LONG-RANGE SINGLE-MODE OTDR: ULTIMATE PERFORMANCE AND POTENTIAL USES

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Abstract A high-performance single-mode optical time-domain reflectometer (OTDR) is described. Dynamic ranges of 30dB and 41dB one-way are achieved using laser diode and Nd:YAG laser sources respectively. A new OTDR technique allows absolute splice-loss measurements as well as active splice alignment to be performed from one cable end only.

1. Introduction

The dynamic-range performance of an OTDR is determined essentially by the energy of the probe-pulse launched into the fibre and the sensitivity of the detection system. In order to achieve the necessary one-way range of 20 to 30dB at long wavelengths in single-mode fibres, it has previously been necessary to resort to liquid-nitrogen cooled detectors and/or high-power laser sources [1-3]. More recently, heterodyne detection has been proposed [4,5] for increased detector sensitivity, but so far this approach has not given any advantage in dynamic range. We have previously demonstrated [6] an approach to long-wavelength single-mode OTDR based on a new ultra-low-noise PINPET receiver. The present contribution describes recent improvements to our approach which enable a significant enhancement of the system dynamic range. We also demonstrate its applicability to a new technique for absolute splice-loss measurements which require access to one cable end only.

2. OTDR System

The experimental arrangement is shown in Figure 1. The light source indicated in the diagram is a 1.3µm laser diode [7] which is driven with pulses of 1µs duration. The effective launch power including optical losses in forward and return directions is +8dBm. An acousto-optic deflector (AOD) is used in place of the conventional beam splitter to provide more efficient coupling of the light to and from the fibre [1]. The AOD can also reduce the dynamic range of the optical signal by gating out the Fresnel reflection from the front end of the fibre, and by shutting off the backscattered light from the near part of the fibre while the far end is being measured. The optical receiver incorporates a HgCdTe PIN diode detector [8] which is operated at room temperature. The detected signal is amplified by a 500MHz transimpedance amplifier whose sensitivity has been optimized for this application so that its noise performance is limited by the thermal noise of the silicon JFET at the front-end. The backscatter signal can be viewed in real time on an oscilloscope or averaged by a multichannel digital averager. The latter provides a 30dB (optical) noise reduction in 20 minutes measurement time by averaging 10^6 traces. The performance of the OTDR system is illustrated in Figure 2(a). The plot shows the backscatter signal obtained from a jointed 39.5km fibre which has a total loss of 30dB at its 1.3µm operating wavelength. The trace was acquired in 3 sections with 10^6 averages used for the final part. Although the far end has been index matched, its position is readily located from the Rayleigh scattering.

The dynamic-range of the equipment is increased by employing a high-power solid-state laser, which is normally operated at 1.32µm and the maximum power limited by the onset of stimulated emission. The peak input power is only 3mW below the laser threshold. A dynamic range of 39.5km fibre length has been demonstrated in tests on a 39.5km fibre length. This dynamic range extends the useful performance of an OTDR.

3. Splice-Loss Measurement

A difficulty usually encountered in measurements of fibre splice-loss is that it is not unusual for the fibres on either side of the splice to be mismatched, and that the true splice loss by OTDR backscatter is usually required to be at least the difference between the two fibres. By using a second laser to provide a reflected probe-pulse returning to the fibre under test and having also been reflected at the splice end, forward and return measurements can be made simultaneously at the splice. Figure 3 shows a backscatter trace from a splice showing the difference between the splice losses for a single splice on a 30km single-mode fibre. The splice loss is shown in the table and the forward and return traces are shown in the figure 4. An OTDR measurement yields the relative splice loss in the initial part of the chart. After this time interval, the backscatter trace from the remaining fibre is used in the calculation. The relative splice loss is obtained by subtracting the value of the backscatter trace from the remaining fibre from the value of the backscatter trace from the fibre under test at the splice end. The measure of the splice loss is obtained by taking the average of the value of the backscatter trace from the fibre under test at the splice end over the period of the chart. An analog-to-digital converter is used to digitize the data, and a digital filter is employed to smooth the data. The result is an average value which gives the true loss.

