calculation of budget of long-haul optical fibre links during installation and repair. A comparison has been made between the Egyptian National Institute for Standards (NIS-Egypt) and the National Metrology Institute of South Africa (NMISA-South Africa) for the calibration of an OTDR. The distance and the attenuation scales of a transfer OTDR have been calibrated by both institutes using their standards according to the standard IEC 61746-1 (2009). The results of this comparison have been compiled in this report.

Keywords—OTDR calibration, recirculating loop, concatenated method, standard fibre.

I. INTRODUCTION

OTDRs are widely used as a diagnostic tool during the installation and repair of optical fibre networks. Their purpose is to detect fault in locations and to measure loss along optical fibre links. Therefore, a regular calibration for OTDRs is required to assure the stated accuracy in attenuation and distance measurements. Several methods are proposed for the calibration of OTDRs [1], [2]. In this report, a comparison has been made between NIS-Egypt and NMISA-South Africa for the calibration of OTDRs by calibrating the distance and attenuation scales of a transfer OTDR and comparing the calibration results. The calibrations are performed according to the standard IEC 61746-1 (2009) [1].

II. BACKGROUND ON OTDR CALIBRATION

A. Distance Scale Calibration

The goal of the distance scale calibration is to find the location offset (ΔL₀) and the distance scale deviation (ΔSₜ) of an OTDR [1]. The parameters (ΔL₀, ΔSₜ) are the intercept and the slope, respectively, of the curve plotted between the location errors of the OTDR measurements (Lₒtdr,i − Lᵣ) and the well-known lengths of the reference fibre (Lᵣ). That’s to say:

\[
\Delta L_0 = (L_{\text{otdr}} - L_{\text{ref}})_{(at \ L = 0)} \quad \Delta S_L = \frac{L_{\text{otdr}} - L_{\text{ref}}}{L_{\text{ref}}} \quad (1)
\]

where, \(\Delta L_0\) is the thermo-optic coefficient for silica fibres which is about \(1 \times 10^{-5}\) [4].

In this report, two methods will be used for the calibration of OTDR, namely, the recirculating loop method which is implemented by NIS and the concatenated method which is implemented by NMISA.

1. Recirculating Loop Method

The recirculating delay line, which is displayed in Fig. 1 (a), places a number of reflective features on the OTDR display, as shown in Fig. 1 (b). Using the reference values of the fibre length, measured at NIS, for the lead-in fibre (Lₐ) and the delay-line (Lₖ), the series of reference locations can be described by (2):

\[
L_{\text{ref},i} = L_a + i \cdot L_b
\]

The guide to the expression of the uncertainty in measurements (GUM) is used to calculate the uncertainties [3]. The uncertainties in the location offset and the distance scale deviation are described by:

\[
u(L_0) = \sqrt{\left(\delta L_{\text{otdr}}/L_{\text{otdr}}\right)^2 + \left(\delta L_{\text{ref}}/L_{\text{ref}}\right)^2}, \quad u(\Delta S_L) =
\]

\[
\sqrt{\left(\delta L_{\text{otdr}}/L_{\text{otdr}}\right)^2 + \left(\delta L_{\text{ref}}/L_{\text{ref}}\right)^2}
\]

where, \(\delta L_{\text{otdr}}, \delta L_{\text{ref}}\), are the absolute and relative uncertainties in the measured and the reference lead-in fibre lengths. Optical fibre length is sensitive to temperature changes. Uncertainty contribution due to temperature changes must be included in uncertainty budget. If the OTDR is calibrated at any other temperature than the one at which it was measured, the following relation must be applied to compensate for the temperature induced length changes:

\[
\delta L = \frac{\delta L}{\delta T} \delta T_{\text{temp}} L
\]

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where, \( L_{\text{ref}} = \frac{cT_{\text{std}}}{n} \) which represents the physical length of the standard fibre; \( L_{\text{OTDR}} \) is the distance as measured by the OTDR; \( \left\langle L_{\text{OTDR}} \right\rangle \) is the average of \( L_{\text{OTDR}} \) as realised with different incremental fibres. \( n \) is the group refractive index as set on the OTDR; \( c = 299 792 458 \text{ m/s} \) is the speed of light in vacuum; \( T_{\text{ref}} \) is the time-of-flight of a light pulse through the fibre; \( L_{\text{OTDR}} \) is a location as measured by the OTDR; \( L_{\text{Leadin}} \) is the length of a lead-in fibre, lead-in patch cords and incremental fibre(s).

