Technical Report

A Systems Study of Fiber Optics for Broadband Communications

Activity No. 9
Compatibility With Existing Systems

BNR Project TR 6259
January 1978

Bell-Northern Research

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Activity No. 9
Compatibility With Existing Systems

N. Toms

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CHAPTER 1: INTRODUCTION AND OBJECTIVES

This report forms part of a contract study on the use of fibre optics for telecommunications undertaken by Bell-Northern Research on behalf of the Department of Communications of the Canadian government.

The present report addresses the general problems of compatibility with existing systems and with system evolution, as set out in the contract work statement. One change in emphasis has been made from the work defined in the work statement. There the compatibility of fibre systems with coaxial cable systems was specified; in view of the star type network now envisaged for rural areas, compatibility with paired systems and with existing telephony plant seems more relevant. This is especially true in rural areas, where the amount of coaxial cable installed is quite negligible. The problems of compatibility with existing televison equipment is discussed, where relevant.

The objective of the report is to highlight areas where compatibility with existing plant may be a problem, to discuss ways in which fibre may be smoothly introduced into the exising network, and then to suggest ways in which the network may evolve to provide improved or expanded services.

The report has been made possible by the comments of many members of the scientific staff in Bell-Northern Research. The comments on signalling have been based largely on work by E. Colombini, while the experience of K. Jones and T. Hutchins has been called upon for chapter 4. Finally, though, the author accepts sole responsibility for the opinions expressed in this report. Specifically, the opinions do not in any way reflect the policy of Bell Canada or Northern Telecom. Operating conditions in a specific region, regulatory considerations and market demand for certain services could radically alter the conclusions of this report.

CHAPTER 2. SUMMARY AND CONCLUSIONS

2.1 STRUCTURE OF THE REPORT

The compatibility problems associated with transmission of telephony are addressed in Chapter 3, especially in the areas of signalling, error detection and powering. Chapter 4 considers the compatiblity of the physical plant for fibre based networks with the copper based telephony plant. The subscribers terminal, outside plant and central office equipment are all considered. Chapter 5 gives a quick look at compatibility problems arising due to the distribution of video. Finally, Chapter 6 is concerned with the evolution of fibre plant, starting with a discussion on the replacement of copper plant by fibre and concluding with observations on the way in which the fibre network can itself evolve to provide a wider range of services.

2.2 CONCLUSIONS

For telephony distribution to the home a new signalling scheme, preferably out of voice band, is desirable. This signalling scheme could also be attractive over the copper pairs, allowing low rate data to be communicated.

Error detection on inter-office digital trunks need special units because of the signal encoding. End to end error detection is difficult if signals are decoded and re-encoded.

At central offices new optical distributing frames will be needed. Much of the volume of current distributing frames is due to electrical protection, which is not required for fibre. Further, a unified fibre frame can be constructed to mix signals at all rates from VF upwards to DS-3 or higher. In designing systems, the losses due to connectors within the frame must be allowed for.

In single subscribers homes, an electro-optic interface unit should be provided in the basement, with in building distribution using copper. Small multiple dwelling units will have an interface unit in the basement with all in-building distribution on copper, while large high-rises will have interface units in each apartment.

System evolution in medium and high density rural areas will require the introduction of fibre based star networks, possibly concurrently with the introduction of digital subscriber carrier. Video will be non-switched initially, with growth by the introduction of video switching when switches and multiplexing terminals have been reduced in price by development. An intermediate level of service expansion can be obtained by simply increasing the level of multiplexing in the star drops without introducing switching. If all the desired services can be provided by this means, and the flexibility needed for switching is not needed, then serious consideration should be given to installing a tree distribution.

In low density rural areas, tree distribution is necessary. The services which will be provided will be single party telephony and simple CATV.

In urban and suburban areas the only way by which fibre optical distribution systems can attract customers will be by providing an expanded range of services compared with cable networks. Improved quality alone is unlikely to persuade customers to pay for the replacement of existing systems. Thus, urban and suburban areas will require switched distribution of video over a star network. The development of the components needed may delay the introduction of integrated networks in these areas until after the introduction of simpler networks in rural areas.

CHAPTER 3: TRANSMISSION COMPATIBILITY WITH TELEPHONY PLANT

3.1 INTRODUCTION

When fiber optics is introduced into the telephony network two broad compatibility problems arise - that of physical plant and that of transmission. In the former category are problems at central office main distribution frames (MDFs), and at jumper wire interfaces (JWIs), together with general problems of maintenance and installation when fibre and copper systems run along the same routes.

The present chapter deals with the transmission compatibility of fibre based systems with copper based systems. Ideally what is required is that replacement of all or part of a metallic transmission path by fibre should not degrade the service and facilities currently enjoyed by subscribers. Several areas are involved.

Firstly, obviously the voice or data message should be transmitted faithfully over the new transmission facility. This is the easiest requirement to meet, since digital transmission of multiplexed telephony signals has been widely demonstrated (ref 3.4) and analogue transmission of a single VF channel is much less demanding. The transmission requirements have been discussed in some detail in activity report 5 of the present study.

The second area of transmission compatibility is in the broad area of signalling, which will be discussed in the next section of this chapter.

The third area is that of error monitoring - of relevance mainly to transmission of digitally multiplexed telephony, especially in the inter-office environment. This topic will be covered in section 3.3 of this chapter.

3.2 SIGNALLING

3.2.1 Loop Signalling

This section considers signalling in the loop plant - that is in the area directly connected to the subscriber's handset.

The function of signalling in any part of the network is primarily to establish a link between two end users in an economical manner. Many secondary functions are involved, such as recording details of calls for charging purposes, generating appropriate sounds to inform the calling party of the progress of his call, alerting the called party, and clearing equipment when it is no longer needed.

Originally signalling relied totally on D.C. current flow operating electromechanical relays, and this is still largely the case in loop plant today. Fig. 3.1 is a schematic diagram of a 500-D telephone set, which is the basic domestic telephone set used in most of North America. When the handset is on-hook, switches S1 and S2 are open. At the office where the subscribers' pair terminates, a 48V battery is connected to the pair in series with a relay. When the subscriber goes off-hook current flows through the relay, alerting the office that a subscriber needs service. How this message is processed depends on what kind of switching machinery is available, but in all cases an attempt is made to give the subscriber access to a switch. If a switch is available, the office transmits the dial tone to the subscriber.

Dialling is performed by opening and closing switch S5 in fig. 3.1, with S6 closed to prevent objectionable noises in the earpiece. This dialling information is received in most modern offices in a register.

Ringing is effected by superimposing an 88 V, 20 Hz signal on the subscribers pair when the subscriber is on-hook (a state determined at the C.O. by no D.C. current flow in the subscriber's pair). As seen in fig. 3.1 the ringer is always connected across the pair coming into the telephone set. When the subscriber answers, the D.C. current flow in his pair disconnects the ringer at the office.

Voice transmission from the set, of course, relies on the resistance of the carbon microphone (transmitter in fig. 3.1) varying with acoustic pressure and thereby modulating the current flow.

It is evident that the existence of a metallic path between C.O. and subscriber' set is central to the signalling schemes in present day loop plant, as well as being needed for the provision of power to the telephone set for ringing and voice reception and transmission.

Although it would be possible to use a DC signalling scheme with fibre optics, it would require a good DC response at the photodetector amplifier, and threshold problems would arise due to variations in light source output level with time and variations in fibre attenuation from subscriber to subscriber due to fluctuations in fibre drop length and in fibre composition.

