



Technical Report

A Systems Study of Fiber Optics for Broadband Communications

Activity No. 3
Integrated Distribution of
Video, Voice and Data

BNR Project TR 6259
August 1977

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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 problems associated with the integrated distribution of video, telephony and data on a single network, using fibre optics. In accordance with the objectives of the DOC, emphasis is placed on the implementation of such a network in rural areas. The report concentrates on the problems in the distribution area to the subscribers homes. Discussion of trunking is mainly in term of the interface requirements with the distribution network.

The objective of the report is to identify the optimum network for the integrated distribution of video, telephony and data, and to provide a description of this optimum network in sufficient detail to allow cost estimates for the network to be derived from costs of the component parts. The criterion for optimisation will always be cost, once the basic service requirements are met. Since reliable cost estimates for network components are not available, a unique optimum solution can not be given. The report attempts to meet its objective, however, but identifying one network concept which is almost certainly optimum, and detailing the various alternatives which are available within this overall concept.

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2. SUMMARY AND CONCLUSIONS

2.1 STRUCTURE OF THE REPORT

The basic services which the integrated network is required to provide are described in Chapter 3, and Chapter 4 discusses the transmission objectives for these services. Chapter 5 gives a detailed discussion of the general network topology, and the components needed to implement several alternative forms of the network are discussed. Chapter 6 applies the principles of Chapter 5 to two types of rural areas, and to urban and suburban areas. Finally, Chapter 7 discusses the phases which could be used in installing an integrated network. In addition, three Appendices are attached. The first discusses the many implications of baseband video versus RF video, while the second gives some traffic curves which are useful for a discussion of channel capacity required. The third summarizes the component count for subscriber terminals.

2.2 CONCLUSIONS

Based on the results of earlier activity reports for the present contract, a star configuration is selected as the most attractive one. Subscribers are served directly by remote switches, which in turn are served by a central office. The serving area of a remote switch can include as few as twenty or as many as several thousand subscribers, depending on the geography of the area. The switch may be modified to suit a specific area.

In rural areas, specified low population density areas, the amount of fibre needed per subscriber is strongly dependent on the degree of multiplexing in the trunk joining the remote switch to the central office. This is a strong incentive to develop highly linearised light sources with sufficient power to permit a high level of multiplexing. In suburban areas this multiplexing is less critical, and is irrelevant in urban areas.

In all areas the video switch is a dominant component. Hardware development is needed to minimise the cost of crosspoints, together with system design to minimize the number of crosspoints needed. The number of crosspoints may be traded off against the number of channels needed on the trunks. It should be stressed that the elementary switch design in this report serve as a basis for discussion only. In very sparsely populated areas the use of a switch may be avoided.

The final area which can easily be taken for granted is the subscriber terminal, both at his home and at the remote switch. If the "component count" presented in this report is priced using discrete components, a high figure is obtained. (These figures are not presented in the report, but are more properly deferred to activity report 6.)

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Development will be needed on light sources to allow them to be manufactured with the required reliability at a low price. Also, integrated circuit design is needed to keep the cost down of the ancillary circuitry.

Many advantages will be gained by using baseband switching and transmission to the home. For this reason, manufacturers of domestic receivers should be alerted to the fact that baseband inputs may be required on their products in future.

In the area of implementation, a network could be implemented in three phases. A network supplying very limited CATV service (2 to 5 channels) could be constructed in the near future, without using any video switching. Telephony and data could be installed at the same time or shortly after. As a second phase, the CATV service could be expanded, introducing Pay TV and a limited visual library service. In this phase a limited number of dedicated upstream video channels could be provided. The final phase would introduce symmetric switched video.

3. DEFINITION OF SERVICES

3.1 INTRODUCTION

An integrated network for the distribution of video, voice and data could be required to transmit virtually every form of signal encountered in the present telecommunications network. Worse, the availability of a flexible network could generate a demand for services not presently encountered. The purpose of this chapter is to identify the principal services which an integrated network should be required to accommodate, based on discussion of presently available services and of forecasts.

