Technical Report

A Systems Study of Fiber Optics for Broadband Communications

Activity No. 7
Operational Considerations

BNR Project TR 6259
January 1978

Bell-Northern Research

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B. Board
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1. INTRODUCTION

This report is part of a contract study on the application of fibre optics to broadband communications undertaken by Bell-Northern Research for the Department of Communications, of the Canadian Government. The present activity is concerned principally with the operational (maintenance) aspects of providing integrated distribution of video, telephony and data on a single network, using fibre optics as described in Activity No. 3 of the present study. A similar approach is possible with the networks of Activity 4 for asymmetric video, and could be adapted to fit the star distribution of CATV recommended in Activity 2. However the network addressed in this document has been chosen since the telephony it carries imposes stringent requirements on the maintainability and reliability of the system. In accordance with the objectives of the department of Communications, emphasis is placed on the operations associated with a rural environment.

2. SUMMARY AND CONCLUSIONS

Following are the key items outlined in this report:

(a) Reliability

- The overall reliability of the proposed network must be such that the availability of telephony services provided by the network to the individual subscribers is comparable with that of telephone services provided by existing switched telephone networks.

- In order to minimize signal deterioration due to aging, the materials chosen for the design of splices must be compatible with respect to their thermal expansion coefficients, and their material properties must remain stable over the required life of the system.

- Connector design should minimize fibre wear since connectors will be subject to a number of mate/remate cycles for maintenance and rearrangement purposes.

- Connectors should provide as much protection as possible to the fibre ends during remating and minimize their exposure to external mechanical damage or contamination when unmated. They should also provide access to the fibre ends to remove contamination.

- Both Silicon PIN and avalanche (APD) type light detectors are available with high reliability figures.

- Presently first production light sources are guaranteed for a life range of 1500 to 6000 Hrs, however, work is being done to improve this situation. It is expected that a guaranteed life in excess of 100,000 Hrs could be attained in the next few years.

- Human damage to cables can be minimized by choosing cable routes with least susceptibility to damage, providing additional cable protection in higher damage areas, and using dedicated easements and rights of way with frequently spaced cable location markers.

(b) Maintainability

- The powering of essential services provided to each subscriber should be monitored from the remote switch.

- Failure of fibres during operation due to internal cable mechanisms can be minimized, by careful cable design and component specification, complemented by suitable acceptance testing and operational support systems, such as the use of cable pressurization systems to limit moisture ingress.

- If economically viable it is recommended that the controlling central office provide a continuous handshake with the individual nodes making-up the network. This will verify the integrity of the fibre links, the remote switch functions and the subscriber interfaces

- The following automatic testing capabilities should be provided from the controlling central office and/or the remote switch as appropriate for the multiplexing method used:

  i) FDM transmission test, involving slope measurements over the frequency spectrum of the video, telephony and data information transmitted.

  ii) WDM transmission test, by measuring the light signal levels at the output of each individual detector.

  iii) mBnB encoded signal monitoring for code violation.

  iv) Customer equipment interface monitoring by local intelligence at the remote switch.

- The following proposed testing capabilities should be provided for fault locating of fibres:

  i) Sectionalized attenuation measurements on a routine basis (i.e. Go/No-Go measurements on all fibres using the optical equivalent of the present splicer test set).

  ii) Distance to fault measurement using a backscatter/time technique.

- Fault indications detected on the network should generate alarm indications at the maintenance control location (e.g. central office).

- Operational measurements collected at the remote switch and/or at the central office should be used to monitor overall network performance and quality of service.

- If results of field trials now in progress internationally indicate significant changes in the transmission properties of optical fibres over the expected life span of the network, routine testing should be used to detect gradual deterioration before it becomes service affecting.

- All functions performed by the remote switch should be monitored on an ongoing basis at the remote location (with scheduled and/or exception reporting to the controlling central office). This statement implies some form of intelligence at the remote switch for error monitoring.

3. OPERATING OBJECTIVES

3.1 GENERAL

This chapter discusses the operating objectives of a fibre optic network for the integrated distribution of video, voice and data with respect to Availability, Reliability and Maintainability.

3.2 AVAILABILITY

Availability is the probability that the network will meet the demands of the customer when he needs it. Availability is a function of the inherent reliability of individual components and the maintainability of the network. Therefore given an objective for availability, it can be achieved either by using highly reliable components or providing the necessary maintenance features to minimize the effects of equipment failures on the quality of service provided to the customer. The availability of a given system or operating unit is given by the following formula:

A = up time / (up time + down time)

The availability objectives for the telephony services provided by the integrated network proposed in Activity #3 of this study should be comparable with that of telephone services provided by existing telephone networks. Table 3.1 gives availability objectives typical of existing telephone networks.