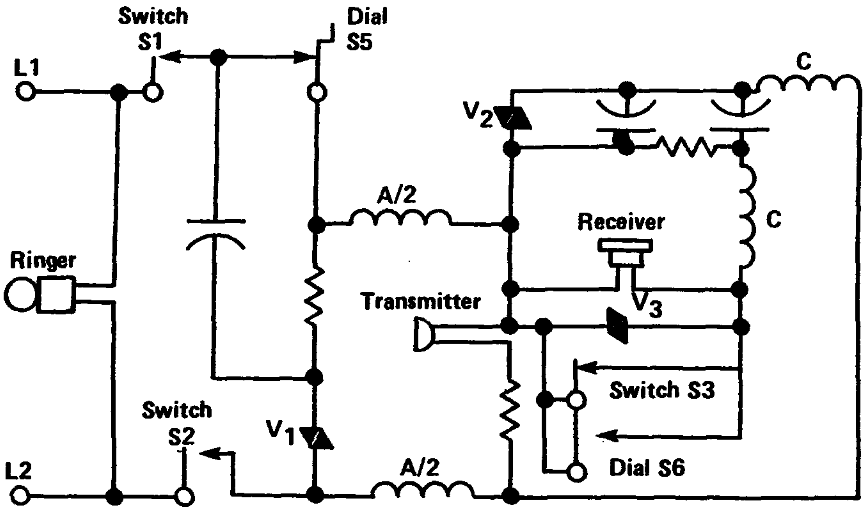

Figure 3.1 Schematic Diagram of 500D–Type Telephone Set

It is, therefore necessary to consider either interfaces between conventional handsets and fibre optical transmission lines, or the introduction of a new signalling scheme. A positive advantage of a new signalling scheme is that low speed data, especially for meter reading and power load shedding type applications, could be transmitted over such signalling systems. A further advantage, of particular relevance to this report, is improved signalling on multiparty lines, which are so frequently encountered in rural areas. With new schemes selective ringing, automatic identification, inter-party signalling and privacy can all be provided on party lines.

We now give some thought to how a new signalling scheme could be implemented. As noted, it is desirable that it should be capable of being used for low bit rate data, and hence should involve the transmission of binary coded information, either at baseband or on an analogue carrier.

One possible scheme would operate as follows. When the subscriber goes off hook a special code is transmitted by the set which is interpreted by the line card at the RLM as a "request for service". On multiparty lines this transmission would be suppressed if the party line was busy. The RLM, on receipt of the request for service code would set up a busy status to block incoming calls, and transmit a dial tone to the subscriber when switching equipment is available. Signalling would then proceed with the transmission of the number required to the RLM register using the same binary code. At this stage all supervisory signals (dial tone, busy tone) would be originated at the called party's C.O. and transmitted by VF, as is standard practice.

To alert a subscriber of an incoming call, either a VF ringing tone would be transmitted for amplification over a loudspeaker at the subscribers set, or a code could be transmitted which would activate a local oscillator and loudspeaker.

The above is the general scheme which will be used, but some attention to detail is needed. It is desirable to try to make such a scheme compatible with copper pair transmission. If such a system were to be used with copper pairs, a serious constraint is imposed by the frequency response of the pairs. Ref. 3.5 shows that loaded copper pairs have a sharp cut-off at 2800 Hz, with un-loaded pairs falling off significantly at 3300 Hz. Delay distortion is also great at higher frequencies than these, and also imposes a lower bound of 300 Hz on transmission. It has been found that, if a signalling method is likely to be used for end to end message transmission over copper pairs, the minimum distortion is achieved when the signal spectrum is centered at about 1600 Hz with little energy at low frequencies. Suitable coding schemes are available to enable baseband transmission to be used which meet the above spectral requirements. The use of FSK is favoured, since cheap FSK modems at the correct bit rates are available.

Despite the attenuation and delay distortion problems, signalling above or below the VF band is possible even on copper pairs. There are several advantages to doing this. Firstly, simultaneous voice and signalling can take place, thus permitting services like meter reading or slow speed data transmission to proceed undisturbed while the voice channel is being used. (Of course, during call setup there would have to be a momentary interruption of these services). Secondly, the fact that the signalling channel would be isolated from the voice channel by filters means that there is no problem with voice simulation of valid codes, either accidental or intentional. Thirdly, signalling cannot give rise to undesirable tones in the voiceband. The disadvantages are that end to end signalling over carrier facilities requires special electronics to shift the signalling in-band, and that, with copper pairs, crosstalk severely limits the maximum signal level which may be used at higher frequencies.

All of the above has been written in the context of analogue voice transmission to the subcriber's home. Should voice signals be transmitted in digital form to the subcriber, the signalling information would almost certainly be encoded as part of the digital bit stream, and the transmission requirements for signalling are simply that the digital VF signal be faithfully transmitted.

3.2.2 Inter-Office Signalling: Analogue

Much of the inter-office signalling also relied on metallic connections, where relays sensed the flow or absence of flow of electrical currents, with the polarity of the flow offering another method of transmitting information.

Ref. 3.6 discusses the inter-office signalling schemes most widely used in the North American content.

D.C. signalling between two offices uses two special wires, designated the E and M wires. The signalling sequence between two offices A and B is illustrated by the states of table 3.1 Note that the terms "on-hook" and "off-hook" are applied by analogy to subscriber's equipment, following reference 3.6, although no physical hand-sets are involved.

A problem with D.C. signalling is that the ohmic resistance on long links means that high voltages must be applied to ensure that adequate currents are available to operate the necessary relays. the widespread introduction of carrier systems between offices also make D.C. signalling unattractive, since the repeaters needed for these systems were not compatible with D.C. transmission and, further, one pair in such systems corresponds to many VF channels.

TABLE 3.1

ANALOGUE SIGNALLING BETWEEN OFFICES A AND B

Signal A to B	Signal B to A	Condition at A		Condition at B	
		M Lead	E Lead	M Lead	E Lead
On-Hook	On-Hook	Ground	Open	Ground	Open
Off-Hook	On-Hook	Battery	Open	Ground	Ground
On-Hook	Off-Hook	Ground	Ground	Battery	Open
Off-Hook	Off-Hook	Battery	Ground	Battery	Ground

A simple single-frequency (SF) signalling scheme between offices was introduced as a method of overcoming range limitations.

To understand the signalling unit operation, assume that a trunk equipped with 2600-cycle SF units is in the idle condition. A 2600-cycle tone (-20 dbm referred to the zero transmission level point, 0 db TL) is present in both directions of transmission.

A seizure signal originating at one terminal results in a change in state on the originating M lead from ground to battery. As a result, the keyer relay M operates and removes 2600-cycle tone from the sending line. The loss of tone is detected at the distant SF signalling unit and the resulting action changes the E lead from an open to ground condition. The grounded E lead results in a request for connection of an incoming register or sender. Since there may be a slight delay in securing a register, the trunk circuit changes the M lead state at the terminating office from ground to battery, resulting in the removal of 2600- cycle tone from the line facility, from the terminating to the originating office. This results in a signal on the originating office E lead to delay the transmission of the address information.

When an incoming register is connected, the terminating trunk circuit restores ground to the M lead of the SF unit, and 2600-cycle tone is reapplied to the line. At the originating terminal the reapplied tone is detected and the resulting E lead signal indicates that pulsing of the address information can begin.

If dial pulsing is used for addressing, the M keyer relay is operated and released in accordance with the dial pulses being transmitted. This results in pulses of 2600-cycle tone, one for each dial pulse, at an augmented level. Interdigital intervals of 0.6 second are inserted between dial pulse trains when transmission is from an outgoing sender.

At the end of pulsing, 2600-cycle tone is removed from the line in the forward direction but tone is still being received from the distant terminal. When the called customer answers, the action of lifting his receiver results in a signal from the terminal trunk circuit to the SF unit, and tone is removed in the backward direction. For the talking interval there are then no tones present in either direction and no band-restricting components present.

On calls for which no charges are made, such as business office, repair or service calls, the tone in the backward direction is not removed, but a band-elimination filter prevents the tone from reaching the calling customer. The transmission path has, of course, been slightly degraded by the introduction of the filter but this is not considered serious on this type of call. On transmission systems equipped with compandors the presence of the backward-going tone may reduce the compandor cross-talk and noise advantage.