3.2 AUDIO

3.2.1 Telephony

Telephony must be considered as a basic sine qua non of an integrated network. The network must allow voice frequency signals to interface freely with the existing switched telephone network. Further, since the telephone is relied on to summon help in case of emergency, the availability and reliability of the service must be extremely high.

3.2.2 Broadcast Sound

CATV networks currently distribute FM radio stations to their subscribers at a higher quality than the subscriber can achieve without the use of expensive antennas. Some networks are also considering the distribution of high quality AM radio. Provision of such services is considered desirable, but not essential, in networks serving domestic subscribers. Its desirability increases in areas where off-air radio reception is poor.

3.2.3 Piped Music

The continuous background music encountered in public places and factories is frequently transmitted by copper pair or coaxial cable from a central location. The provision of such a service is a low priority item. Although it presents no major technological problems, it will not be discussed further.

3.3 VIDEO

Although the telephone may be the fundamental means of telecommunication, the number of television receivers in the world now exceeds the number of telephones. Hence an integrated network must cater for video transmission. Video services can be classified as follows:

- a) CATV

- b) Pay TV
- c) Visual library
- d) Subscriber originated video (no response from viewer)
- e) Subscriber originated video (non-visual response from viewer)
- f) Still picture services
- g) Symmetric video services

At present virtually all video transmitted by cable or fibre falls in categories a) and b), with the market for the rest remaining uncertain. Activity reports 2 and 4 of this study discuss all of the above categories, except g). Following activity report 4, this report classes categories a, b and f together as public access channels. Within this category, still pictures are provided by using frame grabber techniques. The essential property of public access channels is that they are broadcast constantly, and the subscriber chooses to tune in, or not to tune in, to material already provided. Further, any number of subscribers can access the same program at the same time. The still picture services do not exactly meet this definition, of course, but the use of a frame grabber means that they can use a channel which is identical in all its properties, except content, to a public access channel.

Visual library services were shown in activity report 4 to be prohibitively expensive on resources when used by a significant percentage of the subscribers. The service will be retained in this report, but at a much lower level of usage. This lower level could be obtained by providing an attractive selection of programmes on Pay TV and making the visual library expensive, or by limiting the use of the visual library to designated subscribers, such as public halls or hospitals and schools.

For the purposes of this report, asymmetric visual services will use the symmetric video network. The only qualifying statement which will be made here is that it is probable that a symmetric video network will use a lower quality picture than desirable for CATV and other entertainment purposes, although that will not be assumed in this report.

Symmetric video implies a telephone like network where the two parties communicate both visually and by voice. Although several experimental systems have been developed, notably the Picturephone by A.T.&T. in the United States, no system is believed to be currently in widespread public use. The transmission capabilities of an integrated

network using fibre optics (INFO) reduce some of the technical problems which have inhibited the widespread introduction of symmetric video, and this service must be included when designing the INFO. The term "videophone" will be used to describe these services.

3.4 DATA

Whereas telephony can be regarded as having virtually saturated its market, with nearly two telephones per household in Canada (ref. 3.1), and CATV is well on its way to saturation, serving 44% of all Canadian households (ref. 3.2), data communications are only beginning to make their impact. One estimate (ref. 3.3) is that data traffic will increase tenfold over the next ten years. Whereas others (ref. 3.4) are somewhat more conservative, there is consensus that data communications are likely to experience a rapid growth.

Most data communication today uses transmission and switching facilities designed primarily for the transmission of telephony. As a result modems and data terminals have largely been designed to operate in an analogue mode at low data rates.

The most common data transmission services which are not related to computers are telegrams, TWX, Telex and facsimile. The first three have well-defined formats for their transmission, requiring only voice frequency channels. Facsimile normally uses voice frequency transmission in the absence of any better transmission path, but could profit from higher speed lines. Ref. 3.5 lists many other potential data services, of which electronics fund transfer systems (EFTS) are the ones showing the most signs of being implemented in the near future.

