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FIELD INSTALLATION OF A 31·5 km MONOMODE OPTICAL FIBRE SYSTEM OPERATED AT 140 Mbit/s AND 650 Mbit/s

Indexing terms: Optical fibres, Optical cables

We report the field installation of a 31·5 km monomode fibre cable link during February–March 1982. The link provided 21·3 dB loss at $\lambda = 1{\cdot}3$ μm and 16·1 dB loss at $\lambda = 1{\cdot}55$ μm. Also reported are systems trials over the completed link at 140 Mbit/s and 650 Mbit/s.

Introduction: This letter reports the installation of a monomode fibre link between the British Telecom Research Laboratories (BTRL) and the System 'X' digital telephone exchange at Woodbridge. The route is 7·5 km long and cable is installed in operational duct alongside a busy trunk road. The cable sections were spliced together to produce a 31·5 km system. The installation was carried out in February–March 1982. This letter will describe the installation, the measurements performed and a preliminary analysis of the results. It also reports systems trials over the completed link at 140 Mbit/s and 650 Mbit/s.

Fibre: The fibre was produced at BTRL and GEC Optical Fibres Ltd. to a nominal fibre design previously described.[1] The mean values of the equivalent step index (ESI) parameters[2] and the fibre core concentricity of the jointed fibre ends are as follows:

Core radius(a_s) = 4·81 μm; SD = 0·42 μm

Index difference (Δn) = 0·0031; SD = 0·00053,

$$\Delta n = n_1 - n_2$$

Concentricity = 0·52 μm; SD = 0·26 μm

The ESI and concentricity measurements were of fibre samples cut from the cable ends after installation in duct. No attempt was made to order the fibres prior to cabling to minimise splice loss.

Cable construction and installation: The cable* for this trial was manufactured by Telephone Cables Limited (TCL). The cable contained four fibres in a loose tube structure with one fibre per tube. In addition to the four tubes were two quads of copper conductors and a central steel strength member. This design introduced negligible microbending loss on the fibre at the long wavelength window. Indeed several low Δn fibres which had shown significant microbending loss on reel showed a marked reduction in loss at $\lambda = 1{\cdot}55$ μm when packaged and cabled within this structure.

Five cable lengths were installed in 1 km sections and a sixth length in a 2 km section. Installation into operational duct already containing copper cables was carried out by a TCL cable gang using conventional cable laying techniques. The 2 km cable was installed well within a working day and involved two fleeting operations.

Cable measurements: Spectral losses of the primary coated fibre (on reel) were made prior to tubing. Spot loss measurements were made at wavelengths 1·3 μm and 1·55 μm after tubing and also after cabling of the fibre. Once installed the cables were loop-spliced at one end and spot loss measurements carried out on the installed fibre lengths from a test vehicle. By determining the loss of the loop splices (which were cut out as the system was spliced together and subsequently measured in the laboratory) any incremental cable loss which may have occurred during installation could be determined. Fibre and cable loss results are shown in Table 1. Optical time domain reflectometry (OTDR) measurements,[3] spot loss measurements and spectral loss measurements could then be made from the laboratory, as the fibres were cumulatively spliced from BTRL to Woodbridge Exchange.

Table 1 MEAN FIBRE LOSSES (dB/km)

	1·3 μm	1·55 μm
Primary coated (on reel)	0·45	0·77*
Tubed	0·45 (0·02)	0·25 (0·02)
Cabled	0·47 (0·02)	0·25 (0·02)
Installed	0·46 (0·03)**	0·26 (0·03)**
Spliced	0·68 (0·01)	0·51 (0·01)

* This result indicates tension on the primary coated fibre on reel

** Results calculated from field loop spot loss measurements and cutback spot loss measurements on loop splices

Figures in brackets are standard errors in the mean for each measurement

Fibre splicing: One of the major objectives of the trial was to demonstrate that monomode fibre splicing techniques developed in a laboratory[3] could be successfully transferred to the field environment without impairment of performance. Splicing was carried out mainly in a vehicle using the laboratory developed fusion splicing machine. Splicing was also successfully carried out in a tent above a manhole at one of the joint points. The fibre splicing operation does not rely on optical power monitoring and has been previously described.[3,4]

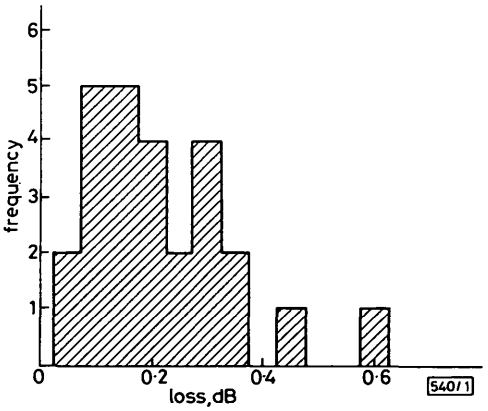


Fig. 1 *System splice-loss results as a measured by OTDR*
$\lambda = 1{\cdot}3$ μm
Mean splice loss = 0·22 dB
26 measured splices
NB. 4 splices rejected by OTDR because of excess loss. Inclusion of these splices could have increased the mean splice loss to 0·25 dB