Since no D.C. power is transmitted, inter-office signalling of this kind could be transmitted by fiber optics. However, all inter-office telephony on fibre will almost certainly be on digital carrier, whose signalling characteristics are considered below.

In passing it may be noted that some inter-office trunks use multifrequency signalling where signalling information is encoded by the combination of two single frequencies, which, parenthetically, are not the same frequencies as used on Touchtone sets at the subscriber's premises. Once the required information has been sent over the trunk and a satisfactory reply obtained the signalling circuitry is removed from the circuit and is used to set up other calls. If inter-office analogue trunks using fibre optics were used they could readily accommodate this kind of signalling.

3.2.3. Inter-Office Signalling: Digital

When digital carrier systems are used, a unit is included in the channel banks at the receive and transmit offices. For a T1 system (ref. 3.7) this encodes the "M" wire status at the transmit office, using one dedicated bit in the 8 allocated to a given voice channel, with the option of using the least significant bit of the voice information for extra signalling capacity. At the receive end the signalling information is duly de-coded and put on the E-wire to activate the local switching machinery. When digital switching machines are used this D/A, A/D action at the receive end can be by-passed.

From the above it follows that, if fibre optics is used for inter-office trunking carrying DS-1 signals or other signals in the digital hierarchy, then as long as the fibre link allows the accurate transfer of the bit stream transmitted by one channel bank to the receiving channel bank, signalling and supervision is automatically handled by the channel banks. In other words, fibre introduces no new signalling problems in the inter-office environment when digital carrier is used, assuming that the digital signal is faithfully transmitted.

In activity report 3, dealing with integrated services over fibre optical facilities, the use of RLM units was recommended, especially in rural areas. These units are similar to channel banks, and they convert the signalling from the subscribers sets to a digitally coded form for transmission to the channel bank at the C.O., and also convert digital signalling information coming from the C.O. to analogue (D.C.) signalling for transmission over the subscriber loop. Here again, the use of fibre optics between C.O. and R.L.M. gives rise to no signalling problems as long as the digital signal is faithfully transmitted.

3.3 ERROR DETECTION

It is always important for telephone companies to be able to monitor the quality of the signal which they are transmitting. In the case of digital transmission this function is performed by using error detection coding. The coding used in the first three levels on the north American digital hierarchy is "alternate mark insertion" (AMI). In this scheme, every alternate "one", or "mark" transmitted is of inverse polarity. Thus, for example, the bit stream 1, 1, 0, 1, 0, 0, 1 would be transmitted as +1, -1, 0, +1, 0, 0, -1. Obviously the two state information (0,1) is being transmitted using three states (+1, 0, -1) creating the necessary redundancy for error detection. This scheme is simple to implement and has the considerable advantage for transmission over copper pairs that it has no DC component.

Although three level transmission could be accommodated on fibre, it is undesirable since it makes more stringent demands on linearity and DC level control than are considered desirable. The topic of coding schemes which offer error detection capability, yet are suitable for fibre systems, has been discussed in ref. 3.8. There, the most likely codes are block codes of the type nBmB, where n binary bits are encoded into m bits, with m greater than n, and the redundancy is used for error detection. It is necessary, then, that at every point where error detection is needed in a digital telephony system, logic should be provided to extract the error detection information from the line codes in order to activate the appropriate alarms. These locations are often those where channel banks are situated, where one has a need for the arrangement shown in fig. 3.2. The output from the channel bank is rectified to unipolar from and encoded in suitable line format for transmission, before entering the driving circuit for the light source. Signals arriving for input to the channel bank are detected and pass through a decoder, which transmits any error signals to the channel bank and independently transmits a reconstituted AMI signal to the channel bank. Areas which still need to be investigated and clarified occur when a digital signal passes through an office instead of being terminated there. If the signal is decoded and re-encoded at such locations, the re-encoded message will be detected as being error-free independent of the errors on the input. The important thing to remember is that, when a cascade of repeaters, coders and decoders are encountered, the error count at the end of the cascade shows only the error on the last segment of the cascade, not the accumulated error.

3.4 POWERING

The metallic wires in existing telephony plant transmit power to the subscriber, and to field repeaters on trunk lines. When fibre optics

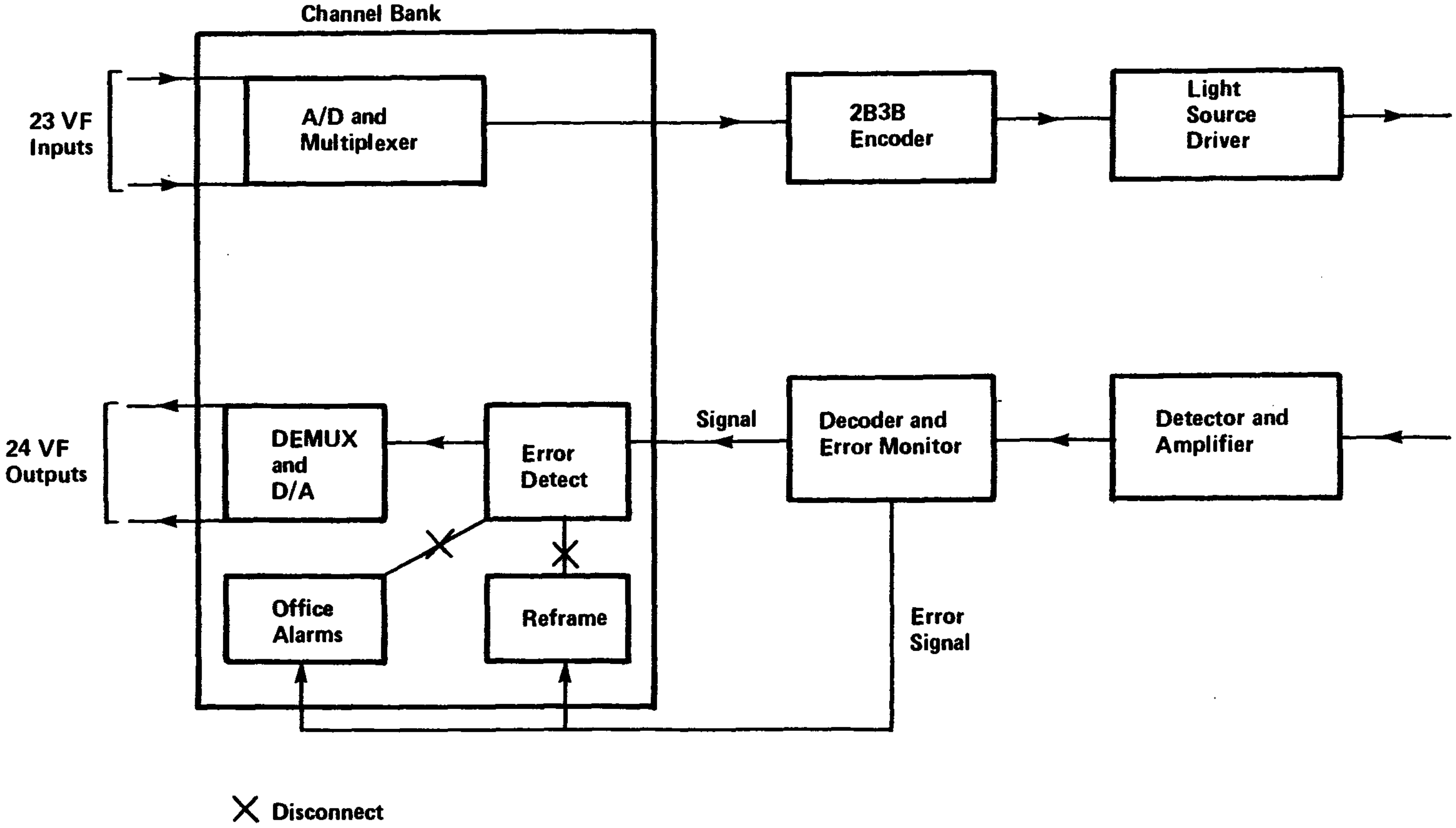

Figure 3.2 Error Detection at a C.O. with Optical Trunk Transmission

is used powering must be separated from signal transmission. One might argue that, since the transmission of signals by fibre optics involves the transmission of light energy, perhaps large amounts of light energy could be transmitted by the same means to power terminal equipment. Unfortunately, leaving aside the inefficiency and cost of electrical/light interfaces, non-linear effects such as Raman and Brillouin cause unacceptable attenuations at the power level required. Thus, one must use electrical powering. This can be achieved by incorporating metallic pairs in the fibre cable, or by using one of the alternative schemes proposed in considerable detail in activity report 8, chapter 3. It is probable that metallic pairs will be used where it is necessary to power field repeaters, but their added expense make them unattractive for use on subscriber drops.