The most rapid growth in data communications, however, is that related to the proliferation of computers. Refs. 3.6 and 3.7 discuss in detail the telecommunications needs of these networks, and also give many examples of the application of extended networks involving several computers and many terminals. The main requirements are for low speed lines linking manually operated terminals to computers and for high speed lines interconnecting computers or connecting computers to high speed terminals (e.g. printers).

In Canada there are two networks specially designed for data transmission - Dataroute, operated by TCTS, and Infodat, operated by CNCP. Both allow subscribers to transmit at a range of speeds up to 56 kbit/s, with asynchronous transmission permitted at lower bit rates (ref. 3.8). These systems operate by circuit switching, as in telephony, where two subscribers occupy a line connecting them for the duration of their call, whether they are transmitting or not. Associated with these networks there are now two packet switching systems offered, where subscribers' data is "packaged" into blocks of data for transmission when a free time slot occurs, allowing higher efficiency use of the

transmission facilities. It is considered essential that the integrated network should be compatible with at least one of these systems.

As an example of the services provided by a private data network, one could consider the case of a major Canadian bank, whose principal computers are located in seven cities. During the day the computers are occupied by the terminals at the bank's branches, of which there are many all operating at low speed. In the evening the terminals are disconnected and the same computers operate in batch mode, generating large amounts of data which must be transmitted between the (relatively few) computers, but at high speed. In addition the bank's computers must communicate with those of other banks for check clearance and related operations. Further inter-computer communications are needed for credit-card operations, with one master computer acting as the hub of the clearance operation. It is considered essential that the integrated network will allow private networks of this kind to be accommodated.

In summary, then, the integrated network should allow low speed data to be transmitted, as well as providing higher speed lines compatible with the existing switched data networks and private networks. As these higher speed lines become available at a reasonable cost, so it is expected that some services currently using low speed lines will adapt their terminals to profit from the higher line capacity. At the top end, high speed inter-computer communications could well use a higher bit rate than the 56 kbit/s limit of present systems.

3.5 SUMMARY

This chapter has attempted to identify qualitatively the major services to be accommodated on an integrated network. The next chapter will attempt to quantify the transmission requirements for these services.

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4. TRANSMISSION OBJECTIVES

4.1 GENERAL PRINCIPLES

In order to set performance objectives for the services described in the previous chapter it is easiest to base the discussion on the performance achieved by systems using existing technology. These systems, however, are frequently not of as high a quality as the customer might desire but, rather, represent acceptable compromises between quality and economy. Due to the large investment in existing transmission and switching equipment, an integrated network will continue to use or interface with this equipment for a considerable time. The guidelines for setting transmission objectives for an integrated network using fibre optics, then, should be that the fibre based section of the network must at least match existing performance levels. If no economic penalty is paid in offering a higher quality of transmission then such high quality transmission should be offered, even if the present equipment with which the fibre network must interface will degrade the overall transmission. Should high quality transmission over the fibre optics facility be expensive now, one should consider the economics of a design which would permit cheap high quality transmission in the future as technology evolves. In this way one avoids the trap of designing a new system to incorporate the limitations of an older technology, and then discovering that one has unnecessarily restricted the options for future growth.

4.2 AUDIO

4.2.1 Telephony

Of all the services to be discussed, telephony is the one in which most of the capital of existing telecommunications networks has been invested. It is, therefore, the service which must be engineered with the most emphasis on compatibility with existing equipment. Unfortunately, many of the requirements which must be met by a network in order to interface with the existing system are ill defined. Reference 4.1 discusses the main requirements.