B. Loss Scale

The goal of an OTDR attenuation scale calibration is to find the attenuation scale deviation, \( \Delta S_A \), using (3):

\[
\Delta S_A = \frac{A_{\text{otdr}} - A_{\text{ref}}}{A_{\text{ref}}}
\]

where, \( A_{\text{otdr}} \) is the attenuation measured by the OTDR and \( A_{\text{ref}} \) is the reference attenuation. The standard reference fibre method is implemented to calibrate the attenuation scale of the OTDR according to the IEC 61746-1 (2009) standard [1]. The calibrated fibre standard is connected to the OTDR through a set of lead-in fibres. The lead-in fibres places the fibre standard at different positions (\( A_{\text{otdr},i} \)) along the OTDR backscatter trace. A variable attenuator is used to move the fibre at different attenuation levels. The attenuation scale deviation, \( \Delta S_A \), is determined for the operating wavelengths of the OTDR at 1310 nm and 1550 nm. The calibration set-up is shown in Fig. 3.

III. REFERENCE STANDARDS

A. Distance Standards

NIS uses a recirculating loop (RL) that purchased from the NPL. The RL consists of a lead-in fibre of \( \approx 2.2 \text{ km} \) and a fibre
The calibration results are given in Table III.

The major contributors to the distance scale deviation ($\Delta S_L$) and to the location offset ($\Delta L_o$) are the reference fibre length and the temperature variations. The combined uncertainty is found by adding in quadrature this contribution to the statistical uncertainty from the measurements. The expanded uncertainty at 95% can be calculated by multiplying the combined uncertainty by 2.17 for infinite degree of freedom (OTDR averages several measurements over one minute).

**B. Attenuation Scale Calibration**

The OTDR is used to measure the attenuation standard uses a pulse width of 5 µm over 1 minute. The calibration results of the OTDR attenuation scale deviation, $\Delta S_A$, at NIS and NMISA are shown in Table IV.

The transfer artefact (OTDR) is calibrated at NIS using the time-of-flight technique, with reference to a time interval counter [5]. In order to complete the traceability chain to the SI unit of time, the counter is calibrated at the time and frequency laboratory at NIS. The results are shown in Table I.

**V. RESULTS**

**A. Distance Scale Calibration**

The following OTDR setting are chosen before starting the measurement: pulse width of 3 ns, group refractive index $n = 1.46$ (for 1310 and 1550 nm), and 1 minute averaging time. The calibration results are given in Table III. The normalized Error ($E_n$) is calculated for the parameter (X) according to (8):

$$E_n(X) = \frac{X_{\text{NMISA}} - X_{\text{NIS}}}{\sqrt{(U(X_{\text{NIS}})^2 + U(X_{\text{NMISA}})^2)}}$$

where $X$ is ($\Delta L_o$, $\Delta S_L$, $\Delta S_A$). Table V shows the normalized error for these parameters.
Fig. 4 Comparison between NIS and NMISA at 1310 nm for (a) location offset (b) distance scale deviation

Fig. 5 Comparison between NIS and NMISA at 1550 nm for (a) location offset (b) distance scale deviation

Fig. 6 Comparison of the attenuation scale calibration between NIS and NMISA at (a) 1310 nm and (b) 1550 nm

The results obtained for attenuation scale deviation at 1310 nm and 1550 nm are shown in Fig. 6.
TABLE V

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Parameter</th>
<th>Normalized Error</th>
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<tbody>
<tr>
<td>1310 nm</td>
<td>$\Delta L_0$</td>
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<tr>
<td></td>
<td>$\Delta S_L$</td>
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<tr>
<td></td>
<td>$\Delta S_A$</td>
<td>0.65</td>
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</table>

VI. CONCLUSION

A bi-lateral comparison between NIS-Egypt and NMISA-South Africa has been conducted. A transfer OTDR has been calibrated by both institutes, NIS and NMISA, for the distance and the attenuation scales using their respective standards according to the IEC standard 61746-1 (2009). Good agreement is found between the results from both institutes which lie within the uncertainty limits of the OTDR.

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REFERENCES