3.5 CONCLUSIONS

The major areas where the transmission of telephony by fibre optics will require additional equipment over and above electro optical terminals are for signalling in the subscriber loop and for error detecting in inter-office trunking. In addition, powering must be transmitted by separate metallic pairs or else it must be provided locally.

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CHAPTER 4. HARDWARE COMPATIBILITY WITH TELEPHONY PLANT

4.1 INTRODUCTION

As fibre optics is slowly introduced into telephony plant it will be necessary to ensure that it can co-exist satisfactorily with the equipment designed for copper cable. The areas to be considered are at the subscribers home, in the loop plant, at the RLM (or C.O), and between offices. An additional area to be considered is that of safety.

4.2 AT THE SUBSCRIBERS'S HOME

4.2.1 Single-Family Dwellings

With copper based installations the subscriber's drop enters the house and is terminated at a protective block as soon as possible, normally in the basement. From there wires are run to the individual telephone sets or jack outlets.

With fibre optics a similar approach could be adopted, with the subscribers' drop terminated at an entrance unit in the basement, and signals distributed over copper facilities to the rest of the house.

A problem which arises here is ease of maintenance. It is inevitable that the fibre optical entrance unit will need more maintenance than a simple protective block, and maintenance will require access to the subscriber's home. One solution which would facilitate maintenance would be to locate the entrance unit outside the subscriber's premises - but this would require expensive packaging to protect the electronics from the outside plant environment. It seems probable that an entrance unit inside the basement will be used to minimise the cost of packaging, despite the maintenance problems.

4.2.2 Multi-Family Dwellings

In high rises and other multi-family dwellings, current practice is to terminate many copper pairs at a distribution point in the building, usually in the basement. At this point protection is provided against surges of current induced in the outside cable, and cross connections are made with the inside plant, either by constant count, using a frame to terminate all the pairs entering the building, or by selective access, where pairs are connected as needed, creating a rather messy situation. Distribution on through the building depends mainly on the size of the building. Very large buildings use outside plant type cable in the risers between floors, with interconnection to the inside plant cable where needed. Smaller buildings connect each subscriber's telephone by inside plant cable directly to the distribution point in the basement.

When fibre optics is used, the problem is where to put the electro-optic interfaces. It would obviously be convenient to keep them all in the basement at the present distribution point, since maintenance operations would be greatly simplified and, further, the equipment could be much better protected against tampering by the subscriber. However, in larger buildings the distribution of broadband services by a dedicated coaxial tube to each home could lead to severe congestion in the in-building duct space. To avoid this the preferred solution in large buildings would be to run a fibre from the basement to each dwelling unit, and to have an optical cross-connect point in the basement, while in smaller buildings the electro-optic interface will be in the basement, with copper connections from there to each subscriber's home.

4.3 IN THE LOOP PLANT

The installation of fibre and copper cables along the same route should not pose compatibility problems just because the cables are co-located. The fibre cable, however, will be required to be capable of installation and operation in the loop plant environment, as discussed in report 8, especially chapters four through six. One possible problem may arise where splicing of both copper and fibre cables has to be carried out at the same location, since different skill levels of crafts people and different tools are needed for the two forms of splice.

An installation commonly encountered in loop plant is the jumper wire interface (JWI). This is a flexibility point where, for example, an 1100 pair cable is connected to a number of subscribers. Since the drops are not permanently spliced to the cable it is easy to accommodate disconnections and re-connections, and a smaller number of wires can also be used in the loop feeder cable to take advantage of the fact that, because of subscriber mobility, not all dwelling units need to have their telephones connected at any given time. A copper based JWI introduces negligible transmission losses. but this may not be the case for optical JWI's, where two connectors are needed to implement a patch panel. Fortunately, the added losses are more tolerable over the shorter links encountered in urban areas, where subscriber mobility makes a JWI attractive. In rural areas, populations are more stable, and a permanent splice type of distribution may be preferred.

4.4 AT THE C.O. (or RLM)

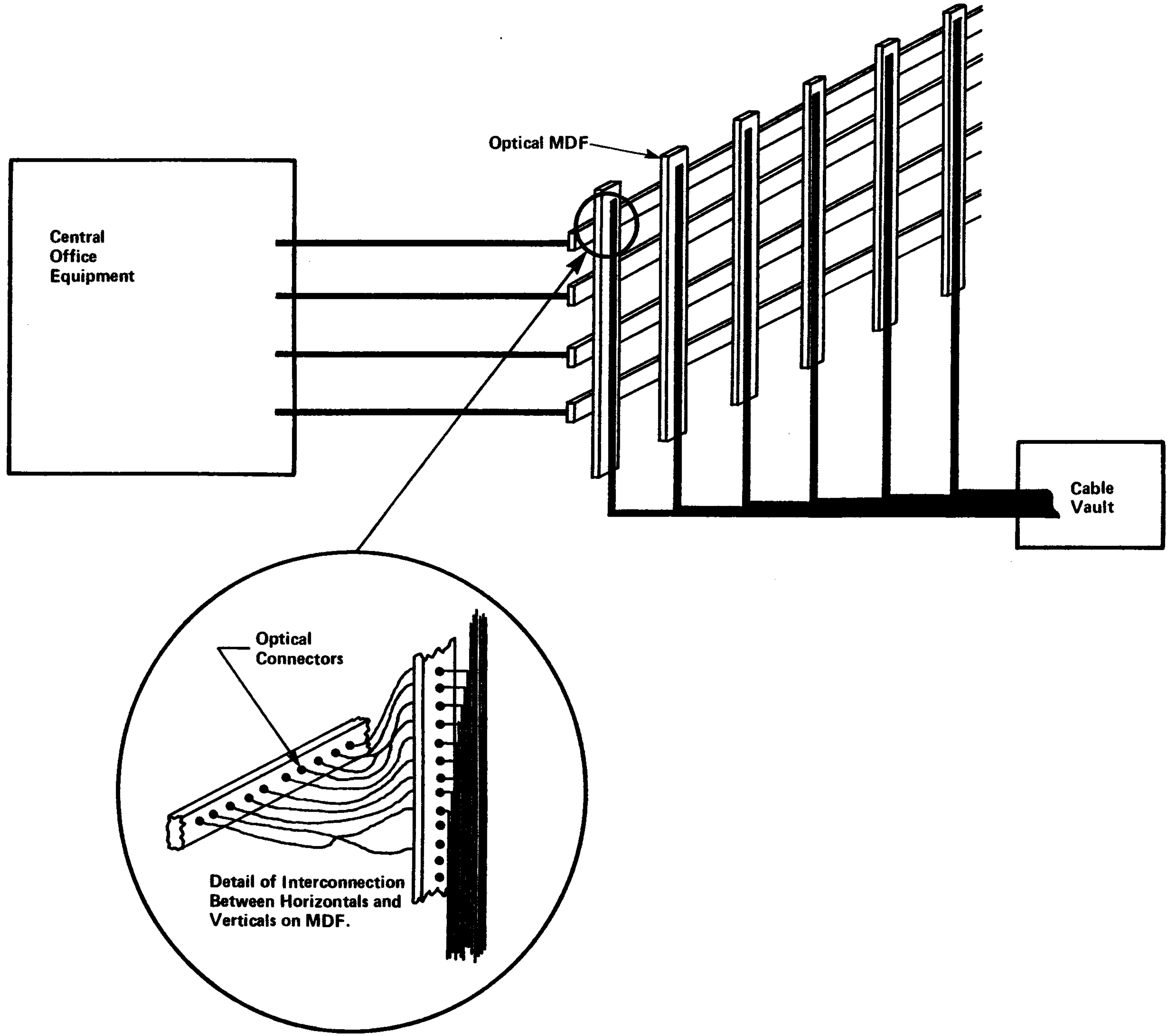
In an existing C.O. the V.F. - carrying pairs come into the cable vault, and from there they are connected by smaller cables to what is known as the main distributing frame (MDF). The MDF consists of vertical posts to which the incoming wires are connected, and of horizontal racks containing the wires connected to the C.O. equipment. The cross-connection between the ouside plant and C.O. equipment cables is made by wire-wrapping, or otherwise connecting, the C.O. equipment pairs to pins on the horizontal part of the MDF. Between these pins and the cables on the vertical posts are plug-in sockets for inserting protective devices against induced voltages and currents in the copper pairs. These devices are carbon blocks with typically three mil gaps to earth, which would be jumped by high voltages, and thermal coils which melt lead slugs if excessive currents are induced in the pairs. Certain cables, because of the environment in which they are placed, do not need one of these protectors, while others used need neither, thus leading to a variety of plug-in protectors.