3.3 RELIABILITY

The overall reliability of a fibre optic network for the integrated distribution of video, voice and data must be such that the availability of telephone and data services to the individual subscribers is comparable with existing switched telephone networks and that the costs associated with system maintenance does not jeopardize the system's economic viability. Table 3.2 gives reliability figures associated with existing switching systems. The reliability of the individual components of the proposed network is discussed in Chapter 8.

3.4 MAINTAINABILITY

Maintainability is a measure of the ease and cost of maintaining the various elements making up the network. A good indicator for evaluating the maintainability of a system is the mean time to repair (MTTR). A prime objective in the design of the network is to minimize out-of-service time. To accomplish this, minimum component reliability is necessary (chapter 8). However, because failures will occur, prompt detection and correction must also be possible, using a combination of manual and automatic techniques. This is particularly important in rural environments because the travel time to field located equipment can add substantially to down time. To offset this, features must be built into the system to detect certain types of failures (e.g. link failure) almost

TABLE 3.1

AVAILABILITY OBJECTIVES FOR TELEPHONE SERVICE[1]

	AVAILABILITY
Individual Call	97%
Individual Subscriber	99.978%
Group of Subscribers (500 subscribers)	99.989% on a per/line basis (equivalent to 1 hour down time/line/year)

$$A = \frac{\text{Up Time}}{\text{Up Time} + \text{Down Time}} = 1 - \frac{\text{Down Time}}{\text{Up Time}} \quad (\text{assuming down time} \ll \text{Up Time})$$

If down time $= \lambda t$ MTTR and Up Time $= T$ and assuming $T \approx t$

where t = operating period
λ = failure rate
MTTR = mean time to repair

Then $A \approx 1 - \lambda$ MTTR

where MTTR = on site repair + travelling time + access time

TABLE 3.2

RELIABILITY OF EXISTING SWITCHING SYSTEMS

RELIABILITY
Between 2 to 10 hours down time in 40 years. *

* As experienced in Bell Canada for stored program common control switchers.

instantly. Furthermore, fault location techniques should be available at a central node (central office) so that no time need be lost in the field for sectionalizing the fault, and that dispatch be made to the right location. Also, in some situations, (e.g. control unit failure), partial or complete service restoration should be accomplishable automatically before the trouble is cleared. The general maintenance requirements deemed necessary for a maintainable network are discussed in the next chapter.

4. GENERAL MAINTENANCE REQUIREMENTS

4.1 GENERAL

Maintenance activities in any communication network are intended to support a quality of service objective to be provided by that network. The quality of service to be provided by a fibre optic communication network will be influenced by many factors, but the two predominant ones are the following:

a) Maintainability;
b) Equipment reliability and design.

Assuming that for a given network and period of a few years, network reliability is relatively constant, then service quality or availability is heavily dependent on the maintainability of the network.

To maintain a network or system involves the following activities:

a) fault detection = being aware that a fault or degradation exists, or is about to occur.

b) fault sectionalization = analysis of trouble indications and test results in order to zero-in on a faulty component or facility.

c) recovery procedures = control and repair activities to restore normal operation of system.

d) administration = updating of records concerning the repaired or restored facility and analysis of service results and maintenance costs.

This chapter defines a set of general requirements for each of the above mentioned maintenance activities in a fibre optic broadband communication network. For the specific maintenance considerations related to the major components of the proposed distribution network, the reader is referred to chapters 5, 6 and 7.

4.2 FAULT DETECTION

4.2.1 General Requirements

Fault detection can be defined as the means of detecting when a function is not being performed properly. The following techniques are generally applied for detecting faults:

a) Monitoring integrity of network on a continuous basis;

b) Monitoring and analysis of operational measurements;

c) Performing routine testing on the network.

In addition to the above, faults can be detected by subscriber reports. However this is not a desirable method and the reliance on such reports must be reduced to a minimum by proper use of the inherent capabilities of the system in detecting and reporting fault conditions within the network, to reduce costs associated with the manual nature of customer report handling.

4.2.2 Monitoring Integrity of Network

If economically viable, it is recommended that the controlling central office (C.O.) provide a continuous handshake with the individual nodes of the network. This will verify the integrity of the fibre links, the remote switch functions and the subscriber interfaces. Additionally, tests should be performed automatically to establish the integrity of a connection on a per/call basis.

