ITT 140 MBIT/S OPTICAL FIBRE SYSTEM

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A 140 Mbit/s optical fibre transmission system has been installed over a 9 km route in the U.K. The terminals are equipped with the full standard hierarchy of digital telephony multiplex equipment and the repeaters are power fed via the cable. The equipment has been made compatible with existing PTT practices as far as possible, and the cable was installed in partially occupied Post Office ducts by a standard installation team. Unrepeatered operation over 6.2 km has been demonstrated.

Introduction

In spite of a number of demonstrations in the laboratory of transmission via optical fibre, many people remained unconvinced that this apparently fragile medium could survive and compete with 'conventional' cable in the real world. The engineers themselves were uncertain as to which areas would present the greatest technical difficulties in the field. Accordingly, to demonstrate the feasibility and benefits of optical communication systems for PTT applications, the decision was made to engineer, and install in a realistic environment, a relatively large-scale system, and in doing so advance the technology.

Bit Rate and Coding

The choice of bit rate was limited by the need to fit into the CCITT hierarchy, and having regard to possible future requirements. Very high bit rates were unsuitable because of a lack of commercially available multiplex equipment. The choice was reduced to 140, 34 or 8 Mbit/s.

140 Mbit/s (139.264 Mbit/s) was chosen, as the increased technical difficulty as compared with the two lower rates would provide more experience for the future.

The code chosen for the demonstration was scrambled binary (2^{15}-1) plus a parity bit inserted after every 17 bits, thus increasing the transmitted bit rate to 147.456 Mbit/s. The scrambling removes the low frequency content and ensures adequate timing content for timing recovery; the parity bit facilitates simple in-traffic error monitoring at the terminals and at each individual repeater for ease of fault location.

Route

A good Optical Fibre Field Demonstration should show up as many of the potential problems associated with optical fibre systems as possible. To test the cable and installation techniques, a fairly difficult duct route was required, one with some empty bores and some sections already containing a variety of existing cables over which the optical cable would have to be drawn. The British Post Office provided such a route over 9 km between the towns of Hitchin and Stevenage, some 40 km north of London. See Fig. 1.

Description of Equipment

A pair of two-way repeaters were included to gain experience of remote power feeding and supervision. Each two-way repeater consists of two single-way repeaters with a common line-fed power supply mounted between them. The two-way repeaters are housed in British Post Office standard pressurised repeater cases. (Figures 2 and 3 a, b, c.) The single-way repeaters were also used for the electro-optic interfaces at the terminals (Figs. 4 and 5). The terminal equipment is accommodated in exchange buildings and includes the full range of digital multiplex/demultiplex equipment, from single telephone channels to 140 Mbit/s (1920 channels), and standard 49 mA constant-current power feed units.

Power is fed via copper conductors within the optical cable to the line-fed power supplies where a d.c. to d.c. converter is incorporated to take account of the high-current (150 mA) low-voltage requirement of the laser and the high-voltage low-current requirement of the avalanche photodiodes used (see under Receiver).

A four-wire engineering order wire is provided at the terminals and repeaters via the power feed conductors for use during installation and maintainance. (Figure 6.)

System Power Budget

When the project was planned more than two years ago it was necessary to decide upon a maximum loss target for each part of the system such that we could have a high level of confidence that the complete system would function correctly in this regard. The decision was made to allocate 1 dB to the demountable connectors, of which there are two, one at each end of the section, and 1 dB to each of the seven splices which it had been estimated would be required in each section. The launched power from the laser was assumed to be -3 dBm and the repeater sensitivity for a bit error rate of 1 in 10^{-9} was estimated to be -48 dBm at 140 Mbit/s. A further 5 dB was allocated for the equalised dispersion penalty. The installed cable loss was somewhat pessimistically assumed to be 8 dB/km and the repeater spacing was set at 3 km. This would have given an operating margin of 7 dB as shown in Fig. 7.

Fibre and Cable

The demonstration required large quantities of low-loss low-dispersion fibre, and it was necessary to develop better quality control techniques to minimise the geometry variations between fibres, so to ensure low splicing losses. The production of low-loss graded-index fibre is now routine. The fibres are in-line coated with silicone resin during the pulling operation, to preserve the initial strength and minimise microbending losses during cabling, and subsequently extrusion coated with polypropylene for general protection. The final overall fibre diameter plus coatings is 1 mm.