An over-riding consideration in the evolution of MDF's has been the density of copper pairs which could be accommodated. With early step by step offices serving maybe ten thousand subscribers, this was no problem. The connector blocks used allowed about 300 pairs to be accommodated on an 11'6" vertical post. As newer switching machines were introduced the MDF size began to become quite unmanageable, so smaller connector blocks and protective devices were introduced. The latest Northern Telecom design (MPCQCM 486) permits about 1300 pairs to be attached to one 11'6" vertical post.

The relevance of this discussion to fibre optics is that, if a network is evolved where one, or more, fibres are run to each house in a switched star configuration, then an MDF of comparable connection density will have to be evolved to give the flexibility which is essential for the practical operation of a C.O. The desired density may be easier to achieve on a fibre MDF since there will be no need for electrical isolation and protection. Thus, one possible fibre MDF which would follow some MDF principles, would be a series of vertical bars containing 1300 optical connectors in an 11'6" rack, with optical fibre cable factory installed in sufficient length to reach the cable vaults for splicing to the outside plant cable. Horizontal trays on the MDF would support fibre cables again terminated with optical connectors. Jumper fibres with connectors at each end would be used for cross-connection.

At the C.O. equipment a second optical connector is desirable to allow the easy replacement of faulty equipment. Thus, a signal entering the C.O. has to pass through two connectors in series. The losses so incurred will have to be taken into account in systems design. The arrangement is illustrated in fig. 4.1

When carrier facilities, such as LD-1 at 1.544 Mb/s, enter a present day C.O. they do not pass by a MDF, but the office equipment is connected directly to the cable in the vault. This is so because the comparatively small number of such cables does not give rise to the same congestion as would be expected if all the VF pairs in a vault were to be connected directly to the C.O. equipment. Also, carrier facilities do


Central
Office
Equipment
Optical MDF
Cable
Vault
Optical
Connectors
Detail of Interconnection
Between Horizontals and
Verticals on MDF.

not experience the same amount of re-arrangement as VF plant, so flexibility is less important. Further, a MDF would have to be designed to have acceptable transmission properties at the high frequencies encountered. As digital transmission becomes more widespread, so the need for flexibility will increase, and the congestion in vaults will increase , leading to the need for MDFs operating at higher frequencies to handle carrier traffic. Such MDFs will most probably be separate from VF MDFs because of their different transmission requirements. At this moment the advantages of a fibre MDF become apparent - crosstalk and transmission characteristics are independent of signal frequency, at least up to frequenices in excess of a hundred megabits/s, when mode mixing effects at couplers may need attention. Although even there no serious problems are anticipated. Thus a single fibre MDF could handle all the signals entering the C.O., simplifying the administration considerably.

4.5 SAFETY CONSIDERATIONS

Craftspeople working in C.O.'s have generally been well alerted over the years to the danger of electric shock which exists with metal plant from induced currents on cables. Many standard safety procedures have been evolved to minimise risk. With fibre optics, though, the principal safety hazard is accidental eye damage from exposure to high light levels. The problem is particularly acute since all present and proposed optical communications systems use light in the infra-red, which is invisible to the human eye, and thus a person can be exposed to dangerous optical radiation levels without being aware of such exposure. Timmermann quantifies some of the hazards in ref. 4.1, but his major conclusions are that a real hazard exists even with present day high radiance LEDs, and a greater hazard can be expected with future lasers. The safety levels on which Timmermann bases his conclusions have not been universally agreed upon, but it is wise to assume for the moment that personnel must be protected from accidental exposure to radiation emitted directly from a light source or from the end of a fibre connected to such a light source.

The area is not one which has been given much attention in the literature. Obvious first solutions would be the use of relays which would switch light sources off if a connector on the fibre fed by the light source were to be left open. Full protection, though, would require two-way transmission, with a feed back system ensuring that light sources are switched off when the detected signals fall below a certain threshold value, indicating a fibre break. These systems need economic evaluation, while the industry should also monitor publications by government and optical authorities on the latest safety standards for light sources.

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CHAPTER 5: COMPATIBILITY WITH CATV PLANT

5.1 INTRODUCTION

The problem of compatibility of fibre installations with copper based CATV installations is less severe than that of compatibility with telephony plant. Firstly, almost no CATV plant exists in rural areas and even that which exists in urban areas represents a smaller capital investment than does telephony plant. Secondly, in more densely populated areas where coaxial cable CATV systems might be encountered, the preferred topology for a fibre based system would be a star network, which would require the total replacement of the coaxial distribution system. The only way in which a smooth transition could be obtained would be by running the two systems in parallel during the transition period. The main areas where compatibility should be considered are at the subscribers' premises and at interfaces where fibre is used as a trunk between copper distribution systems.

5.2 THE SUBSCRIBERS' PREMISES

As was mentioned in the previous chapter, the fibre optical system will terminate at an entrance unit somewhere in the subscriber's home, from where the video signals will be distributed on coaxial cable drop to the subscriber's television set or sets. The main compatibility problems will depend on what frequency and in what format video is delivered to the subscriber's set. Throughout this study it has been assumed that distribution to the home will be in NTSC VSB analogue form or, possibly, in baseband analogue form. Any other form of distribution, such as digital or FM, would require interface equipment at each subscriber's home which is unacceptably expensive. The trade-offs between analogue sub-VHF band and VHF-band transmission have already been discussed at some length in activity reports 3 and 4. Briefly, baseband may be attractive for simplicity in video switch design. At the subscriber's home, though, domestic television sets are not capable of accepting baseband inputs.

Thus, if switching considerations dictate the use of baseband transmission, either manufacturers must be persuaded to market a baseband input receiver, or modulators must be used. A special baseband only set would be cheaper than an existing set, but subscribers may require a set capable of off-air reception as well as baseband reception. Rediffusion experience in England (Ref. 5.1) has indicated that many subscribers are satisfied with a set incapable of off-air reception, and this will be especially true in rural areas with little or no broadcast coverage. Certainly, from a systems viewpoint, it is preferable to have a set with baseband input rather than use an external modulator to modulate a baseband signal to RF for subsequent demodulation by the set's demodulator.

