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WORKSHOP ON OPTICAL FIBER COMMUNICATION
(24 February - 21 March 1986)

OPTICAL FIBER CABLE INSTALLING TECHNIQUES.

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Optical Fiber Cable Installing Techniques

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Optical Fibre Cable

Installing Techniques

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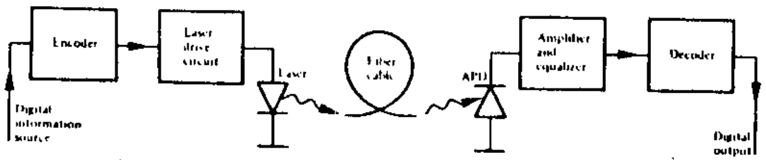
1. Introduction

The use of light for long distance communications is an old concept. However, the great innovation of our time is the production of a ray of light, modulated at extremely high frequencies, which is transmitted for great distances along an optical fiber made of highly pure glass. The equipment at the input and receiving points makes it possible to code, modulate, de-code and demodulate telephone, television and other communication channels which are to be transmitted along the fiber.

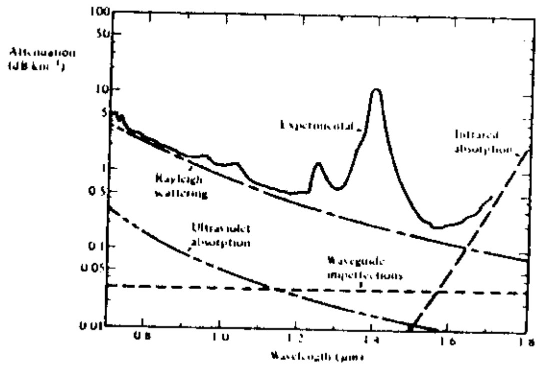


A digital optical fiber link using a semiconductor laser source and an avalanche photodiode (APD) detector.

Besides, the inherent attributes of optical fiber transmission systems make them suited for high performing high information capacity links over a range of 1 to 40km. So optical fiber technology offers an efficient transmission alternative to present day metallic cable and microwave modes of communication.

The main transmission parameters of optical fibres which make them so attractive from a technical point of view in respect with the other physical carriers are:

a) the characteristic attenuation of optical fibers, which has fallen from 20 dB/km in 1970 to the current values and which can be as low as some fractions of dB/km;
b) the transmission bandwidth within the fiber, taking into account the dispersion phenomena. As it is linked to the distance covered by the light signal, it is expressed in MHz·km. The order of magnitude of the bandwidth may be around 2 or 3 GHz·km for graded index fibers of good quality and more than 100 GHz·km for single mode fibers with monochromatic light sources.


The measured attenuation spectrum for an ultra low loss single mode fiber (solid line) with the calculated attenuation spectra for some of the loss mechanisms contributing to the overall fiber attenuation (dashed and dotted lines)

From these considerations it is apparent that optical fibers have attenuation and bandwidth values which are substantially lower than the conventional coaxial pairs with copper conductors. Therefore, the regeneration length is not 2-4 km but substantially longer. Typical lengths of 20-30 km are those relating to multimode fibers, by which it is normal to carry PCM transmission systems at 2, 8, 34 and 140 Mbit/s corresponding to 30, 120, 480 and 1920 channels per pair of fibers.

In the case of single mode fibers with a monochromatic source, laboratory experience shows that the repeater length may be of the order of 100 km , with transmission systems of 140 Mbit/s up to some Gbit/s.

The most important field of application of optical fibers is that of data transmissions, telephone communications, television programmes. In these cases, current designs with multimode fibers cover medium distance connexions while for long distance transmissions single mode fibers are becoming the standard.

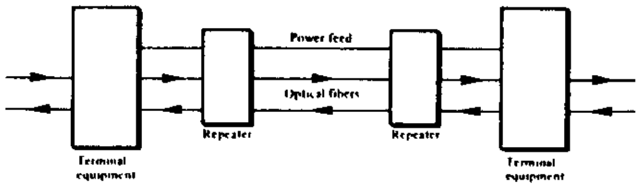
In addition to the fundamental field of telecommunication systems, other interesting fields of application are open to optical fibers by reason of their merits such as total immunity with regard to interference from external electro-magnetic fields, extremely small dimensions and low weigth and the practical impossibility of tapping the signal being transmitted.