The cable comprises a central steel strength member around which three specification fibres, one filler and four copper conductors are stranded. Finally, this assembly is protected by a polyethylene jacket of 7 mm overall diameter. 12 km of cable were produced for the demonstration with good and consistent attenuation, dispersion, geometry and strength, and with minimal changes in fibre characteristics due to the cabling operation itself. The average characteristics are as follows:

Cable attenuation:

4.7 dB/km measured at 0.85 μm with filled aperture launch.

Incremental cabling loss:

<0.6 dB/km.

Pulse dispersion:

1.6 ns/km.

Core geometry:

32 ±0.5 μm.

Connectors and Splices

The cables are joined by means of splices, demountable connectors being used only on the repeaters.

The demountable connectors are adjustable to enable the loss to be minimised. The collapsed tube splicing technique was used[1] in which the fibre ends are prepared by stripping the plastic coating and cleaving to produce optically flat ends. One end is then inserted halfway into a short length of pyrex capillary tubing which is then heated around the fibre and collapsed onto it, producing a socket on the fibre end whose internal diameter corresponds to the fibre overall diameter. The second fibre is cemented into the socket using a cement of the same refractive index as the fibres. After curing the completed splice is strengthened and protected by a stainless steel tube and the splices enclosed in a lengthened standard British Post Office joint housing. This whole operation is performed in the field using a small portable jig complete with integral microscope. Typical splicing losses of 0.3 dB can consistently be achieved by relatively unskilled operators.

Electro-Optics

Optical Source

Six double-heterostructure 20 μm width stripe GaAℓAs lasers were used in the system. Due to the steep slope of the optical-power-out versus current-input characteristic (Fig. 8) a laser feedback control circuit is necessary to ensure correct operation and eliminate variations that would otherwise occur due to changes of threshold with temperature and life. An additional requirement at high bit rates is pre-bias of the laser close to threshold to minimise turn-on delay and to avoid a large spectral width which would produce material dispersion in the fibre due to different propagation velocities with wavelength. Two different types of laser control circuit were used[2]. One a mean Power Control circuit in which the mean power only is controlled and the modulation depth is determined by a preset adjustment of the modulation current. Such a circuit performs well if there is no change in slope efficiency with life, but if such changes were to occur (though such changes are not expected with low degradation rate lasers) then it might be necessary to use the second type of control circuit, the Sampling Feedback Control Circuit[2]. In this, the optical power levels, both the '1' and '0' levels, are sampled and independently controlled, thus eliminating variations due to slope efficiency. The laser package has a window on the rear face to allow light from the rear face of the laser to fall onto a monitor photodetector. Light is launched from the laser into the fibre by means of a simple butt joint. The fibre window of the package is also an element of the male part of one of the demountable connectors.

Receiver

The demonstration system uses avalanche photodiodes of the 'reach-through' type (RCA CA 30884) for signal detection. Special bias circuits were required to overcome the variation of constant-gain bias voltage with temperature, and from device to device. The circuit used operated in constant d.c. current mode for low power levels and constant voltage at higher power levels. Constant-current mode provides AGC by changing the avalanche gain. The low-noise amplifier was of the transimpedance type using bipolar transistors, giving a sensitivity of <15 nW for 1 in 10^9 errors. See Fig.9. The low-noise amplifier was followed by a conventional AGC and an adjustable equaliser before timing recovery and regeneration. The dynamic range of operation is ∿25 dB, and to allow for reduced optical losses a facility was incorporated into the detector mount whereby fixed optical attenuators could be inserted.

Installation and Performance

Before installation, the equipment and cables were assembled in the laboratory and tested[3]. The cables and equipment were then installed in the field by regular STC installation teams to show the practicability of the system (Fig. 10). The route had many sharp bends through ducts and manholes, but the ten cable lengths, several greater than 1 km, were installed in the 9 km route without breaking a single fibre or producing a significant change in optical characteristics.

Since the demonstration the evaluation phase has been going on. Error rates of <1 in 10^{11} have been obtained for two system configurations:

(a) 9 km duplex with 3 km repeater spacing;

(b) 9 km duplex with one repeater bypassed.