4.2.3 Fault Indications and Alarms

Any fault condition detected on the network should be reflected by the following alarm indications:

a) critical alarm = condition requiring immediate corrective action.
 (Affects many subscribers or priority services)
b) major alarm = condition requiring short-term action.
 (Affects small number of subscribers or alternate routes available)
c) minor alarm = condition requiring future action.
 (Affects non-essential services and/or alternate services available)

These indications must provide accurate information to maintenance forces about the fault to permit efficient recovery procedures.

4.2.4 Operational Measurements

Operational measurements (reflecting the usage and failure rates of the individual components of the network) collected by the central office or the remote switch should be used to monitor overall network performance and service results. These measurements should be made available to maintenance forces in any of the following circumstances:

a) scheduled intervals = formatted printouts on an hourly or daily basis;

b) exception report = generated when preset thresholds are exceeded;

c) on request.

4.2.5 Routine Testing

These tests are scheduled to run in periods of low traffic, at a priority lower than call processing tasks. In general, routine testing is most effective in areas where the service may deteriorate gradually.

By detecting measurement deviations from expected measurements before they significantly affect service, routine testing is a method of early prevention maintenance. If the results of field trials now in progress internationally indicate significant changes in the transmission properties of fibres over the expected life of the network, routine testing could be used to detect any gradual deterioration before it can affect subscriber service.

4.2.6 Verification

Fault verification is the means of determining if a fault still exists or existed in the first place. It is an essential maintenance function insuring the efficient use of manpower resources by avoiding unnecessary dispatches. Fault verification can be realized by employing directed testing techniques such as discussed in chapters 5, 6 and 7.

4.3 FAULT SECTIONALIZATION

4.3.1 General Requirements

Once a fault has been detected and identified, it must be sectionalized to the extent that recovery procedures can be initiated. This implies the need for the necessary features to localize a fault to the individual facility level (fibre), to the individual repeater level, or in the case of the remote switches and terminals, to the circuit pack level. Significant savings can be achieved in total maintenance cost if the system is designed to permit rapid and precise localization of faults within the network.

4.3.2 Test Features

It should be possible to test all parts of the network from a central location (C.O.), including the remote switch function, the local and individual fibre links and each subscriber interface.

4.3.3 Fault Location

Fibre fault location techniques (e.g. backscatter/time) are now being investigated (chapter 7). These techniques must allow accurate sectionalization of faults within a given fibre link without necessitating the dispatch of repair crew to more than one location for a given fault.

4.4 RECOVERY PROCEDURES

4.4.1 General Requirements

Once a trouble has been sectionalized, the first priority is service protection. Several corrective actions (fault recovery) can be taken to diminish the effect the fault has on the level of service quality provided by the network. They are:

a) Isolate faulty component or facility;

b) Manual and/or automatic protective switching.

c) Repair or change faulty component.

4.4.2 Verification of Recovery

After recovery procedures are taken, it is mandatory that the success of such procedures be verified. This function consists in testing to verify system performance after a fault is cleared. (See 4.3.2).

4.4.3 Repair and Spares

Procedures for the repair and storing of circuit packs should follow similar procedures adopted for the existing transmission network. (spares could be located at the controlling central office or possibly at a centralized location.)

4.5 ADMINISTRATION

4.5.1 General

The administration functions related to the maintenance of a communication network generally consist of monitoring the performance of individual sub-systems within the network to effectively direct maintenance efforts where most required. The key indicators to be monitored should reflect component usage and failure rate.

4.5.2 Performance Evaluation

Service and performance results are a key administrative tool for making management decisions by identifying areas of deteriorating service quality. These results could be collected on a periodic basis (e.g. monthly, quarterly) and would be used in the preventive and corrective maintenance operations of the network.

5. REMOTE SWITCH MAINTENANCE

5.1 GENERAL

The Remote Switch being probably the most critical item in the distribution network will necessitate the right balance of maintenance features and reliability so as not to impede the economic viability of the overall network. This chapter therefore identifies techniques and procedures that should lead to cost effective maintenance of the remote switch. The terminology used is that of activity report 3, chapter 5.

5.2 INTERNAL MAINTENANCE

It can be assumed that in a rural environment, the Remote Switch unit will be located at some distance from the central office. It is therefore an important requirement that all the functions performed by the Remote Switch be monitored continuously at the Remote Location (with scheduled and/or exception reporting to the controlling central office). This requirement implies some intelligence at the Remote Switch for error monitoring.