2. System design

Many of the problems associated with the design of optical fiber communication systems occur as a result of the unique properties of the glass fiber as a transmission medium.

However, in common with metallic line transmission systems, the main design criteria for a specific application using either analog or digital transmission techniques are the required transmission distance and the rate of information transfer.

In optical fiber communications these criteria are directly related to the transmission characteristics of the fiber, such as optical attenuation and dispersion. In fact, it is these factors which limit the maximum distance that may be tolerated between the optical fiber transmitter and receiver. Where the terminal equipment is more widely spaced than this maximum distance , as in long-distance telecommunication systems, it is necessary to insert repeaters at regular intervals. The repeater incorporates a line receiver in order to convert the optical signal back into an electrical one that is amplified and equalized before it is retransmitted as an optical signal via a line transmitter. When digital transmission techniques are used the repeater also regenerates the original digital signal before it is retransmitted as a digital optical signal. In this case , the repeater may provide alarm, supervision and engineering order wire facilities.



The use of repeaters in a long-haul optical fiber communication system.

The installation of repeaters substantially increases the cost and complexity of any line communication system. Therefore, a major design consideration for long-haul communication systems is the maximum distance of unrepeated transmission so that the number of intermediate repeaters may be reduced to a minimum.

In this respect, optical fiber systems display a significant improvement over alternative line transmission systems using metallic conductors.

Anyway, power budgeting for an optical fiber communication system is performed in a similar way to power budgeting within any communication system. When the transmitter characteristics, fiber cable losses and receiver sensitivity are known, the evolution of power budgeting allows the repeater spacing or the maximum transmission distance for the system to be evaluated. However, it is necessary to take into account a system margin into the optical power budget so that small variations in the system operating parameters do not lead to an unacceptable decrease in system performance. This margin in often included in a safety margin Ma which also takes into account possible source and modal noise. This safety margin depends on the system components as well as system design procedure and is typically in the range 5-10 dB.

The optical power budget for a system is given by the following equation:

$$P_i = P_o + (\alpha_{fc} + \alpha_j) L + \alpha_{cr} + Ma \quad dB$$

where P_i is the mean input optical power launched into the fiber, P_o is the mean incident optical power required at the receiver, α_{fc} is the fiber cable loss per unit length, α_j is the loss due to joints specified in terms of an equivalent loss per unit length and α_{cr} is the loss contribution of connectors used for coupling the optical source and detector to the fiber.

This equation allows the maximum link length without repeaters to be determined. On the contrary, if the maximum transmission distance and the required bandwidth are already known, the optical power budget is used to provide a basis for optimization in the choice of the system components.

3. Installation of optical fiber systems

The installation of an optical fiber communication system is carried out through four different phases:

a) laying of the optical cable;
b) splicing of the various cable lengths;
c) termination of the regeneration length;
d) field measurements on the system.

3.1 Laying

The laying of optical cables entails the study and development of some techniques suitable for the following situations:

a) laying in ducts;
b) laying in trench;
c) aerial laying.

The first laying technique is that in duct. In this case, the cable is pulled along the duct with a winch at a laying speed which is comprised between 5 and 20 m/min, depending on the difficulties of the route.

The changes in direction and/or level, which occur along the route, are smoothed with the aid of pulleys suitably installed in manholes. The friction between cable and duct is lowered with lubrificants . The pulling force exerted on the cable end is kept under constant control: if its value exceeds the pre-set limit , the winch is automatically decoupled from the cable.The typical values of the pulling force are comprised between 150 and 250 kg, depending on the cable structure.

If, owing to excessive difficulties in the route, it is considered impossible to lay the whole cable length by pulling from one end only, the installation operations imply the following phases: laying of part of the length in one direction; unwinding on the ground in the shape of an 8 of the remaining part of the cable before pulling into the duct in the opposite direction.

In some difficult circumstances, use is made of an intermediate pulling device which is suitably positioned along the route and works with the main winch but an indipendent way.