Configuration (b) resulted in an unrepeatered section length of >6.2 km: Fig. 11 shows the equalised 'eye diagram'.

Conclusion

Optical fibre communication systems had reached the stage of development where a practical full-scale field demonstration was the obvious next step. Our 140 Mbit/s Hitchin-Stevenage link is now providing both ourselves and PTT administrations with vital information necessary for planning and developing the optical fibre systems of the future.

Acknowledgements

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References

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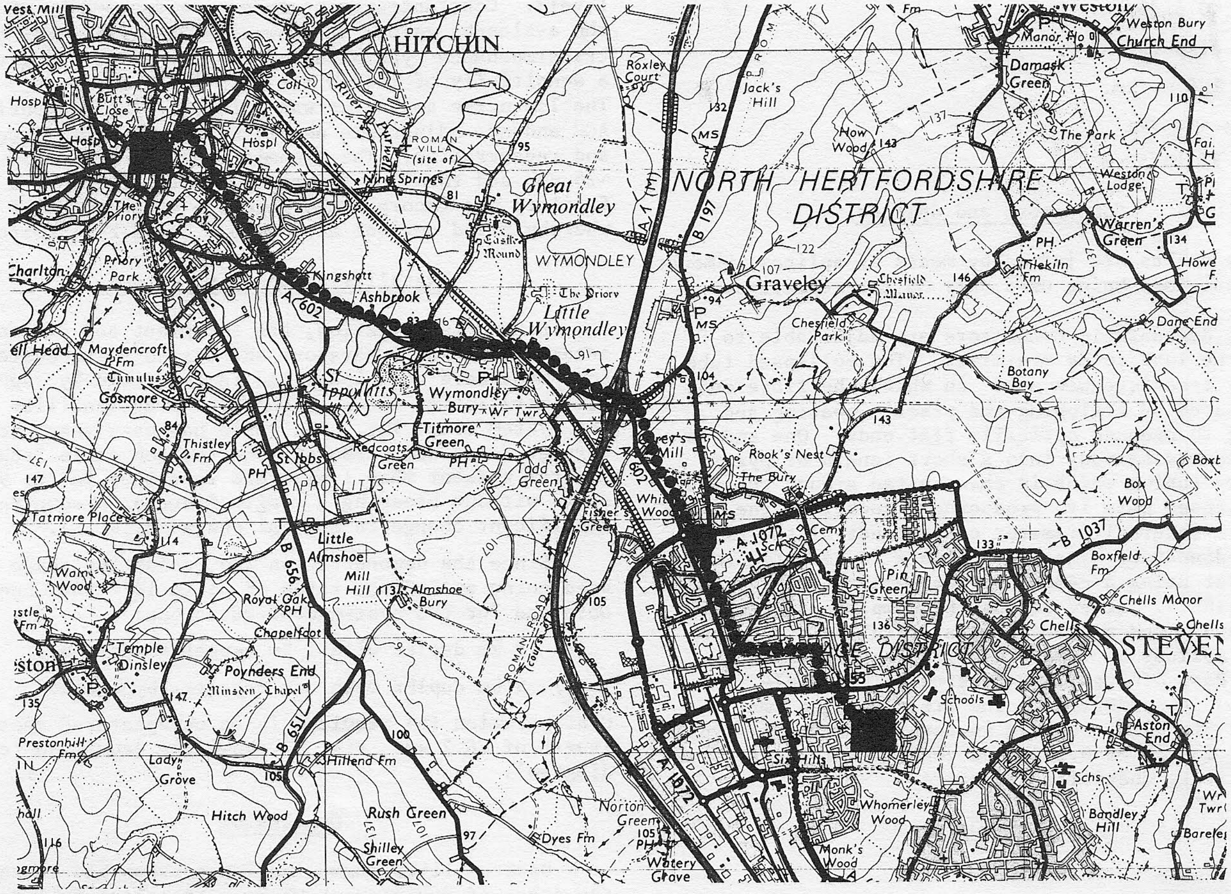