4. Splice Alignment

Active alignment of single-mode fibres is essential to achieve the lowest losses, and the current practice is to use a laser to move the fibre cores slightly eccentrically within the fibres to provide the alignment information. When the alignment information has been transmitted to the jointing bay, by an OTDR must be sufficient to enable the alignment to be updated rapidly. With our apparatus, the accuracy of the measurement is within one second measurement, and the principle is demonstrated in Figure 5. The joint measured by the OTDR is shown in Figure 6. The folded-path technique simultaneously the joint-loss data is obtained, which has the true splice loss has been achieved, and the middle curve. The data is based on the average of the RMS deviation of the experimental data, which has been determined to be 0.016dB. In this case, the optimal
The dynamic range of the OTDR system can be further increased by employing a high-power laser source. The semiconductor laser was replaced by a Q-switched Nd:YAG laser operating at 1.32μm, and the maximum probe pulse power is then limited by the onset of stimulated Raman generation. With an input power (~1W) 3dB below the level at which Raman generation is first detected, a dynamic range of some 41dB is attained, as demonstrated by the measurement shown in Figure 2(b) on the same 39.5km fibre length. This dynamic range far exceeds any single mode OTDR performance reported to date.

3. Splice Loss Measurement

A difficultly usually encountered in backscatter measurements of fibre splice loss is that the backscatter factors differ for the fibres on either side of the splice. In order to obtain the true splice loss by OTDR, backscatter measurements are required from both ends of the fibre. The achievement of a 30dB dynamic range in a potentially field-portable OTDR system makes feasible a new approach to single-mode splice-loss measurements which overcomes this problem. The technique involves applying a reflector to the cleaved far end of the fibre, as illustrated in Figure 3. In our case a front-silvered mirror was butted against the fibre end, a method which readily gives reflectivities above 90%. In practice the reflector could be applied to the fibre prior to installation, e.g. by dip-coating.

An OTDR measurement yields the normal backscatter signal at the launch end within the initial period of twice the fibre transit time. After this time interval, backscatter is received from the reflected probe-pulse returning to the launch end, the scattered light having also been reflected at the mirror before reaching the launch end. Forward scatter from the outward and return journeys of the probe pulse will also reach the launch end, but will arrive simultaneously with the reflected probe pulse.

Figure 4 shows a backscatter trace obtained without averaging on a short demonstration fibre using the folded-path technique. The 7km single-mode fibre has splices at 1km and 5km. The splice losses shown in the table were computed from a digitised and averaged trace. As expected, the results obtained from a one-way measurement have little meaning, whereas the average value gives the true loss.

4. Splice Alignment

Active alignment of single-mode fibre splices is desirable to achieve the lowest losses [9], particularly when the fibre cores are slightly eccentric. OTDR is ideally suited to providing the alignment information if the backscatter data can be transmitted to the jointing bay. The dynamic range of the OTDR must be sufficient to enable the splice-loss data to be updated rapidly. With our apparatus, the range for 0.1dB accuracy in a one second measurement time is 15dB one-way. The principle is demonstrated in Figure 5 where the loss at a butt joint measured by OTDR is shown as a function of fibre lateral displacement. The folded-path technique has been used to obtain simultaneously the joint-loss data as seen from both ends, from which the true splice loss has been calculated by averaging (middle curve). Theoretical curves [10] using the Gaussian mode approximation have been fitted to the experimental points. The RMS deviation of the experimental values from the curves is only 0.016dB. In this case the optimal joint loss was 0.07dB.
5. Conclusions

We have developed a long-range single-mode OTDR system which exceeds the requirements for field measurements, and have shown its applicability to splice-loss monitoring using a new folded-path technique. Additionally, using a 1W input power from a Nd:YAG laser, we have achieved the greatest dynamic range reported for single-mode OTDR measurements.

References

Fig. 1 Experimental arrangement

Fig. 2 Backscatter traces from 39.5 km single-mode fibre
(a) Laser diode source (b) Nd:YAG laser source

Fig. 3 Folded-path OTDR test

Fig. 4 Splice-loss measurement using folded-path technique

SPLICE-LOSS VALUES

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<td>dB</td>
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Fig. 3 Folded-path OTDR technique

Fig. 4 Splice-loss measurement using folded-path technique

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Fig. 5 Joint-loss against fibre lateral displacement