5.2.1 Video Switching

The following parameters must be monitored to assess the performance of the video switch:

- Video signal level at output (frequency selective)
- Crosstalk
- Blocking, if concentration is used (not applicable for simple CATV switches).

5.2.2 Telephony Switching

The Telephone Switch is the interface between the local trunk multiplexer and the subscriber multiplexer. Essentially it performs the following operational functions:

- Two way voice transmission
- Supervision
- Signalling
- Concentration
- Local Switching

Existing telephone switches (common control) check the above functions on a per/call basis, on a routine basis, and provide means of testing the functions on a demand basis when a fault is suspected. Failure in performing the operational functions should be detected within the Telephone Switch and flagged to the maintenance personnel.

5.2.3 Data Switching

In order to avoid blocking problems, this unit has been recommended to be a simple multiplexer interfacing with a circuit switch at the Central Office where some concentration occurs, for ultimate transmission to a packet switching node. Maintaining this unit would involve the monitoring of parameters such as synchronization and parity.

5.2.4 Control

The control unit, as described in Activity 3 of this report, is mainly responsible for controlling the distribution of the Video Signal. This unit will also be responsible for recording for accounting purposes, processing customer requests for video and ongoing monitoring of the remote switch functions and facilities for fault indications. Faults detected by, or occuring in the control unit should be reported to the maintenance personnel responsible for maintaining the Remote Switch.

5.2.5 Subscriber Multiplexing and Electro Optic Interfacing

The subscriber multiplexing and electro optic interfacing can be split into two main elements: (Reference; activity Report 3, section 5.3.5)

- bidirectional unit allowing the output optical signals (to and from the subscriber) to be transmitted over the same fibre. (However since bidirectional units are still in a development stage, they may or may not be used in operating systems of the future).

- unit accepting electrical signals from the Remote Switch, converting them into optical form for transmission to the subscriber, accepting optical signals from the subscriber, and converting them into electrical form for use by the Remote Switch.

Therefore, to efficiently monitor the performance of this interface, it is necessary to monitor both the electrical and optical signals involved. The optical signals should be monitored in both directions for presence of signal and/or high signal attenuation. The electrical signals however, could be monitored on a frequency selective basis in order to detect the failure of individual signal components when using Frequency Division Multiplexing (FDM). One method presently used in monitoring FDM transmission is by introducing two pilot signals at frequencies below and above the frequencies utilized for the transmission of video, data and telephony information. These signals are then monitored to yield the approximate level slope over the frequency spectrum used for the information. Very large slopes are used in coaxial systems, with attenuation differences of 8 dB between high and low frequencies. However with fibre, much less slope is needed and much lower bandwidths are predicted, therefore alternative methods could be used, i.e. monitoring a pilot signal at each frequency band (video, data, telephony) or monitoring a pilot signal at the telephone frequency band. When Wavelength Division Multiplexing (WDM) is used, it can be treated as a series of non-multiplexed lines in parallel (i.e. each source has its matching detector).

Therefore if Source #1 is transmitting and Detector #1 is not receiving, while all other detectors are receiving, then Detector #1 (or the associated short fibre link) is (most likely) faulty. However if all detectors fail to receive, the main fibre link can be assumed faulty. Since the operation of laser diodes may require ongoing monitoring of the output light (from the back of the laser cavity) no additional detectors would be required.

The above mentioned signals could be monitored on a routine basis by the Remote Switch and/or when a request for service is being processed.

5.2.6 Local Trunk Multiplexing and Electro Optic Interfacing

This unit accepts optical signals carrying video, data and telephony from the central office converting these signals into electrical form to the video, data and telephony switches and performs the reverse operations with electrical signals from the remote switches and optical signals output to the Central Office.

Since this unit is shared by all subscribers, outage due to failures must be minimized by effective monitoring of its functions and quick restoral of service. Monitoring of optical signals is similar to the subscriber multiplexer and Electro Optic interface. However, in addition to frequency selective monitoring of video signals, the integrity of the "mBnB" encoded digital telephony signal must be monitored at the central office and at the remote switch to detect faults affecting telephony and data transmission. This can be accomplished by detection of code violations (e.g. an occurrence of 3 consecutive zeros or ones in a 2-level AMI code).[6]

5.3 HOUSING AND POWERING CONSIDERATIONS

This section identifies the general maintenance requirements associated with the Remote Switch Housing and powering.