With these procedures, it is possible to lay cable lengths up to a distance of 2 km. The ducts already existing are generally dimensioned for the conventional metallic cables and their diameter is about 100 mm. The very small dimensions of the optical cables, with outer diameter comprised between 10 and 20 mm, suggest a better use of the ducts with introduction of 3 or 4 subducts in each hole. These subducts consist of high density polyethylene pipes, with diameters between 30 and 36 mm and a thickness of 2 mm.

Outside urban districts and on long - distance links, where ducts are not present, it may be convenient to carry out multihole ducts at low cost which allow future extensions of the network without having recourse to new and heavy expenses for civil works of excavation and backfilling. This solution is suggested by the high incidence of the laying operations on the total cost of a system and the reduction in the dimensions and weight of the optical cables.

The multi-hole duct consists of a unit of 3 high density polyethylene tubes connected by a complanar stripe. The inner diameter of the holes is 34 mm and the thickness is 3 mm. The potentiality of the duct can vary according to requirements: one or more multi-hole ducts can be laid in the same trench at a depth of 80-100 cm . In particular cases, such as towncrossings, bridges,tunnels, the multi-hole duct, before backfilling, can be protected concrete or iron boxes.

Along the route concrete manholes are located at intervals of 500 m and at those points where remarkable changes in direction and/or level occur. Their function is to facilitate the laying operations and to house the splicing closures.

On the contrary, when it is not convenient to construct a multi-hole duct, the optical cables can be laid directly in the ground at depths varying between 80 and 100 cm following procedures similar to those adopted for the conventional cables. In this case, the cables can be laid directly in the ground or protected with suitable concrete boxes. In both cases, cables have to be armoured by corrugated and welded steel sheaths or by steel tapes.

In addition to laying in ducts or in trench another important laying technique is the aerial laying.In this case, three different installing situations can be considered:

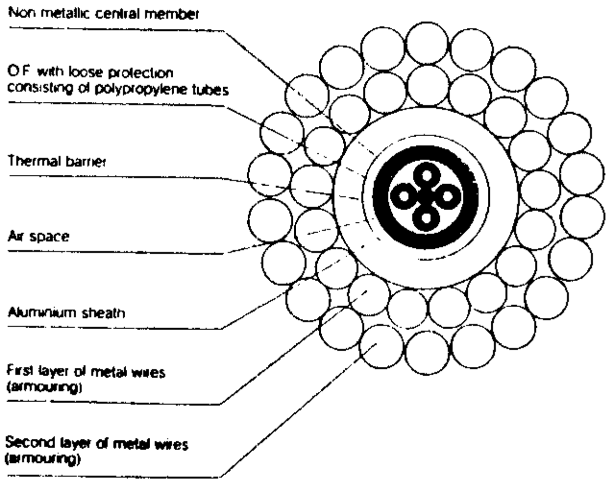
a) laying of clipped or lashed overhead cables;
b) laying of self-supporting overhead cables;
c) laying of ground wires containing optical cables.

In the first case, the optical cable is clipped or lashed on a supporting wire stretched in advance along the pole route. The clipping is suitable for any type of pole route and it is generally carried out with steel clips applied at intervals of 30 to 50 cm.

The lashing can be mainly applied to new lines or to lines already existing which in any case allow the la

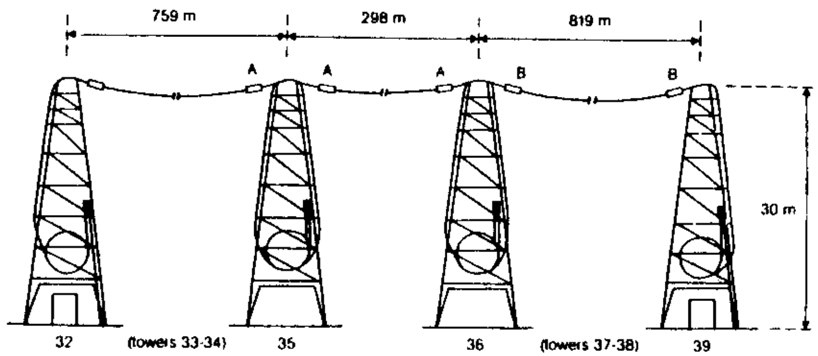
shing machine to rctate around the supporting wire.