Fig. 1 MAP OF 9 KM ROUTE

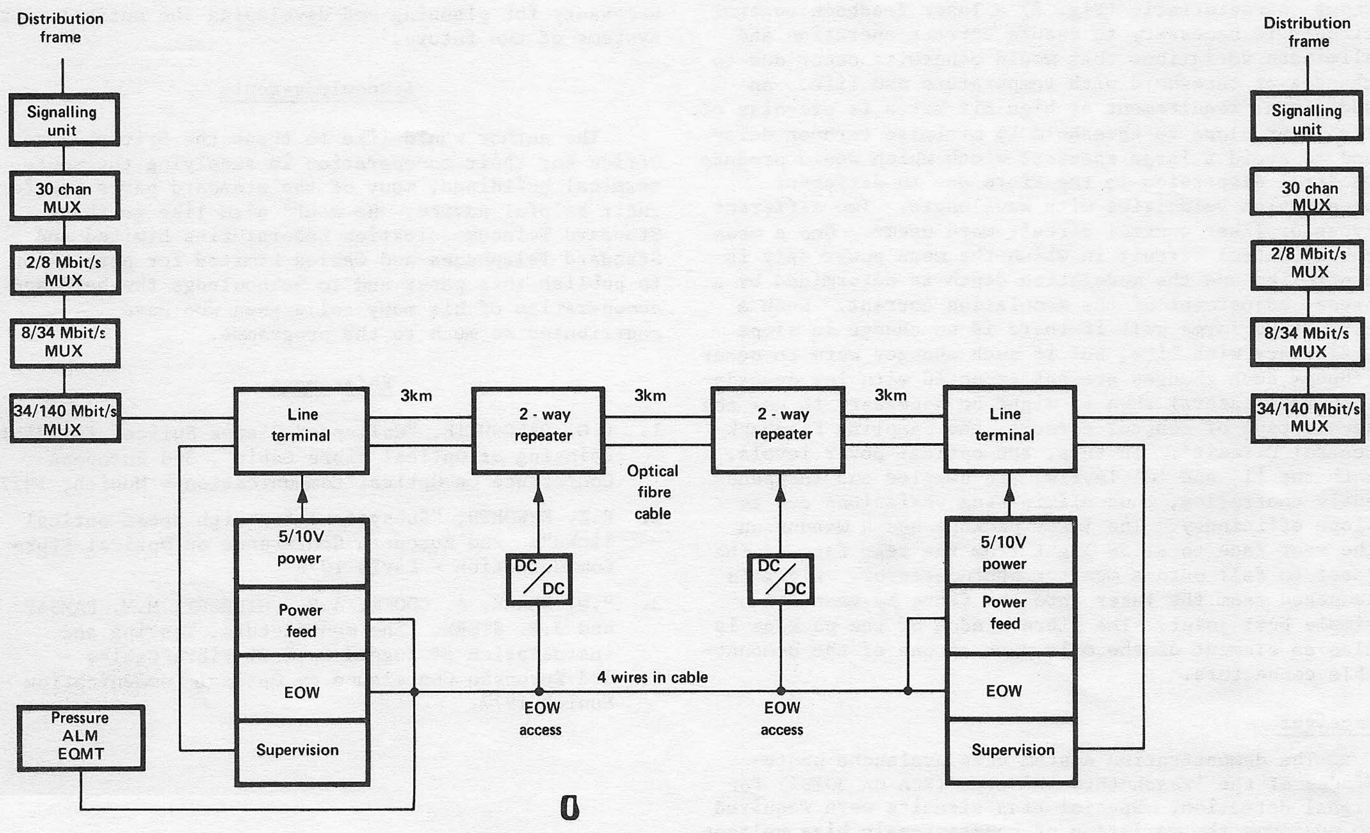

Fig. 2 OVERALL SYSTEM CONFIGURATION

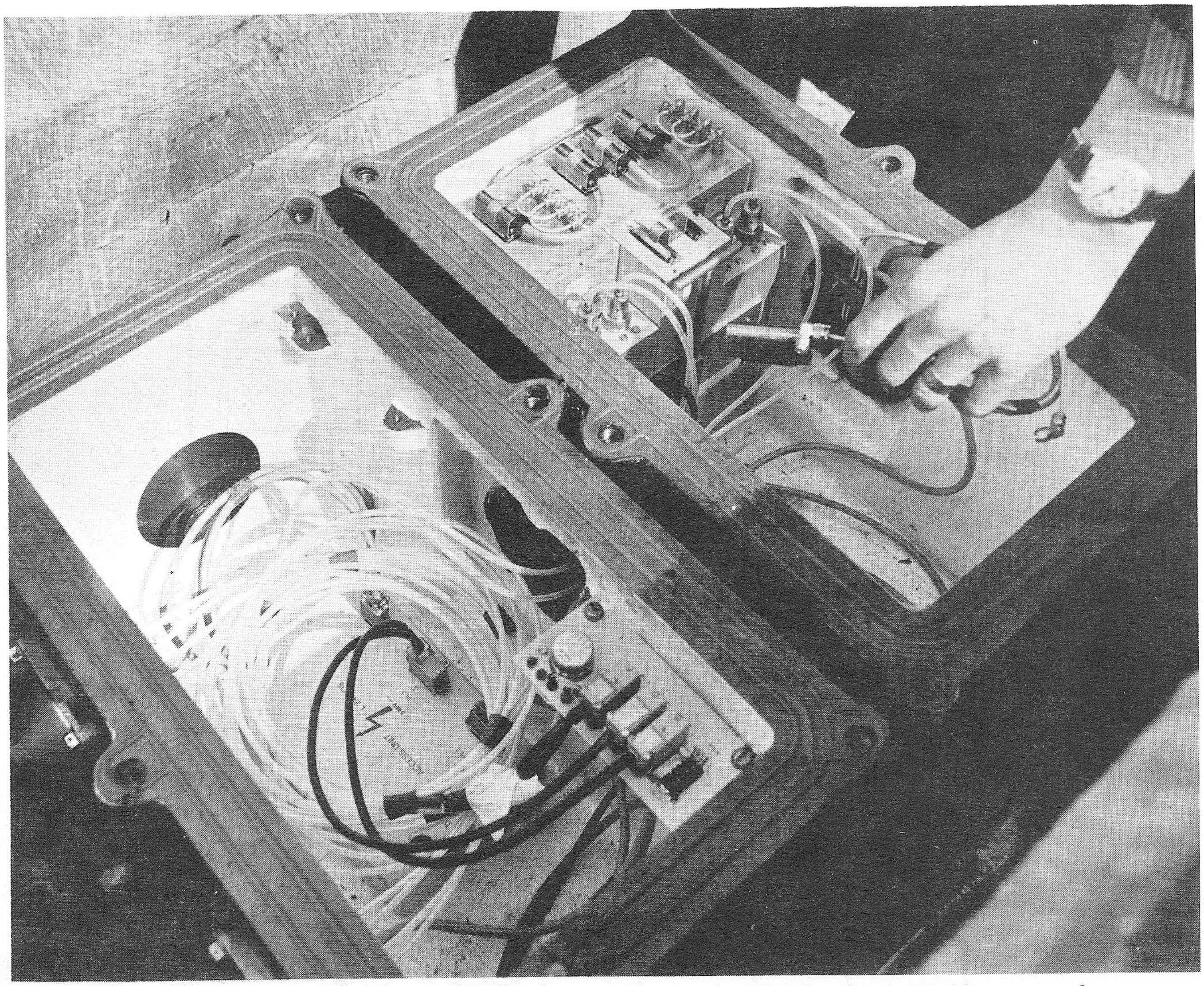

Fig. 3a Pressurized repeater cases opened up to show double repeater and power supply.