5.3.1 Alarm Indications

The following alarm indications should be provided at the central office controlling the Remote Switch:

- Power failure (commerical AC or other)
- Backup power failure
- Air compressor failure (when provided)
- Ventilation failure (heating/cooling)
- High-low temperature
- High-low humidity
- High water level (underground housing)
- Fire/smoke alarm
- Open door alarm

5.3.2 On Site Maintenance

The following facilities should be available at the Remote Switch location to facilitate on site testing and repair by dispatched maintenance personnel:

- Adequate work area
- Spare circuit pack and tool cabinet
- Communication link with central office (and repeater sites when provided).

6. SUBSCRIBER EQUIPMENT MAINTENANCE

6.1 GENERAL

The most basic requirement of an integrated communication network is that it should allow a conversation to take place between two people who are separated by some distance. No matter what transmission techniques are used, the user emits and receives signals in the form of acoustic energy. Thus the objectives concerning acoustic level, overall loss, noise,crosstalk, echo, side-tone and distortion apply to a fibre system as well. Apart from providing a voice channel for two people to converse, the network must provide mechanisms for a user to request service when he wishes to originate a call; to specify which terminal in the network he wishes to be connected to; and to be alerted of incoming calls. These functions are traditionally called "supervision" "dialling" and "ringing". A common feature of these functions is that they all require the transmission of machine-compatible information over the subscriber fibre. Such capability is more generally called signalling.

The network must also provide some subscribers with video service and the means of selectively choosing the channels available to them. Finally the network should support data transmission to and from certain subscriber terminals.

6.2 TESTING AND MONITORING

The proposed network must provide the intended services with a minimum amount of interruption due to system failure. The system should incorporate testing and maintenance facilities which enable failures to be efficiently detected, diagnosed and restored. In a network using optical fibres, it is assumed that, no metallic connection is provided to the subscriber. Therefore, it is necessary to use a form of data exchange (possibly out of band) for testing purposes. Per-call testing and/or routine testing of the subscriber equipment interface should be performed. This testing would be a short "go/no go" type of testing and should be completely automatic. The tests could be initiated by local intelligence in the Remote Switch, with results reported to the controlling central office on a demand basis or as an exception report.

The powering of essential services provided to each subscriber should also be monitored from the Remote Switch. This includes telephone handsets, telephone interface (modulator-demodulator) and the light source-detector for video reception. However if some intelligence is located at the subscriber interface, tests could be performed locally to recognize failed features.

7. OPTICAL FIBRES FAULT DETECTION AND ISOLATION

7.1 INTRODUCTION

As part of the operational considerations of an optical fibre distribution system, repair in the event of cable damage will undoubtedly be required. As a prerequisite for repair, the physical location of the fault must be determined, often under conditions not conducive to leisurely analysis. Based on present telephony experience, plant location may not be accurately known, working conditions terrible, and customer expectations for prompt repair high. Without effective maintenance tools and methods, the cost of locating and repairing faults may be unreasonable.

This chapter will examine the most probable maintenance strategy for the optical fibre portion of the system described in Activity 3. This will include construction of the original system and subsequent 'routine' repair.

7.2 CONSTRUCTION MAINTENANCE AND TESTING

Because of the large amount of handling and splicing involved in placing cable, some damage will occur and must be corrected prior to cut-over. The requirements for this type of maintenance fault locating are much less stringent than for in-service faults, since customer service is not immediately involved and highly-skilled labour is usually available. As well, the physical location of the cable (particularly if buried) will still be apparent and little further environmental damage incurred by manual excavation.

Fault locating would begin with sectionalized attenuation measurements;[2,3] on a routine basis, these would be Go/No-Go measurements on all fibres. The test set would be the optical analog of the present splicers' test set, i.e. a remote (optical) source of reasonable stability and a local receiver with some form of threshold indication. Two signal sources are envisaged: an on-demand, standard signal available from a C.O. (if splicing construction is proceeding from the office out), and a portable source to cover all other situations.

The Go/No-Go test set would pick up gross fibre damage such as occurs during backfilling, as well as splicing faults. The next level of fault locating would then be called up, and would involve distance-to-fault measurement from either end of the affected section. Because the system is broadband, a backscatter/time technique somewhat analogous to time-domain reflectometry (TDR)[4] on co-axial cables would be appropriate. Distance resolution to one metre would be adequate and would require a test set with time resolution of about 4 nanoseconds.[5] Such a test set will also require low-reflection temporary connectors and rugged design to survive the Outside Plant environment. However a higher level (than is currently normal for construction) of craft skill will be required to interpret optical backscatter results.

