IMPROVED-DYNAMIC-RANGE SINGLE-MODE OTDR AT 1·3 μm

Indexing term: Optical communication

A high-performance single-mode optical time-domain reflector (OTDR) incorporating a new low-noise receiver design utilising a PIN diode detector and a transimpedance amplifier is described. With a 1·3 μm laser diode source a dynamic range of 30 dB one way is achieved, and using an Nd:YAG laser source the dynamic range is 41 dB one way.

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 a one-way range of 20 to 30 dB it has previously been necessary to resort to liquid nitrogen cooled detectors and/or bulky high-power laser sources.[1-3] More recently, heterodyne detection has been proposed[4-6] for increased detector sensitivity, but so far this approach has not led to any gain in dynamic range, and there are no sufficiently coherent portable sources at present for the normal 1·3 μm single-mode-fibre operating wavelength. We have previously shown[7] that at this wavelength an ultra-low-noise receiver design with a PIN diode detector can match the sensitivity of a germanium APD cooled to 77 K used in photon-counting mode.[2] The present contribution describes further improvements in our approach which enable a significant enhancement of the system dynamic range.

OTDR system: The experimental arrangement is shown in Fig. 1. The light source indicated in the diagram is a 1·3 μm laser diode[8] which is driven with pulses of 1 μs duration. The effective launch power including optical losses in forward and return directions is +5 dBm. An acousto-optic deflector is used in place of the conventional beam splitter to provide more efficient coupling of the light to and from the fibre.[1] The acousto-optic deflector can also reduce the dynamic range requirements on the receiver by gating out the Fresnel reflection from the front end of the fibre and by shutting off the backscatter signal from the near part of the fibre while the far end is being measured. The optical receiver incorporates a PIN photodiode detector, together with a 500 MΩ transimpedance amplifier whose sensitivity has been optimised for this application. Whereas previously[7] some cooling of the detector was required to reduce its noise contribution below that of the amplifier front end, the detector is now an HgCdTe device[9] which has a dark current of 0·8 nA at room temperature. This figure is sufficiently low that the detector gives a satisfactory noise performance operated without cooling.

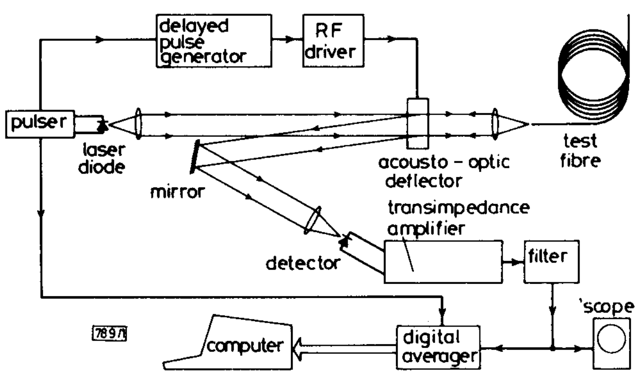


Fig. 1 *Experimental arrangement*

The detected backscatter signal can be viewed in real time on an oscilloscope or averaged by a multichannel digital averager. The latter provides a 30 dB (optical) noise reduction in a 20 min measurement time by averaging 10^6 traces. The sensitivity of the detection system after averaging is 3×10^{-14} W. The apparatus described is potentially compact and field-portable.

Results with laser-diode source: Fig. 2 shows real-time oscilloscope traces obtained from a 39·5 km fibre length made up of 22 sections joined by arc-fusion splices. The fibre has a total loss of 30 dB including 7 dB of splice loss. Note that these real-time traces are extremely stable and reproducible, and in contrast to backscatter traces obtained with heterodyne detection[10] show no polarisation or source coherence effects. The splice at just over 18 km is some 15 dB one way down the fibre, but is nevertheless visible in real time in Fig. 2*b*. Similarly, the reflection from the end of the fibre in Fig. 2*c* is well above the noise after a 60 dB round-trip loss.

Fig. 2*d* shows the backscatter signal obtained from the entire fibre length after averaging. The far end has been index-matched to eliminate the Fresnel reflection. The trace was averaged in three sections with 10^6 averages for the final part. The position of the fibre end at 39·5 km is readily located from the Rayleigh scattering.