a) Bandwidth

Current FDM systems for toll transmission use carriers at 4 KHz intervals, and digital transmission samples at 8 kHz. Further, the frequency response of a standard hand-set falls off rapidly above 4 kHz. These facilities represent such an enormous investment that it is unlikely that they will be supplanted. Therefore, there is no point in using more than 4 KHz in any analogue system which must interface with the existing switched telephony network. Increasing the bandwidth of transmission increases the noise at the detector, and hence decreases the range of transmission for a given signal power level. Thus, this report will set

as an objective a bandwidth better than that of existing copper pairs, but not excessively so. To quantify this, ref. 4.1 states that the bandwidth of a telephone channel from end-to-end varies between 2300 Hz and somewhat over 3000 Hz. This bandwidth is defined as being between the points at which the response is 10 dB down on the response at 1 kHz. In order to maintain such end-to-end performance a suitable requirement for a fibre network would be that required of a carrier system, namely a frequency response between 200 Hz and 3450 Hz which is never more than 3 dB down on the response at 1000 Hz. (This is the requirement of the N3 carrier system.)

b) Loss and Noise

It is next necessary to look for some objective equivalent to SNR. In telephony, due to the wide range in signal level, it is more usual to specify maximum permissible signal attenuation and maximum permissible noise levels at the receiver. Signal attenuation will be expressed in terms of the ratio of acoustic pressure at the receiver's earpiece to the acoustic pressure at the transmitter's mouthpiece. Ref. 4.2 gives the results of a wide range of measurements in this area. For these measurements one could conclude that it is desirable to keep the end-to-end loss on any telephony path less than 15 dB.

The allocation of attenuation on a telephony network, however, is mainly made in order to minimise echo. Since the annoyance caused by echo of a given volume varies nearly linearly with the delay between the signal and its echo, telephone networks are designed according to the "via network loss" (VNL) plan. With this plan the attenuation in the trunk portion of the network is increased in a linear fashion with distance up to a maximum value, when echo suppressing circuitry is used. The constant of proportionality depends on how severe an echo problem one expects with the transmission and switching equipment used. As fibre is introduced into the toll network new constants of proportionality may be needed.

The most crucial factor affecting the echo performance of a network is the two-wire to four-wire interface encountered at the telephone switching office serving a subscriber. Here the four-wire circuits of the inter-office toll network, using two wires for each direction of transmission, interface with the two-wire circuits of the loop plant, using one pair of wires for both directions of transmission between the subscriber and the office. Echoes are created at these interfaces which are typically only 11 dB down on the signal.

Should a fibre be used in the loop in a bidirectional mode, we have reason to believe that the echoes would be considerably lower (Ref. 4.3), avoiding the need for high losses to be introduced in the network.

Reference 4.1 (Vol. I, p. 604) states that the maximum trunk attenuation between local switching offices is 8.9 dB over distances of 4000 miles. Thus in order to meet the 15 dB total loss objective considered desirable on the basis of ref. 4.2, the losses in the loops at both ends should not exceed 3 dB. This compares with a Bell System average of 3.8 dB, with standard deviation of 2.3 dB. (It must be stressed here that an end-to-end attenuation of over 15 dB by no means results in an unacceptable signal - the reader is referred to ref. 4.2 for a full discussion of the effect of noise and attenuation on signal quality.)

As stated above, it is necessary to specify a maximum permissible noise level at the receivers set. This is widely agreed to be 20 dB_{rnc}, meaning 20 dB above a reference noise level of -90 dB_m, using the "C" weighting curve described in ref. 4.1 (Vol. 1, p. 56).

c) Crosstalk

Intelligible crosstalk severely limits the transmission capability of copper paired systems. Such systems are required to have nearly 80 dB isolation in order to keep far end crosstalk (FEXT) below an annoying level. In trunk transmission of digital telephony, errors due to crosstalk severely limit the number of pairs in a cable which may be used simultaneously. Typically, in an 1100 pair cable only about 200 pairs can be used simultaneously at 1.544 Mbit/s, and even fewer can be used at higher bit rates. In view of the inherently low crosstalk (virtually zero) expected in fibre systems, no problems are anticipated in meeting the crosstalk requirements, even with all fibres operating at 1.544 MHz.