In the second case, the cable containing a kevlar strenght member, is stretched directly between the poles, with anchoring carried out with preformed grips or with clamps. In this case, secondary loose protection of the fibers is necessary if the stresses on the cable, due to thermal swings, ice sleeves or wind blows, are not to be transmitted to the fibers.



Cross section of a composite conductor

In the third case, the optical cable is inserted inside the ground wire for the medium and high voltage power lines. In fact, adeguate experiments have proved the total immunity of the optical fibers to high over - voltages and overcurrents from lightning. So, any new medium or high voltage power line should be equipped with such a ground wire, while in the power lines already existing it is more reasonable to aim at clipping or lashing a dieletric optical cable around the ground wire.



General layout for the Fontanelle-Colli Alti power line (130 kV)

A — Distribution grip
B — Compression clamp

3.2 Splicing

To carry out links in optical fibers over a certain length it is necessary to joint together permanently adjacent lengths of cable. The number of intermediate fiber joints is dependent upon the link length between repeaters, the continuous length of fiber cable that may be produced and the length of fiber cable that may be practically or conveniently installed as a continuous section on the link. Current practise allows single lengths of fiber cable of around 2 km to be installed, while repeater spacing on optical fiber links is a continuously increasing parameter with currently installed digital systems operating over spacings of up to 40 km together with the prospect of repeater spacings of many tens of km for single mode systems.

It is therefore apparent that fiber to fiber joints with low loss and minimum distorsion is of increasing importance within optical fiber communications in order to extend the repeater spacings required for developing systems.

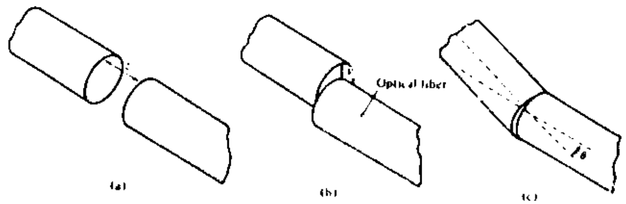
So fiber to fiber splices are mainly required to transfer the maximum possible power between the two fibers connected. This object cannot always be easily achieved: at present, the average insertion loss in the splices of a link varies typically between 2% and 4% of the incident power.

Losses are mainly caused by the generation of the modes not guided or weakly guided to which, in some cases, it is necessary to add the reflection losses, associated with the step changes in refractive index of the jointed interface. For the losses, there exist causes intrinsic and extrinsic to the splicing process.

The intrinsic losses are due to the lack of homogeneity to be found in the geometry and in the composition of the fibers to be spliced.

The extrinsic losses are due to the alterations

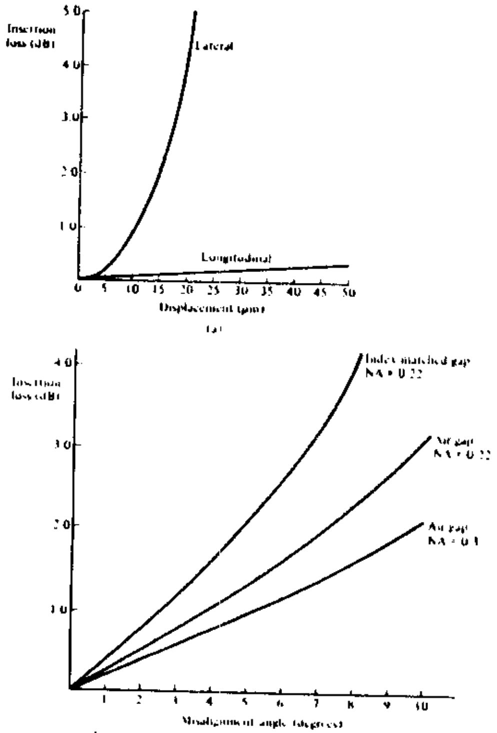
introduced in the fiber structure by the melting process, or the misalignment of the two fiber ends. This misalignment may be represented by the longitudinal separation between the fibers, the offset perpendicular to the fiber core axes and the angle between the core axes.



The three possible types of misalignment which may occur when jointing compatible optical fibers [Ref. 58]: (a) longitudinal misalignment; (b) lateral misalignment; (c) angular misalignment.