If sub-VHF is used for transmission, then the subscriber must be equipped with a channel converter. Because of the widespread use of such devices in wide-band CATV systems their price has been considerably reduced in recent years. The operator is cautioned, though, to carry out stringent quality testing before selecting a given product, since it is believed by some operators that reliability has often been sacrificed to cut costs.

If light sources are used which transmit efficiently at VHF, then no compatibility problems arise for inputting the video signal to the domestic signal.

When switched video of any type is used (star or demand-assignment), then a unit has to be provided at the subscriber's home to allow him to signal for a change in channel. Such a device need not be complex, and has already been discussed in report 3. If an out of band telephony signalling scheme is used savings will be realised by incorporating the video signalling in that scheme.

5.3 TRUNKING

Report 5 has considered the techniques available for the transmission of high quality video from head-end to hub or between hubs in different cities. All that can be said here is that the transmission method for use over such a link will be chosen as the cheapest capable of meeting the transmission objectives. Should the video be transmitted in any form other than VSB analogue, it must be converted back to VSB analogue form for distribution - but this requirement exists for any trunking arrangement, and nothing new is introduced by fibre otpics.

5.4 POWERING

The problem of powering for CATV is not as severe as for telephony, since the subscriber's terminal (TV set) is not powered by the system operator in current cable systems. The only place where powering is a problem is at repeaters. Distribution has been planned to be repeater-free in the star networks concentrated on in this study for medium to high density rural areas, so the problem will only arise on trunks between offices. Chapter 3 of report 8 discusses possible powering schemes at these locations, with local AC powering as the preferred solution.

5.5 TREE STRUCTURES

It has already been pointed out that tree structures are only likely to be installed in low density rural areas, where no coaxial systems exist today. Thus, no discussion is needed on compatibility with existing outside plant. At the hub of the system, frequency conversion to sub-VHF bands may be needed to extend range, as discussed in report 5, with block converters in the subscribers' homes. Block converters, as their name implies, convert the sub-VHF bands in a block to VHF channels. The problems of repeater powering and cable installation are the same as those for trunking, and have been discussed in report 8.

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CHAPTER 6: SYSTEM EVOLUTION

6.1 INTRODUCTION

Two aspects are involved in the evolution of a fibre network - firstly the orderly introduction of fibre into an environment containing copper transmission facilities and, secondly, the evolution of the fibre based plant to cater for future services.

Throughout this discussion regulatory considerations are totally ignored. The report, rather, tries to determine the most economical fashion of distributing the required broadband and narrowband services to the subscriber.

6.2 THE INTRODUCTION OF FIBRE INTO AN EXISTING NETWORK

6.2.1 Rural Areas

In most rural areas one will be considering the introduction of fibre carrying broadband and narrowband signals in a network with no broadband facilities, and with telephony on a star or multiparty distribution.

The policy recommended throughout this study for medium to high density rural areas has been to use a star type approach for distribution, with remote switching units as nodes serving groups of subscribers with both video and telephony. The implementation of such a fibre based network will closely resemble that of a copper based digital subscriber carrier system, such as ITT's DM32S or Northern Telecom's DMS-1 system. It is in some ways fortunate that fibre technology is approaching maturity just as these new systems are being proposed for installation. Thus, technically, these subscriber carrier sytems could be wired up from the start using fibre optics as the subscriber drops, allowing broadband services to be introduced in future. It is essential that the most detailed economic studies, together with technical field trials be carried out as soon as possible. This is important since many subscriber carrier systems will be installed in rural areas over the next few years, and it is necessary to know whether or not these systems should be installed initially using fibre. A retro-fit of such systems with fibre after they have already been fitted with copper would be expensive. So, however, would be the installation of a fibre based systems which later proved to be prohibitively expensive. A solution with considerable technical merit would be to instal drops containing one copper pair and one fibre. The copper pair could be used as the medium for baseband telephony now while cheap terminals for transmitting video and telephony over the fibre are developed using integrated circuitry.

The trade-off involved here would be between the savings to be realized when the optical system is finally commissioned by awaiting cheap integrated terminals, and the increased cost of a hybrid cable containing copper and fibre. The cost of the hybrid cable is likely to be increased by the fact that the cable will be regarded by manufacturers as a temporary measure which will eventually be made obsolete. Thus, manufacturers may be reluctant to produce the cable in economical quantities. The approach, though, would allow a very smooth transition from conventional narrowband to fibre based integrated services.

The study required to select the optimum from the above strategies is obviously a lengthy one, requiring a cost comparison in present dollars of different strategies with time, and different revenues. This type of comparison can be performed in a fairly straightforward procedure once reliable estimates of the costs of the various components have been obtained as a function of time. It is in this area that the process becomes lengthy, since cost depends on quantity, which in turn depends partly on which strategy is used for the introduction of fibre systems. Report 6 of the present study provides a good basis from which to start this study.

In low density rural areas star distributions become less attractive, and a tree distribution becomes the only economical way to provide service. The implementation of a tree distribution requires development work on the installation of couplers in the outside plant. For this reason it is likely that earlier fibre based systems will be installed in medium to high density rural areas suited to star distribution, with tree systems being installed in low density areas some time later. A tree system will not have the same capacity for growth, especially for private video services, but it would allow the provision of single party telephony, data and CATV in areas previously served only by multiparty telephony. Here there are fewer alternatives than in the case of a star distribution, since neither the installation of all metallic cable for retrofit nor the installation of hybrid copper/fiber cables has much merit. The installation of such a system could be gradual, with a short length of fibre trunk initially feeding the nearer subscribers and with the trunk being gradually extended with amplifiers until the farthest subscriber is served. Obviously, all signal levels must be designed from the start to permit the farthest subscriber to be served. Although the tree type distribution network is very different from a star, the compatibility problems will not be very different. Telephony will need a frequency multiplexer/demultiplexer associated with each subscriber's line card at the telephone switch, with a matching unit at each home. CATV may be transmitted in the same form as in the star, or the longer range required may require either the use of lower transmission frequencies or a reduction in channel capacity. In the outside plant the same rights of way can largely be used - only the nature of the cable and the use of couplers and repeaters will differ.

One final comment on tree and star networks is in order. The preference expressed throughout this report for switched star distribution has been based on three assumptions. Firstly, it has been assumed that a demand exists for interactive or bidirectional video services requiring a switch. Secondly, the multiplexing capacity of fibre networks has been assumed to be limited to 3 to 5 channels over distances in rural areas. Finally, the problems of optical taps in the field were assumed to make trees unattractive for earlier applications. These assumptions need to be kept in mind by the operator, who may find that, due to one or more of these assumptions not applying in his case, his needs are better met by a tree.

6.2.2 Urban and suburban areas.

Unlike rural areas, most urban and suburban areas are already served by telephony and CATV of acceptable quality and cost. There is little interest in installing radically new distribution systems, although improved urban switching and inter-office trunking for telephony and data is receiving much attention. Thus, a new integrated fibre based network cannot be smoothly introduced as part of a separate natural evolution in the distribution network. Instead, it will require replacement of the existing copper pair drops by fibre cables following exactly the same route. Unlike rural areas the new network would not immediately offer new services to the subscriber by just providing single party telephony and CATV, although the quality of the latter should be greatly improved over that in present cable systems. In order to justify the investment needed to install this system it will be necessary to provide the subscriber with new services which he is willing to pay for, since he is unlikely to pay enough just for better quality CATV. Thus, the introduction of integrated networks in urban areas may lag behind their introduction in rural areas until system operators are convinced that enough demand exists for new expanded services or until present systems need replacing due to age. The evolution of urban integrated networks will largely depend on the ability of operating companies to select from among the wide range of futuristic services already referenced in this study (ref. 6.1) those for which a real market exists, and then aggressively market them. Videophone services are an obvious area where the bandwidth capabilities of fibre could usefully be used to introduce a service which has not been a success on copper pairs.