* TCL, teloptic type 'F' optical fibre cable

Splice loss results: The splice loss distribution as measured by OTDR ($\lambda = 1{\cdot}3$ μm) is shown in Fig. 1 with a mean value of 0·22 dB. This result agrees well with the mean splice loss obtained by the cutback technique, 0·215 dB at $\lambda = 1{\cdot}3$ μm. Theoretical calculations of the intrinsic losses[4] due to profile mismatch and to concentricity error show that a 0·15 dB mean loss is expected. These calculations are based on the splice loss formulas of Nemoto and Makimoto[6] and use as input data the measured values of the fibre concentricity error and ESI parameters for the fibre pair at each splice. A computer program accounts for the statistical nature of the azimuthal orientation of the concentricity error vectors, and the expected splice loss is predicted for the link.

Losses due to core deformation,[4] arising from the fusion technique and the machine parameters used, have shown that for 'good' concentricity fibre a mean splice loss of 0·08 dB is expected (Fig. 2). The sum of these losses (0·23 dB) is the expected mean splice loss for the system and this value agrees very well with the measured mean splice loss (0·215 dB). This result also shows that the splice loss of this system is dominated by intrinsic losses due to fibre tolerances. It should be noted that the fibre used in this trial was made from several preform types and under diverse manufacturing conditions and hence the spread in fibre parameters was quite large. This indicates that once a particular fibre design is adopted improved tolerances may lead to reduced splice losses.

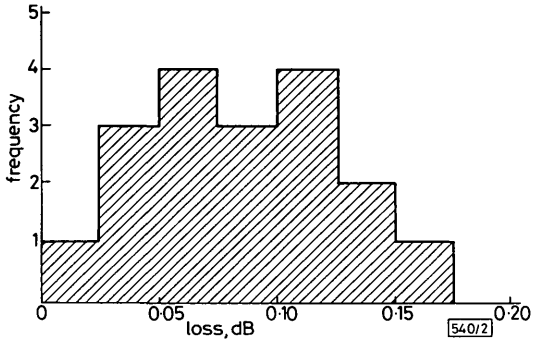


Fig. 2 *Splice-loss histogram for identical fibres*
20 splices (two rejected on visual appearance)
$\lambda = 1{\cdot}3$ μm
Mean loss = 0·08 dB (18 splices)
Standard deviation = 0·04 dB
Concentricity error $\simeq 0{\cdot}3$ μm
ESI core radius = 4·3 μm
ESI $\Delta n = 3{\cdot}2 \times 10^{-3} = n_1 - n_2$

The mean splice loss obtained from cutback measurements at $\lambda = 1{\cdot}55$ μm is 0·25 dB. This is a larger loss than that predicted by splice loss calculations. Experiments are currently under way to investigate whether the extra loss may be attributable to micro- or macrobending effects caused by coiling the fibres in the joint housing.

Systems operation: After completion of the cable installation and measurement programme two systems experiments were carried out.

In the first experiment 650 Mbit/s and 140 Mbit/s systems were operated at $\lambda = 1{\cdot}3$ μm (10*-9 BER) over the 31·5 km of fibre. The power budget for these systems is shown in Table 2.

Table 2

System budget: $\lambda = 1{\cdot}3$ μm	140 Mbit/s	650 Mbit/s
Fibre loss (cabled)	14·8 dB	14·8 dB
Total splice loss (30 splices at 0·215 dB mean)	6·5 dB	6·5 dB
Connector loss	0·6 dB	0·6 dB
Receiver sensitivity	−45 dBm	−34 dBm
Launch power	−7 dBm	−8·7 dBm
Margin	16·1 dB	3·4 dB

Total installed system length = 31·5 km

The receiver assembly was as described by Malyon and McDonna,[6] while the connector was a precision ferrule device manufactured at BTRL.

In the second experiment the 31·5 km system was fusion-spliced to a previously reported laboratory 31·6 km cabled monomode link.[3] The connector and 500 m of fibre were removed and a 140 Mbit/s system ($\lambda = 1{\cdot}3$ μm, 10*-9 BER) operated over 62 km of cabled monomode fibre. The link contained 44 splices (mean splice loss = 0·203 dB) and provided 38 dB optical loss.

Conclusions: These results have shown the feasibility of the field installation of monomode fibre systems unrepeatered over 30 km and operating at 650 Mbit/s. We have also shown that the target unrepeatered link length of 30 km for the UK inland trunk network may indeed be conservative for 140 Mbit/s systems.

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SIMPLE AND ACCURATE SIZE CALCULATION OF MOS TRANSISTOR

Indexing terms: Semiconductor devices and materials, Metal-oxide-semiconductor circuits and devices, Transistors

The letter describes an analytical solution to the problem of finding a correct size of a MOS transistor required to charge a load capacitance to a wanted voltage level within a given time. The resultant formula is extremely simple, yet very accurate. It could be utilised by an LSI designer, as well as in automatic design algorithms. The expression for the channel width over channel length ratio was derived from the second-order drain current equations for both regions, saturated as well as linear (not from simplified, first-order approximations).

Introduction: One of the most basic tasks in MOS design is a determination of channel width over channel length ratio