A PRACTICAL HIGH-PERFORMANCE SINGLE-MODE OTDR SYSTEM FOR THE LONG-WAVELENGTH REGION

M.P. Gold and A.H. Hartog

Department of Electronics, The University, Southampton, UK.

Abstract: A single-mode OTDR using a 1.3μm laser diode source and direct detection is reported. A dynamic range in excess of 26dB one-way is demonstrated.

INTRODUCTION

High performance Optical Time-Domain Reflectometers (OTDR) are required for locating faults in long-haul long wavelength single-mode fibre telecommunication links. Although several long-range OTDR schemes have been reported, the techniques used have all been unsuitable for field operation, since either high power Nd:YAG lasers (1,2) or cryogenic detectors (3) were required. More recently, the alternatives of heterodyne detection (4) and direct detection with a PINFET module (5) have been demonstrated, but neither has achieved a performance comparable with references 1-3.

We report here a single-mode OTDR system which has none of the drawbacks mentioned above, and yet our initial results achieve a dynamic range significantly greater than has been previously published. Our approach uses a semiconductor laser source, and an ultra-low-noise optical receiver together with multichannel digital averaging.

OPTICAL RECEIVER

The detector is a GaInAs PIN (6) photodiode connected to a low-noise transimpedance amplifier. The design of the latter has been developed to allow a feedback resistor of 500MΩ and a bandwidth of approximately 1MHz. The very high value of the feedback resistor ensures that its thermal noise contribution is small compared with that of the front-end active device, a silicon JFET.

The detector diode has a room-temperature leakage current of 5nA at 5V bias. The device is cooled by a single-stage thermo-electric module to -18°C which reduces the dark current to a point where its noise contribution is below that of the amplifier first stage. The amplifier output is connected to a low-pass filter to remove high frequency noise which would be aliased when the signal is sampled for digitising. The filter has a rise-time of 1μs to allow 100m resolution on the backscatter trace, and a Bessel response to provide negligible distortion of the signal in the time domain. The equivalent input noise current of the receiver was measured to be 17pA in the bandwidth defined by the filter. The noise level is reduced by a factor of 1000 after digital averaging to give an optical sensitivity of 3×10^{-14}W, a performance which is similar to that achieved by photon counting with a germanium APD at 77K (3).

MEASUREMENT SYSTEM

The experimental arrangement is shown in Fig 1. The light source is a 1.3μm laser diode (7) which gives pulses of 1μs duration and an effective launch power including beamsplitter and other optical losses in both directions of -1.5dBm. The launching cell and low-incident-angle beamsplitter described in a previous publication[8] allow polarisation-insensitive detection of the backscatter signal. The backscatter power obtained from the near and far ends of the fibre differ by many orders of magnitude. An optical shutter synchronised to the laser pulses is therefore inserted in the backscatter signal path in order to reduce the linearity requirements on the receiver. After amplification and filtering, the detected signal may be viewed in real time on an oscilloscope, or passed to a multichannel digital averager. The latter digitises and averages the waveform with 10bit resolution and 1μs sample spacing. The data is transferred to a computer for further averaging and storage. In a 20 minute measurement time 10^6 traces can be averaged, giving a 30dB (optical) noise reduction.

RESULTS

Measurements were performed on a 36.1km single-mode fibre length consisting of a total of 21 sections joined by arc-fusion splices. The nominal lengths of the sections are as follows: 1 x 2km, followed by 11 x 1.1km, 8 x 2.2km, and a final 3.6km length. After splicing, the total fibre attenuation was measured to be 26.5dB at the operating wavelength; this figure includes approximately 6dB for the loss of the 20 splices. Real-time oscilloscope traces of the backscatter obtained from the 36km fibre are given in Fig. 2. The first 20km are shown in Fig. 2(a). Backscatter factor variations[8] are visible on the first fibre section, and differences in the backscatter factor between fibre sections result in a large spread of apparent splice losses (including some with an apparent gain). The excellent signal-to-noise ratio allows the individual fibre lengths and splices to be seen clearly over the first 14km (i.e. about 12dB one-way loss) without any averaging. This performance surpasses any previous real-time backscatter traces reported from single-mode fibres. Fig. 2(b) shows the final ~16km. The Fresnel reflection from the far end of the fibre is well above the noise even after a round-trip attenuation of 53dB.

A logarithmic plot of the backscatter signal obtained after averaging is shown in Fig. 3. The far end of the fibre has been index-matched to eliminate the Fresnel reflection. The data was acquired in three sections; 10^6 averages were used for the final section. It may be seen that the averaged trace is virtually noise-free for a one-way loss of more than 20dB. Fig. 3(b) shows the last 8km on a linear scale, where the far end of the fibre can be located by the cessation of Rayleigh scatter after a one-way loss of 26.5dB. Thus even non-reflecting faults can be located over this fibre dynamic range, a figure far in excess of that required to penetrate half of a state-of-the-art 1.3μm single-mode fibre link.

CONCLUSIONS

We have demonstrated a single-mode OTDR system at 1.3μm incorporating a new low-noise analogue optical receiver which matches the sensitivity of photon counting at this wavelength. Using a semiconductor laser source, a dynamic range performance has been achieved which surpasses previously published results, including those where a high power Nd:YAG laser was employed. The system reported is potentially field portable, and the operating wavelength could be readily extended to 1.5μm, as sources and detectors of the required performance have been produced. Further improvements to the performance of the equipment will be reported at the conference.