A detailed study of the market for new telecommunications services is currently being performed by DOC and Bell Canada, and the results of this survey should be very relevant to the future of broadband urban networks, whether fibre based or not.

The need for service flexibility and for a wide range of services to each home in urban areas dictates the use of a star distribution, and not a tree. Thus, the new network will run along the routes used by the present day telephone lines.

6.3 THE EVOLUTION OF A FIBRE BASED NETWORK

Once a fibre based distribution network has been installed, one has to consider the way in which it will evolve. The simplest integrated network which would provide a useful service to subscribers is illustrated in fig. 6.1. This network will be discussed briefly here, since much of it is similar to that already considered in report three, and the ways in which it can evolve to provide wider service are also discussed. This section will also look at tree structures, and their evolution.

In the network of fig. 6.1, telephony is provided by the remote line module (RLM) of a digital switch. The output of each subscribers' line card in the RLM is fed to a light source driver for transmission at baseband over a fibre drop to the subscriber. A small number of frequency multiplexed CATV channels is mixed to the telephony, without switching, and transmitted over the same drop. The number of video channels so transmitted can be calculated by applying the rules of report 5 to the longest subscriber drop.

The cost differential between this arrangement and a straight copper-based system arises in three areas. Firstly, there is the difference in the cost of the transmission medium itself. Secondly, there are the extra costs involved at the RLM, and thirdly the costs at the subscriber's homes. The terminal units both at the RLM and at the home are much simpler than those in report three, since no modulation or frequency conversion is used. If a new signalling scheme for telephony is already provided as part of the standard telephone service, as discussed in chapter three, then no incremental cost for signalling or powering of the telephone set can be attributed to the fibre network itself. Other costs, such as head-end programming and video trunking will be shared by many subscribers and hence should not be too great.

In order to evolve such a network towards one with expanded video capacity, one has two choices. Either the multiplexing capacity can be increased on each drop, allowing the same non-switched distribution network to be used, or a video switch can be introduced at the remote switch location, as discussed in report 3. In order to increase the multiplexing capability, the intermodulation products at the detector must be acceptably low when the signal is at a high enough level to give the desired signal to noise ratio. It is assumed that bandwidth is not the major restriction, but it is obviously necessary to ensure that adequate bandwidth is available. Several means exist by which the level

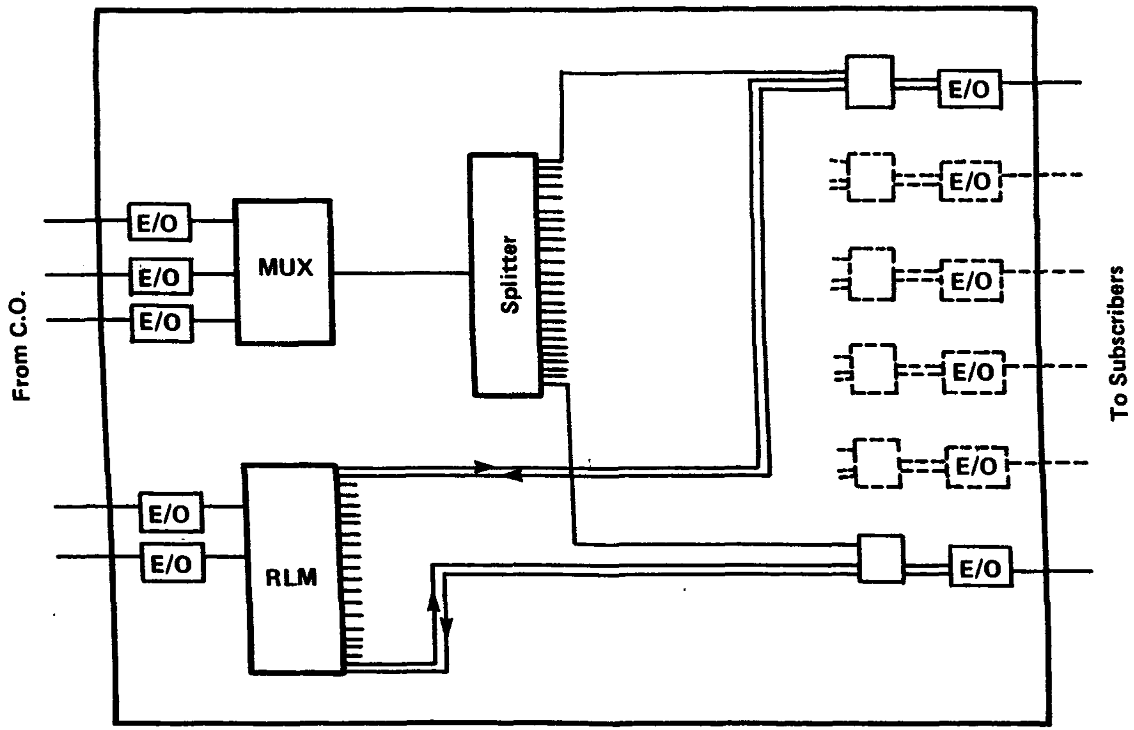

Figure 6.1 A Simplified Remote Switch Without Video Switching

of multiplexing can be increased. By changing the structure or composition of the light source its linearity at a given power level may be improved, and its maximum power output increased. Linearisation can also be achieved by the use of compensating circuitry (6.2). The capacity can also be increased by lowering the system attenuation, thereby allowing the light source to be run at a lower power level, and hence more linearly. This decrease in attenuation may be achieved by development of better fibres, splices and connectors, or by using light sources operating at longer wavelengths, as discussed in section 6.4 below. If adequate service can be provided by increasing the multiplexing alone, without switching, the operator should ask whether he would not be better served by a tree distribution topology.

The switched approach is more flexible in the range of services it can provide and it is largely for this reason that it has been recommended for use whenever subscriber densities justify it. In order to provide a switched network at an acceptably low price two areas need development work - the area of video switching and the area of terminal design. Hopefully the application of medium scale integration techniques to both switch and terminal design can reduce the prices from those quoted in activity report six. Only after this development work has been pursued can a reliable cost comparison be made between a switched and a non-switched approach to distribution, taking into account the increased revenues to be expected from a switched network. The increased revenues to be expected from new services need to be estimated by a market survey.

Should tree structures be used, for example in low density rural areas, the evolution towards greater channel capacity can only be obtained by increasing the multiplexing level by one of the techniques discussed above. Repeater spacings, unfortunately, will have to be designed to be optimum for early systems, and will therefore, not be optimum for higher capacity sytems. Thus, the capacity of a network designed with present day devices in mind and then upgraded with later components will not be as great as one designed for use with those later components. However, considerable scope exists for increasing the channel capacity with improved devices.

6.4 MISCELLANEOUS CONSIDERATIONS

The above sections have discussed the general evolution of the network. However, within the domain of fibre optics as a transmission medium, many details are under discussion. Firstly, one must consider the light sources. Two most important questions arise concerning light sources - their structure and their wavelength. Light source structures encompass many variations on LEDs and lasers, as reviewed in report 1 of this study. Report 5 shows the advantages to be gained by using lasers with good linearity, in terms of increased multiplexing capability and system range. Although lifetime considerations are still a problem, improvements are being reported which give rise to cautious optimism for the future of these devices. At the third European conferences an optical communication in 1977 AEG - Telefunken reported 18,000 hours operation at room temperature of a laser with 5 mW at each facet.

It is however likely that LEDs will be preferred to lasers when their performance is adequate, since lasers need more accurate control of the curret bias driving them and because lasers are predicted to be more expensive than LEDs (see activity report 6).