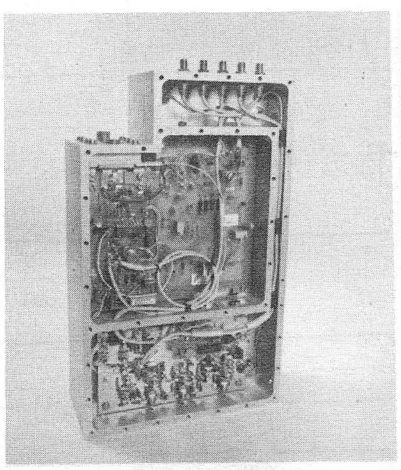

Fig. 3b Repeater transmit side

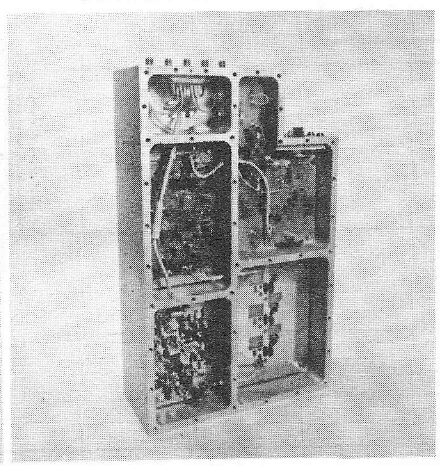

Fig. 3c Repeater receive side

Fig. 4 Terminal repeater undergoing final adjustments.