d) Signalling and Powering

Present networks make use of the conductive nature of copper pairs to provide power for the subscriber's transmitter, receiver and bell. Thus, the availability of service to the subscriber depends on the availability of the power supply at the telephone office, assuming the pair serving the subscriber is undamaged. Since a damaged cable causes loss of service whether it is copper or fibre, it will be omitted from discussion here. An objective is set that the

availability of power to operate the subscriber's telephone should be at least as good as at present. This can, of course be using hybrid glass and copper-pair cables to each subscriber. This is a possible solution, but the alternatives when non-conducting cables are used must also be studied. A common practice at telephone plant with no generating equipment of its own is to provide eight hours of back-up supply in case of power failure. Therefore, we set a minimum objective that the power supplied to a handset should be adequate to maintain it in operation for at least eight hours after a hydro failure. This whole area is receiving much attention, since the introduction of carrier systems in loop plant may require widespread use of electronic equipment in the field needing its own powering. It is believed that the collection of data on availability of hydro supply, especially in rural areas, will allow the objectives for powering to be stated with more confidence.

Once powering has been supplied, the system is free to use any form of signalling which performs the following functions:

- i) alerts the subscriber of an incoming call (i.e. causes his bell to ring)
- ii) alerts the switching centre that the subscriber wishes to make a call (off-hook signal)
- iii) allows the switching centre to identify a busy line and inform the calling party
- iv) causes the switching machinery at the switching centre to function correctly.

e) Summary

Fibre systems for the transmission of telephony should have a frequency response between 200 Hz and 3450 Hz which will be no less than 3 dB down on the 1000 Hz response. Loop attenuation (from switching centre to subscriber) should not exceed 3 dB, and noise at the subscriber's receiver from all sources should not exceed 20 dB_{rnc}.

4.2.2 Broadcast Sound

The objectives set out in BP23 for FM signal levels on a CATV system are as follows:

"FM (Broadcasting) Signal Level shall be 100 microvolts minimum, referred to 75 ohms impedance (or -20 dBmV). The maximum signal level shall be 500 microvolts referred to 75 ohms impedance (or -6 dBmV), except for carriers between 88 MHz and 90 MHz which shall be at least 10 dB below channel 6 visual carrier level where the CATV System distributes a signal on channel 6. FM signal levels on adjacent channels of the system shall not differ by more than 3 dB."

Although no noise figure is specified here, a system with adequate noise performance for video should have no problems in providing an acceptably "clean" FM signal.

4.3 VIDEO

The transmission objectives for video have been widely discussed in activity reports 2 and 4 of this study. Briefly, for compatibility with existing domestic receivers, signals should be analogue NTSC format video signals, or such signals modulated in VSB form on a carrier. Baseband transmission will be made more attractive if domestic receivers with baseband inputs are available. A discussion of the relative merits of baseband and RF transmission is presented in Appendix A.

The basic transmission objectives for domestic entertainment video are set out in the Canadian Department of Communications' standards document BP23 (Ref. 4.4). The present network should meet these standards, and aim for an improved SNR of 42 dB instead of 40 dB as specified in BP23. The requirements for baseband transmission may be derived from these objectives (see ref. 4.5 and activity report 5).

The symmetric video services, loosely referred to as videophone in this report, will be treated here as NTSC signals. The transmission objectives, however, can be poorer, since signals must pass through two distribution networks and the trunk network. 40 dB SNR is specified tentatively.

The whole symmetric video network needs careful design. Firstly, switching is a problem, as discussed in Appendix A, especially if many analogue switches must be cascaded. To avoid this, trunk transmission will be assumed to be digital. Secondly, the use of full 6 MHz bandwidth signals is wasteful on transmission facilities, especially on the local trunks, as defined in chapter 5, and inter-office trunking.

Although lower bandwidth signals will probably be used for videophone services, the distribution portion of the network on which this report concentrates is relatively unaffected, and so 6 MHz NTSC signals, or their baseband version, are assumed.