Optical losses resulting from these three types of misalignment depend upon the fiber type, the fiber core diameter and the distribution of the optical power among the various propagating modes.

Anyway it may be observed that relatively small levels of lateral or angular misalignment can cause significant losses at a fiber joint and this especially the case for small core diameter fibers which are currently employed for most telecommunication purposes.



Insertion loss characteristics for jointed optical fibers with various types of misalignment: (a) insertion loss due to lateral and longitudinal misalignment for a 50 μm core diameter graded index fiber, reproduced with permission from P. Mossman, *The Radio and Electron. Eng.*, **51**, p. 333, 1981. (b) insertion loss due to angular misalignment for joints in two multimode step index fibers with numerical apertures of 0.22 and 0.3. Reproduced with permission

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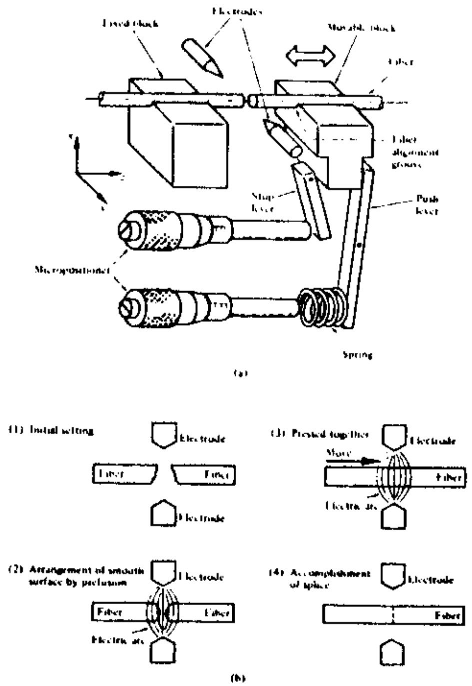
Splices may be divided into two broad categories, depending upon the splicing technique used:

a) fusion splices
b) mechanical splices.

Fusion splicing is obtained by applying localized heating, by a flame or by an electric arc, at the interface between two butted, prealigned fiber ends causing them to soften and fuse.



Electric arc fusion splicing (a) an example of fusion splicing apparatus [Refs 81 and 85]; (b) schematic illustration of the prefusion method for accurately splicing optical fibers

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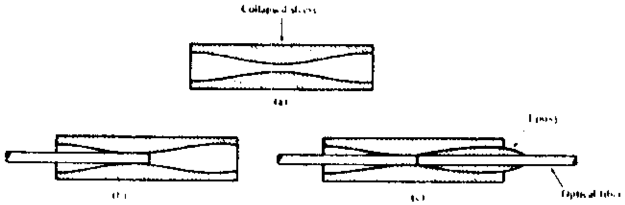
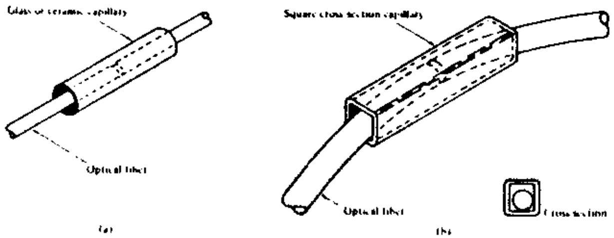
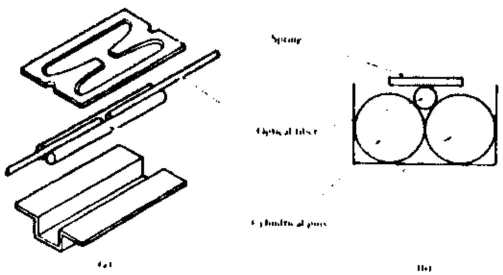
Mechanical splicing, in which the fibers are held in alignment by some mechanical means, may be achieved by various methods including the use of tubes around the fiber end or V-grooves into which the butted fibers are placed.



The collapsed sleeve splicing technique [Ref. 98].



Techniques for tube splicing of optical fibers. (a) snug tube splice [Ref. 94]; (b) loose tube splice utilizing square cross section capillary [Ref. 96].