(Note - straightforward reflection detection from a broken fibre end would be simpler to implement, but present literature suggests it may be severely affected by the break angle. At best, under 4% of the incident light is reflected, and if the fracture angle is long enough, no light may be reflected).[5]

7.3 UPKEEP MAINTENANCE AND TESTING

Initial fault detection will be provided by system monitoring (and possibly customer complaints) and will demand speedy restoration of service. If current practice is a guide, temporary relief can be provided by transferring service onto a spare fibre, or re-arranging remote multiplexing equipment. Nonetheless, fibre faults will have to be corrected eventually and the wide variety of installation situations encountered in distribution will pose problems of location.

Fault locating on distribution plant could begin with simple sectioning if access points are available, for example at a remote switch (R.S.). Test signals could be transmitted from the R.S. towards the subscriber either by portable equipment or from an office-originating source. If fibre ends are available at splices, etc., a straightforward level test set will be adequate (perhaps with a Go/No-Go indication). A more elaborate technique can be envisaged whereby an uncut fibre is bent to force it to emit light, hence measuring transmission without opening the path. This possibility is not well developed, and does present the hazard that a fibre flaw at the point of bend will emit copious radiation, erroneously indicating a good fibre. Also, such a technique requires an optically transparent fibre jacket that can be exposed without fibre breakage.

Beginning at the subscriber, a damaged drop fibre would probably be best abandoned unless the fault is obviously right at the subscribers' premises, i.e. visible, above-ground damage. Although a very accurate distance-to-fault measurement would be made on a drop, the difficulties of physically locating the point of the break and the expense of excavation make repair uneconomical.

In aerial plant, re-connecting a drop fibre would pose no great difficulty. In buried plant, however, major expenses will be incurred locating the splice unless auxiliary marking methods have been installed at the time of construction. Even more difficult to locate will be the local distribution cable, unless it carries a tracing mechanism as an integral structure.

Distance-to-fault measurement can utilize equipment similar to that used during construction, i.e. timed backscatter.[5] From experience, a major obstacle to acceptance of this technique will be the difficulty of interpreting the display, especially if it is a straightforward time-amplitude plot. Similar considerations apply to whatever cable and splice location systems are installed.

The difficulty of locating and repairing fibre, coupled with the increased revenue resulting from the provision of a wider range of services may permit a higher level of integrated scheduling, where expert assistance is applied sequentially to find and repair a fault. The magnitude of such scheduling would require some form of automated direction, and the generalist training now given I & R craftspersons would be supplanted.

8. RELIABILITY DISCUSSION

8.1 GENERAL

Availability of a system or network depends on the following factors (see chapter 3):

a) The "Mean Time Between Failures" (MTBF) of cables and equipments (reliability);

b) The "mean times to restore" (MTTR) the system;

c) The use of protection channels on the same or on other transmission media (re-routing)

High availability objectives may be achieved in transmission networks including cables and equipments with low MTBF, by using short times to restore or suitable re-routing schemes. Because of the high cost of optical fibre cables, at least in the near future, the re-routing practice employed on fiber optic broadband distribution systems, where it is deemed necessary, is likely to be one which employs automatic protection channels on the same transmission media (cable), rather than using separate fibre cables on the same or alternate routes. Protection switching could be provided to automatically substitute the spare channels/fibre(s) for the failed channels/fibre(s). The fault can then be identified, located, and repaired (see Chapter 4) without service being affected. This re-routing approach was adopted on the LD-4 long haul digital transmission system. One automatic protection channel was provided for every five regular channels in each direction of transmission. Thus two of the twelve tubes in the coaxial cable were dedicated as protection tubes. Provision of protection channels on fibre optic cables will be more important on local trunk and feeder cables than on distribution and drop cables, and it may be prudent to adopt a similar degree of channel protection on these cables as that mentioned above. If the failure exceeds the protection switching capabilities, service is immediately affected and the problem becomes one of restoration.

8.2 RELIABILITY OF COMPONENTS

8.2.1 Optical Fibres and Cables

Optical fibres have undergone continuous improvement since the possibility of their use as a communications transmission medium was first proposed. Major advances have since been made in fibre technology; firstly, in reducing the attenuation, then in reducing the modal dispersion through precise control of the refractive index profile. Current emphasis is now on identification of the most suitable, stable coating materials, control of coating application (see Activity Report No. 8), Section 5.4.1), improvement of the average fibre strength, and repeatability in fibre production: factors related to fibre reliability.

For the purpose of this discussion, fibre failure can be regarded as the deterioration of the transmission signal level outside the system specification (inadequate signal to noise ratio, excessive error rates) or complete signal interruption, as produced at a physical fibre break.