REFERENCES

1. M. Nakazawa et al., Electronics Letters, 1981, 17, pp. 783-785.
2. K. Noguchi et al., ibid., 1982, 18, pp. 41-42.
3. P. Healey, ibid., 1981, 17, pp. 751-752.
4. P. Healey and D.J. Malyon, ibid., 1982, 18, pp. 862-863.
5. P. Healey and D.R. Smith, ibid., 1982, 18, pp. 959-961.
6. Plessey type HRD 200.
7. S.E.H. Turley et al., Electronics Letters, 1981, 17, pp. 868-870.
8. M.P. Gold and A.H. Hartog, Proceedings of the 8th European Conference on Optical Communication, Cannes, 1982, pp. 633-638.

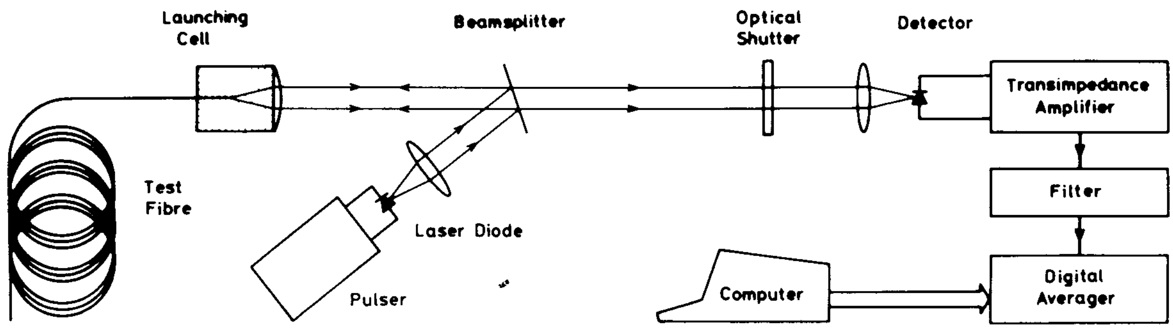
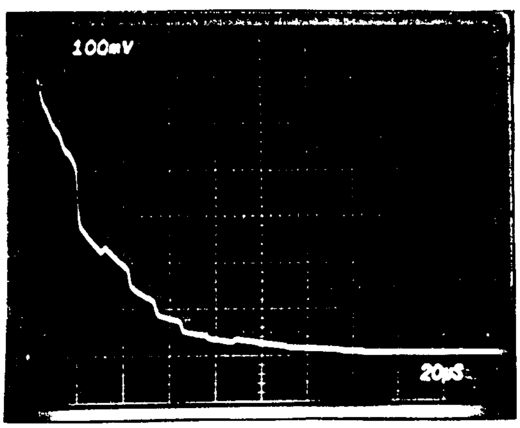
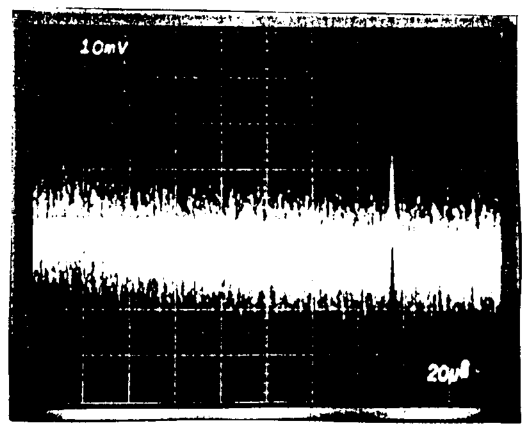


Fig. 1 Experimental Arrangement





(a) First 20km (b) Final ~16km

Fig. 2 Real-time Oscilloscope Traces of Backscatter from 36.1km Fibre at 2km/division.

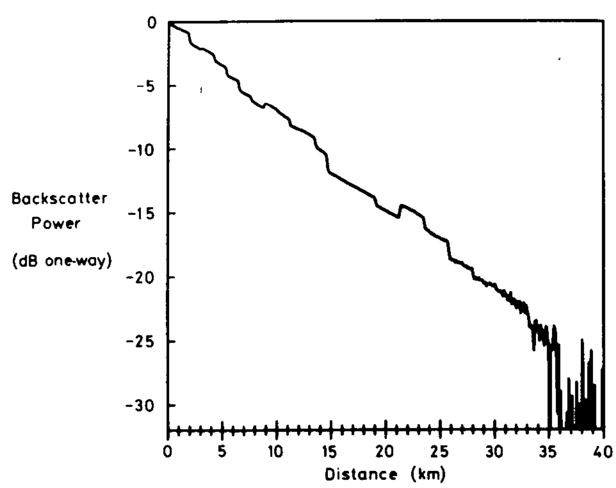


Fig. 3(a) Logarithmic Plot of Backscatter from Entire Fibre Length

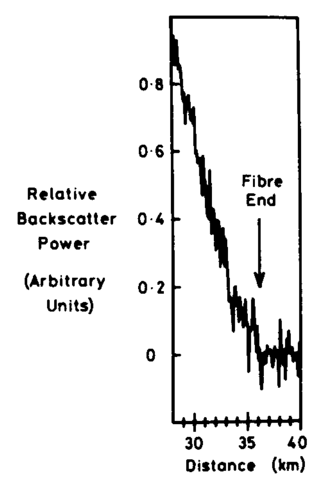


Fig. 3(b) Final 8km on Linear Scale