The use of digital transmission of video in the trunk portion has several advantages. One is that analogue video switches do not have to be cascaded. Another is that the range of transmission can be increased considerably. Digital transmission to the subscriber, however, is not considered likely to be attractive before 1990, if ever. The changes which would make digital transmission to the home attractive would be the development of flat displays to replace CRT's, and LSI implementation of bandwidth compressing techniques.

In addition to specifying the quality of the television signal delivered to the subscriber, it is necessary to specify the quantity. A conventional FDM CATV system supplies a number of channels - typically 5 to 35 - simultaneously to the subscriber who, in principle, can view any number of these channels at once. A "star" type distribution, however, may have any number of channels available at the hub, but the number which a subscriber can watch at any time is limited by switching considerations and by the capacity of the subscriber's drop. For the purposes of this report the network will have as a target the ability to supply up to three channels simultaneously including videophone. In a switched network every extra channel requires additional investment, and it would be reasonable to expect subscribers to be charged for such extra channels. Since present-day CATV networks charge for a second connection one could argue that a precedent exists.

4.4 DATA

4.4.1 Teletypewriter and Telex

Teletypewriter (TWX) transmission is at 150 bits/s, using FSK (ref. 4.6). Telex is a similar system, but operates at 50 bauds. The typical error rates are one or two bit errors per 100,000 bits transmitted and four or five character errors per 100,000 transmitted (ref. 4.7). Transmission quality over the INFO should not degrade this end-to-end error rate.

4.4.2 Voice Frequency Rate Data

Data in this category originates from modems or facsimile units designed to transmit over voice frequency transmission circuits, with data modulated on a carrier. Angle modulation (PSK, FSK) is the most common modulation scheme. Error rates in existing systems are reported in ref. 4.8 to be typically 5 bits in 1,000,000 at 1200 bits/s and one bit in 100,000 at 2400 bits/s. Systems finding this overall error rate unacceptable use error correcting or, at least, error detecting codes. For transparency to the total system, the subscriber portion (C.O. to subscriber) will be required to have an error rate not exceeding one part in 1,000,000 at 2400 bits/s, with correspondingly lower error rates at lower bit rates.

The overall performance of a data transmission network is specified, not by simple average error rates, but by the availability and mean error free seconds of the network. Availability is defined as the absence of an error event or of a loss of signal lasting longer than one second. Ref. 4.9 characterises the performance of the Dataroute network by 99.8% availability and 99.8% mean error free seconds. The most difficult requirement imposed on a fibre network is the high availability, which must be ensured by the provision of adequate back-up power at all locations.

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5. THE NETWORK AND ITS COMPONENTS

5.1 COMPARISON OF NETWORK TOPOLOGIES

The three principal distribution topologies, namely star, tree and ring, are reviewed here. Since a considerable amount of discussion has been given to the first two topologies in activity reports 2 and 4, they will only be covered very briefly here.

5.1.1 Star Distribution

It is first necessary to make the definition of a star network clear. In this report both the networks of fig. 5.1 are star networks. In activity reports 2 and 4 the network of fig. 5.1b was referred to as a tree-star hybrid. The reason for the change in terminology lies in the nature of the traffic between the primary and secondary nodes of fig. 5.1b. In activity reports 2 and 4, essentially the same signals flowed to each secondary node, a situation described quite well by the term tree-star hybrid. In the present situation a different set of signals flows to each secondary node and the term tree-star hybrid is inappropriate. Should it ever be necessary to distinguish between the topologies of figs 5.1(a) and 5.1(b), the latter will be referred to as a multi-node star network.