Coaxial cable and paired copper transmission media have direct electrical failure modes: open circuits, short circuits, high resistance of the coaxial centre conductor to the outer conductor, etc. In contrast, there is no known internal optical degradation mechanism in optical fibres. Degradation or interruption of signal is the result of external influences on the fibre primarily mechanical stress, although ionizing radiation can also affect fibre. Thus optimization of fibre reliability is a matter of firstly manufacturing the fibre to have minimum possible sensitivity to stress and secondly protecting and isolating the fibres from the stresses within and external to the cable. Sensitivity of fibre to stress is determined by several factors, principally freedom from thermal stress and freedom from microcracks, ensured by protection of the fibre by a suitable coating immediately after manufacture. Protection of the fibre against external stress is a problem of cable design. Thus, for a given fibre, reliability is determined by the quality and reliability of the cable.

The failure modes may be classified as follows:

(a) Cable internal modes

- (i) microbending effects
- (ii) fibre tensile strength deterioration due to the effects of moisture on the fibre surface in the presence of residual stress.
- (iii) bending and microbending effects caused by compressive forces generated by ice formation within the cable core.
- (iv) mechanical damage during manufacture.

(b) Cable external modes

- (i) mechanical damage during cable installation: excessive tension, excessive crush and impact forces, excessive bending.
- (ii) accidental human damage during operation: digging up of buried and underground cables, damage to aerial pole lines.
- (iii) wind and storm damage (aerial).
- (iv) vandalism and sabotage.
- (v) lightning damage to cables containing metallic components.
- (vi) gopher damage (buried cables), squirrel damage (aerial).
- (vii) damage due to ice formation external to the cable.

The internal compressive stresses that give rise to microbending losses can be generated by many different mechanisms, the most common of which are related to the coatings: the thermal expansion coefficient of the coating may be so high in value that excessive 'shrinkback' of the coating occurs following extrusion or in cold operating environments, the coating material may be unstable over a period of time, the coating parameters may be incorrectly defined or the coating incorrectly applied, or the coating may simply be inadequate, providing too little protection for the fibres from the adverse effects of strength members or other adjacent components and the cable manufacturing stresses. It is desirable that the fibres be suitably protected as early as possible in the cable manufacturing operation in order to minimize the quantity of fibre damaged and to limit the need for complex and precision purpose built cabling machinery to as few (early) stages as possible.

The cable internal modes of failure, including those associated with the presence of moisture within the cable core, have been discussed at length in Activity Report No. 8, Chapter 5, and therefore will not be treated further here. It is sufficient to state that failure of the fibre during operation due to internal cable mechanisms can be minimized, if not avoided altogether, by careful cable design and component specification, complemented by suitable acceptance testing and operational support systems, such as the use of a cable pressurization system to limit moisture ingress.

In contrast, many of the cable external failure modes are only partially controllable, occur during operation, and are often catastrophic in nature (i.e., they exceed the protection capabilities and require complete cable restoration). Installation damage can be reduced by the use of correct procedures and suitable equipment and monitoring devices, and, if it does occur, can usually be identified and corrected by testing before cut-over (see Chapter 7). The most serious form of damage, as measured by service outage times, is caused by construction activity along the route. Most of this damage is caused by workmen of other utilities and construction forces, or contractors, and is largely independent of the transmission medium (i.e., glass fibers, copper pairs, coaxial tubes). This human damage, whether accidental or deliberate, cannot be eliminated, but it can be reduced. Sensible precautions include choosing a cable route with the least susceptibility to damage, providing additional cable protection in higher damage areas, and control or close supervision of all construction activity along the route. The use of dedicated easements and rights-of way, with frequenty spaced cable location markers, reduces the incidence of damage. In some areas it is prudent to use steel and concrete-encased ducts, or armoured cable, or to place the cable at lower depths.

Rodent damage can be avioded by appropriate sheath armourings, and external ice damage to buried cables minimized by placing at a suitable depth (over 5' in Montreal).

The incorporation of metallic components into the cable will render it more susceptible to sheath damage (a secondary failure) from lightning strikes. Whether lighting strikes will damage the fibres or their coatings, causing a primary failure and affecting the overall system reliability, is not known. However, it will be dependent on the radial location and proximity of the conductive components relative to the fibres and the dielectric properties of the non-metallic components, as well as the use of protective fuses and grounding and the external conditions. Protectors should be used on any copper pairs (for signalling, powering of remote equipment, and alarms) to protect against surge currents induced by lightning or power faults. Metallic sheaths and strength members should be grounded periodically. High-voltage power lines and subway routes and areas of high ground resistivity should be avoided if possible. Hills and areas in the proximity of towers have above-average lightning counts, and should be avoided also. The use of conduit or external shield wires will reduce cable vulnerability to lightning damage.