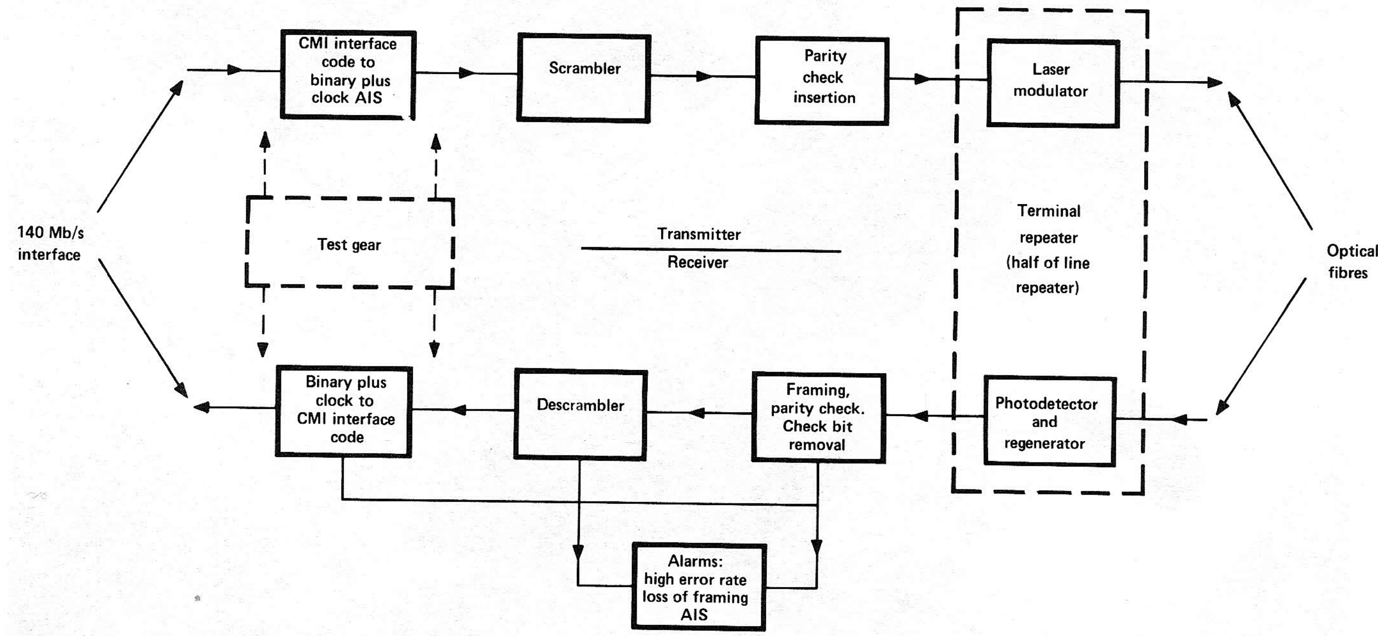

Fig. 5 LINE TERMINAL

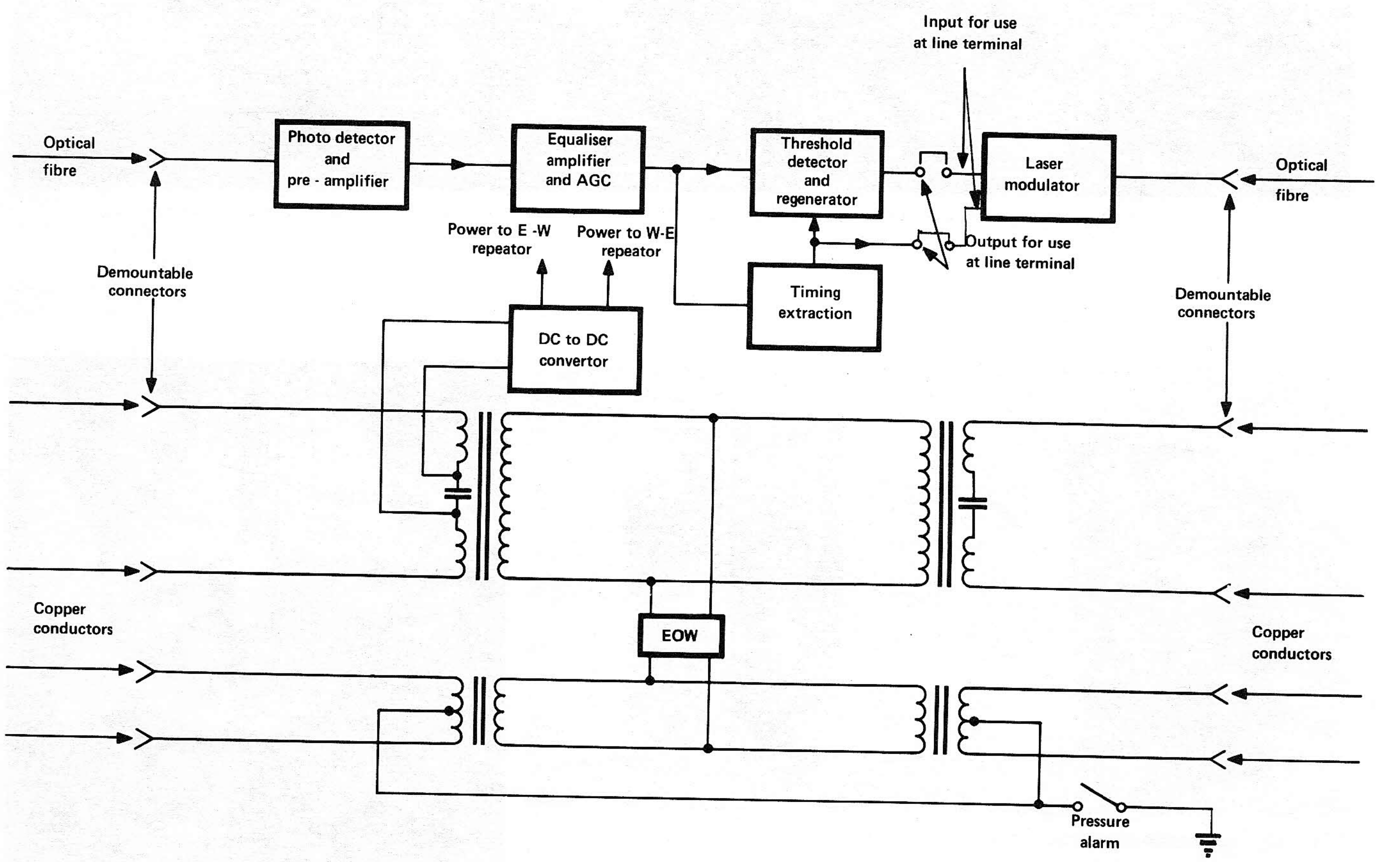

Fig. 6 LINE REPEATER

	Budgeted 1975	Achieved 1977
Power launched into fibre	- 3.0 dBm	- 3.0 dBm
Connector losses (2 at 1 dB)	- 2.0 dB	- 2.0 dB
Jointing losses	- 7.0 dB (7 at 1 dB)	- 1.8 dB (4 at 0.45)
Cable losses (8 dB/km)	- 24.0 dB	- 15.0 dB
Dispersion penalty (7 ns/3 km dispersion)	- 5.0 dB	~ - 3.0 dB
Required receiver sensitivity	- 41.0 dB	- 24.8 dBm
Achievable receiver sensitivity	- 48.0 dBm	- 49.0 dB
Overall system margin	7.0 dB	24.2 dB

Fig. 7 140 Mb/s System Power Budget.