Results with Nd:YAG laser source: In order to demonstrate the extra dynamic range achievable when a high-power source is available, the laser diode was replaced by an Nd:YAG laser. The laser was operated in *Q*-switched mode at a wavelength of 1·32 μm to produce 1 μs FWHM pulses. A trigger from the optical pulses was provided for the electronics of the OTDR system. The maximum probe-pulse power in this case

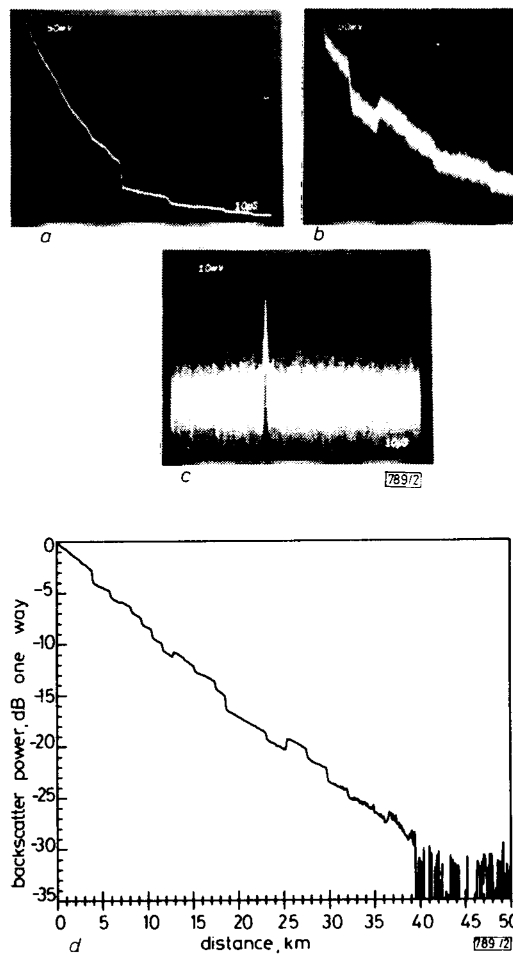
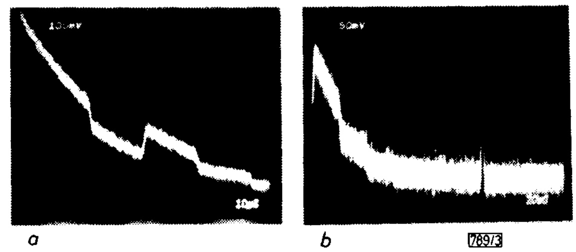


Fig. 2 *Backscatter traces from 39·5 km fibre with laser diode source*

a Real-time, 0–100 μs (0–10·2 km)
b Real-time, 100–200 μs (10·2–20·4 km)
c Real-time, 350–450 μs (35·7–45·9 km)
d Logarithmic plot of entire fibre length after averaging



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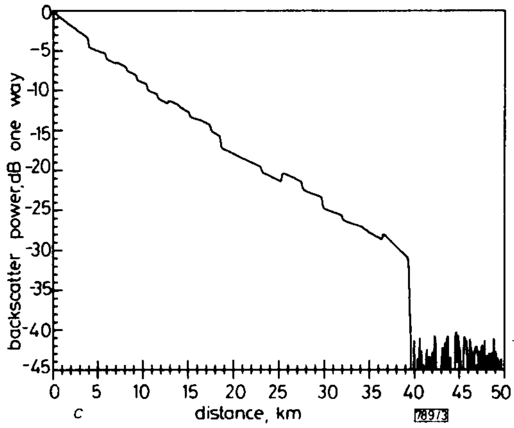

Fig. 3 *Backscatter traces from 39·5 km fibre with Nd: YAG laser source*

a Real-time, 200–300 μs (20·4–30·6 km)
b Real-time, 250–450 μs (25·5–45·9 km)
c Logarithmic plot of entire fibre length after averaging

is limited by the onset of stimulated Raman generation in the test fibre. This point is found by observing the output spectrum at the far end of the test fibre with a monochromator, and the measurement is performed at an input power about 3 dB below the level at which Raman generation is detected. The peak power launched into the fibre is then ~ 1 W.

Figs. 3*a* and *b* show real-time oscilloscope traces obtained from the same 39·5 km fibre length as measured above. The dynamic range *before* averaging is now over 25 dB one way and the backscatter signal is clearly visible to over 30 km. The backscatter trace obtained after 10^6 averages is shown in Fig. 3*c*. The peak noise floor is at -41 dB. With state-of-the-art single-mode fibre, this figure would correspond to a distance in excess of 100 km at 1·3 μm. This performance is nearly 10 dB one way greater than any reported previously using a high-power laser source, including measurements where the input power was well above the fibre nonlinear threshold.[3]

Conclusion: An improved-performance single-mode OTDR system operating at 1·3 μm has been described. With a semiconductor laser source the equipment is potentially field-portable and yet achieves a dynamic range for nonreflecting fault location of 30 dB one way. This range is sufficient to penetrate the entire repeater length of 1·3 μm long-haul single-mode links envisaged at present. When a higher-power laser source is used, a further dynamic-range enhancement of 11 dB one way has been demonstrated.

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