The Springroove® splice [Ref. 101]: (a) expanded view of the splice; (b) schematic cross section of the splice

All these techniques seek to optimize the splice performance through both fiber end preparation and alignment of the two jointed fibers. Typical average splice insertion losses for multimode and single mode fibers may be lower than 0.1 dB.

After splicing, that part of the fiber that remains uncoated must be protected and reinforced.

Protection and reinforcement are generally carried out by inserting the splice in a steel cylindric structure and by filling the interspace with silicon rubber.

An alternative method can be had by using thermo shrinking materials coupled with a small steel cylinder.

Inside the closures the fibers are housed in suitable modules, each of them can contain 4 to 10 individual splices according to the structure of the cable. These closures can be metal or plastic, circular or rectangular according to the requirements of the plant or to the specific requests of the customer.

3.3 Termination

After laying and splicing, optical fiber cables have to be termined into the exchanges with connectors which are devices for connecting two or more optical fibers not permanently. They are therefore used as interface cable-equipment and as a mean of distribution wherever is requested the possibility to accede to the fiber.

Demountable fiber connectors are more difficult to achieve than optical fiber splices. This is because

they must maintain similar tolerance requirements to splices in order to couple light between fibers efficiently, but they must accomplish it in a removable fashion. Besides the connector design must allow for repeated connections and disconnections without problems of fiber alignment which may lead to degradation in the performance of the transmission line at the joint. Therefore, to operate well, the demountable connector must provide reproducible accurate alignment of the optical fibers.

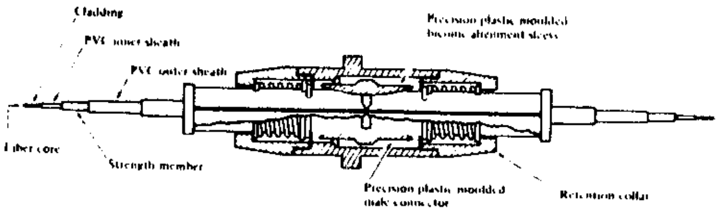
In order to maintain an optimum performance the connector must also protect the fiber ends from damage which may occur due to handling. It must be insensitive to environmental factors and it must cope with tensile load of the cable. Besides, the connector must be a low cost component, which can be fitted with relative ease.

There are a large number of demountable single fiber connectors which have insertion losses in the range between 0.2 and 3.0 dB.

These connectors may be separated into two broad categories:

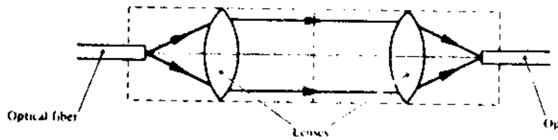
a) butt jointed connectors;
b) expanded beam connectors.

Butt jointed connectors rely upon alignment of two prepared fiber ends in close proximity to each other so that the fiber core axes coincide.



Cross section of the biconical connector

Expanded beam connectors use interpose optics at the joint, such as lenses or tapers, in order to expand the beam from the transmitting fiber end before reducing it again to size compatible with the receiving fiber end.



Schematic illustration of an expanded beam connector showing the principle of operation.

These connectors must have the following characteristics: low loss, high reliability, great number of operations, low attenuation variations against temperature and low cost.

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3.4 Field measurements

The main measurements to be carried out on an optical fiber link are the following:

a) control of the link regularity;
b) control of the loss in the splices;
c) measurement of the insertion loss on the repeater section;
d) measurement of the fiber bandwidth on the repeater section (in the case of single mode fiber links this measurement is replaced by the measurement of the chromatic dispersion on the repeater length).

The control of the link regularity, generally carried out with the backscattering technique, supplies information on the trend of the attenuation coefficient along the fiber and besides it aims at verifying the presence of any imperfections located along the same.

The control of the loss in the splices is important in order to verify the quality of the splicing technique. Besides, if repeated at regular time intervals, it allows the control of reliability of the connections versus time. This measurement is carried out with the backscattering technique and consists in evaluating the power decaying on the backscattered curve in the splicing point.

The measurement of the insertion loss on the repeater section aims at supplying an evaluation of the total loss on the route including cable, splices and terminal connectors.

At last, the bandwidth or chromatic dispersion measurement on the repeater section is carried out in order to verify that the link has a bandwidth sufficient to the transmission rate requested.

February 18, 1986

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