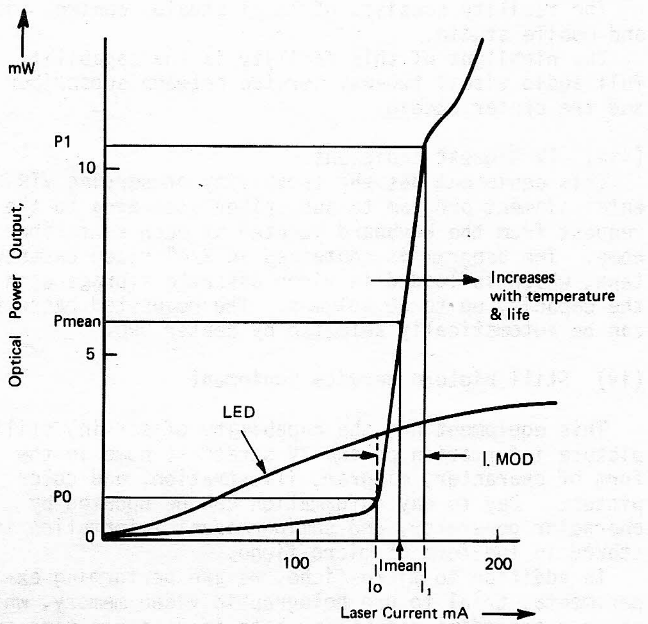

Fig. 8 Laser characteristics (compared with LED)

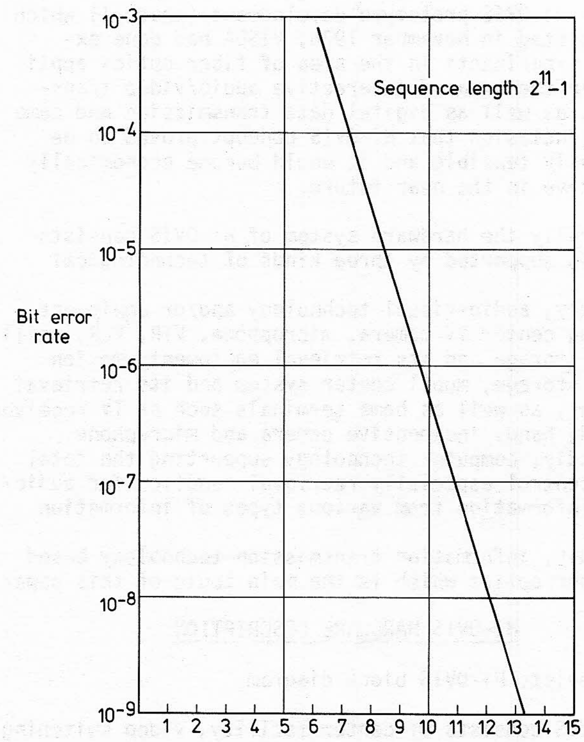

Fig. 9 Receiver sensitivity

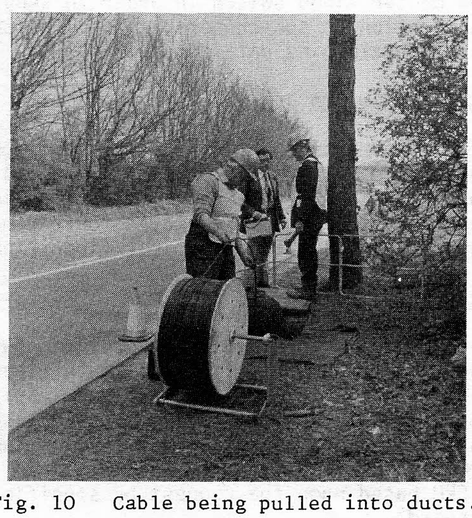

Fig. 10 Cable being pulled into ducts.

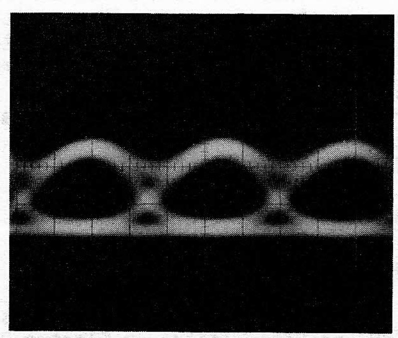

Fig. 11 Equalized "eye" over 6.2 km section length. 2 nsec/cm horizontal scale