From the point of view of system evolution, one can be hopeful that lasers performance (linearity, and lifetime power) will improve over the years, while LEDs will at least improve further in reliability. If a system is installed today with either source one can be optimistic that future sources will allow improved system performance in terms of increased channel capacity, range, and reliability. Thus, a first generation non-switched distribution network of the type discussed above could be installed using lasers anticipated to be available shortly and having a channel capacity of three or four video channels. The advent of more powerful linear lasers would allow an increase in system capacity by several channels. The only negative aspect is that drive circuits for different devices may differ in their need for bias control and correction for device non-linearities, hence adding some expense to the retrofit.

The subject of wavelength is an interesting one. The range from 800 to 900 nm is used today for three reasons. Firstly, it is the range covered by ternary Gallium Arsenide components, especially $Ga_x\ Al_{1-x}\ As$. Gallium Arsenide and related compounds have been the object of intensive materials research for several years because of their application to microwave technology, and their theortical interest because of their direct band-gap. The second reason for the use of this wavelength is that attenuation of silica fibres is relatively low in this region, while the third reason is that Si photodetectors, already well developed for use in the visible range, are sensitive up to about 900 nm.

The reason why longer wavelengths are now being studied is twofold. Firstly, as shown in fig. 6.2, fibre attenuation increased between 0.9 and 1 micron, due mainly to water absorption, but it drops substantially after 1 micron. Secondly, one of the factors limiting the bandwidth of communication by fibre optics is the chromatic dispersion. As mentioned in report 1, the dispersion is minimised by operating near 1.3 micron, where low attenuation is also obtained. The difficulty in

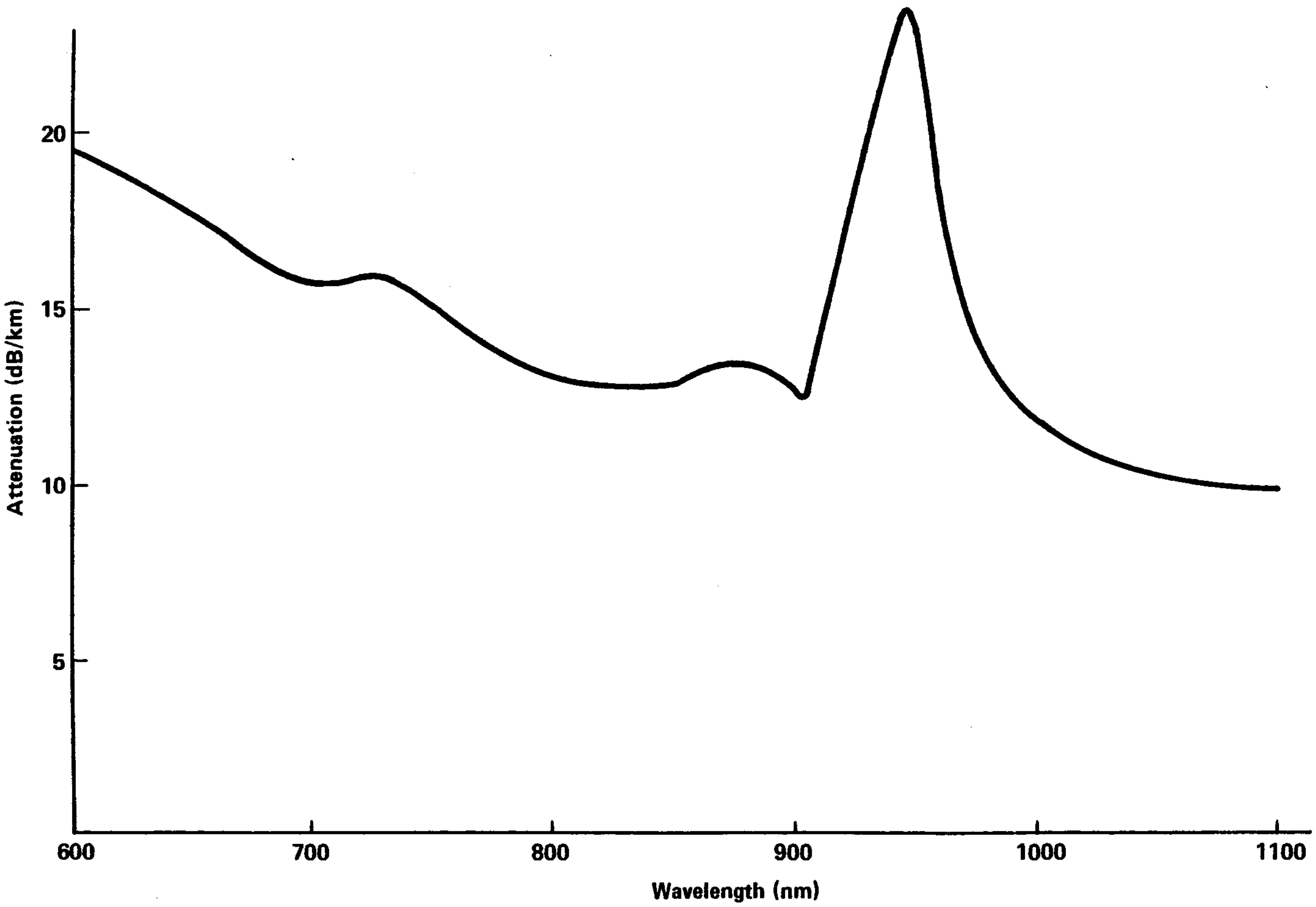

Figure 6.2 Fibre Attenuation v Wavelength. Based on Corguide Figures

operating at these wavelengths lies in finding suitable light sources and detectors. Light sources are likely to be less of a problem than detectors, where the lower bandgaps will inevitably mean degraded noise performance.

The choice of an optimum wavelength is discussed in ref. 6.3. It looks likely, though, that systems installed before the early nineteen eighties will all operate in the wavelength range 800 to 900 nm. These systems can be retrofitted with longer wavelength devices to improve performance later. In the evolution of the system, some very distant subscribers may have their connections deferred until longer wavelength systems are available to provide the attenuation and bandwidth needed.

Another subject which needs discussion in the evolution of an optical network is integrated optics. In the early sixties many workers (refs. 6.4, 6.5) started, producing miniaturized optical components. These components are potentially compatible with fibre optics transmission systems, where they could in principle fill such roles as couplers, switches, modulators, multiplexers and demultiplexers. The advantages to be gained include compactness, switch isolation and the avoidance of unnecessary electro-optical converters. Some references even suggest that amplification might be achieved optically, using lasers in a manner analogous to masers, thereby totally avoiding the need for electro-optic conversion except at the subscriber's terminals.

The development of such systems has been somewhat slower than early enthusiasm might have predicted. Direct amplification of light signals by the laser principle has been shown in ref 6.6 to be noisy. Integrated switches and modulators have been demonstrated in the laboratory (ref 6.7, 6.8), and an integrated optics source for wavelength division multiplexing has also been demonstrated (ref. 6.9). Most of these devices, though, have been single mode devices whereas virtually all fibre communications systems use multimode fibres. Although single mode integrated optics components can launch light efficiently into a multimode fibre, they are very inefficient at coupling light out of the fibre. Two solutions are obvious - either develop multimode integrated optics components or introduce single mode fibre into the telecommunications network. The latter will greatly increase difficulties in splicing and connecting fibres, and will probably only be used for special very wide band applications. The introduction of multimode integrated optics requires improvements in the technology to construct thick film waveguides, and, further, the theoretical analysis of such components is complicated. It is probable that isolated integrated optics components, possibly for directional couplers and wavelength division multiplexers, will find application in networks of the early eighties, but the all-optical network is very unlikely to be seen before the nineties. By then, substantial amounts of multimode fibre are likely to be in use, adding to the pressure to make integrated optics compatible with multimode fibre. Although systems planners should be aware of the evolution of integrated optics, it is not likely that these developments will influence the design of networks for use in the eighties.

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