8.2.2 Connectors & Splices

Connectors and splices differ with respect to reliability. Splices are sealed, passive devices which have no inherent catastrophic failure modes, barring of course physical abuse beyond their design capabilities. The most likely potential mode, if any, will be a gradual signal deterioration due to aging.

The rate and extent of the aging process is dependent on the particular design, the quality of the original installation and the operating environment. To avoid signal deterioration due to aging, the materials choosen for the design must be compatible with respect to their thermal expansion coefficients (also with that of the glass fibre) and their material properties must remain stable over the required life of the system. These design aspects are particularly important where materials such as metal and polymers (e.g. epoxy adhesives, etc.) are used in a splicing package.

Proper installation will also be a factor in splice reliability. Because fibres are small and relatively fragile (compared to metallic connectors), the installation tooling will be more sophisticated than that used to splice metallic conductors. Good installation tooling and procedures will be a compromise between tool complexity and the operator skill level required.

Another factor which will affect the splices reliability is the severity of the operating environment. The degree of the effect will depend upon the ambient temperature, the frequency and size of change in temperature and the humidity and corrosiveness of the environment.

Connectors are intrinsically more susceptible to degradation because they are mate/remate devices and hence are subject to more a degenerative mechanism. Amongst these are mechanical wear which tends to increase the fibre-to-fibre misalignment, exposure of the fibre end faces to mechanical damage, and contamination, which can introduce both blockages of the light path and abrasive materials. Connectors are also subject to aging and installation losses, but to a greater degree because of their greater complexity. Connector design, therefore, requires the inclusion of a greater number of factors than necessary for splices. A good design will be one which minimizes wear, or tends to compensate for it. It will provide as much protection as possible to the fibre ends during remating and minimize their exposure to external mechanical damage and contamination when unmated. Another prerequisite of a good design is to have access to the fibre ends to remove contamination. The ambient contamination present will determine the frequency of cleaning which may or may not be required.

(Note: For safety purposes, the optical signal should be interrupted when a connector is unmated, therefore preventing possible eye damage to repair personnel).[8]

The number of mate/remate cycles required of a fibre optic connector is a function of the type of system and the location of the connector in the system. Many may never be opened while others may see relatively high activity. The main concern is for the latter. Connectors in a fibre optic telecommunication system will be remated for a number of reasons including; - maintenance, installation/reinstallation, equipment replacement and removal, feature modification, and movement for system management. These are the type of activities, for example, which take place at a crossconnect point in a telecommunication distribution system. Qualification specifications for conventional connectors in the telecommunication industry run between <u>10 and 200 rematings</u>, depending upon the application and required life time.

At this time published data (reference Activity 1, Chapter 6) is insufficient to predict failure rates for either fibre-optic connectors or splices.

8.2.3 Light Detectors

Both Silicon PIN and avalanche (APD) type light detectors are available with high reliability figures. For this latter the normal operating currents are 2 or 3 orders of magnitude lower than those corresponding to damage due to breakdown and therefore the only precaution to be taken is to verify that the operating point stays within its normal range. In these conditions, the light detector's life is of the same order as that of any other semiconductor used in electronic circuitry.[7]

It must be noted that the use of an avalanche photodetector involves using a DC/DC converter and therefore the MTBF slightly decreases for the increased circuit complexity.

8.2.4 Light Sources

Unlike light detectors, light sources suitable for fibre communication system, present today strong limitations on system reliability[7]. There has been some argument in the past about the meaning of accelerated life tests conducted on light sources at high temperature, and their extrapolation to life expectancy at room temperature. A more convincing extrapolation is that of determining the "half-power" life (at room temperature) from the measured (small) decrease in power, observed in tests conducted entirely at room temperature. From this latter type of tests, conducted on both high radiance LED's and semiconductor lasers, it has been demonstrated that, at least in some laboratories, operation at constant drive current has been observed for more than 14,000 - 20,000 hrs with decrease in output optical power of a few percent. The extrapolated half power life for these devices is therefore in the range of 100,000 hrs[7].

Presently however, first production devices are only guaranteed for a much shorter life span, ranging from 1500 to 6000 hrs approximately; the lower figures being attributable to laser diodes.

Work is being done to improve the above figures and therefore we may expect that guaranteed lives in excess of 100,000 hrs with negligible power degradation (e.g. less than 10%) may be attained in the next few years[7].

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