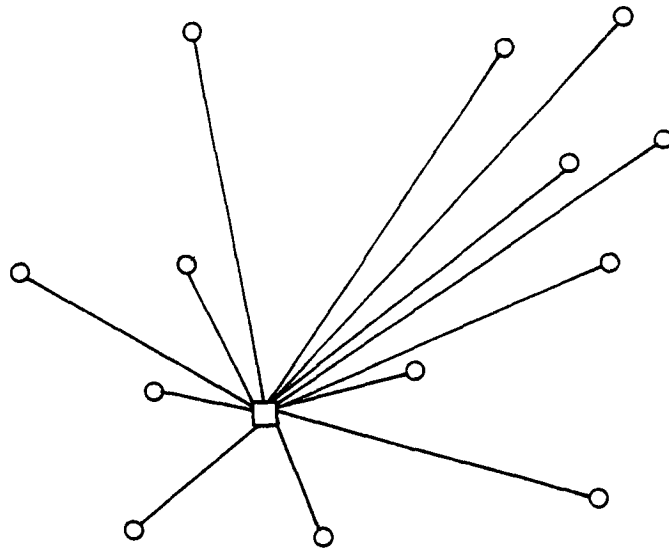
Summarizing the discussion of the earlier reports, star networks have two main advantages over tree networks. They require a lower level of multiplexing, and are more flexible when new services are required over a network already installed. Even for the system with the least requirements, namely a CATV system, activity report 2 identified star systems as being attractive for near term implementation in rural and suburban areas, and for use in urban areas in both near-term and future systems. For asymmetric interactive switched video services, activity report 4 recommended networks based on a multi-node star configuration. Since the present report deals with systems accommodating both a larger amount of traffic and a more diverse range of services, a star network is even more attractive.

5.1.2 Tree Distribution

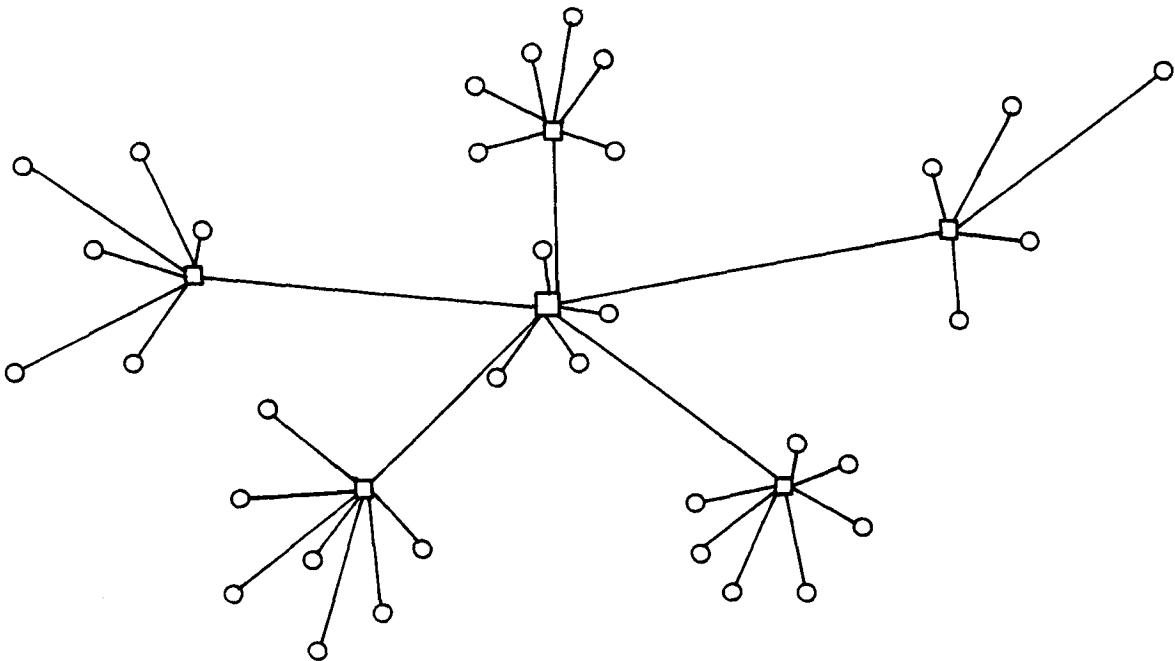
For reference, fig. 5.2(a) shows a tree network. It is attractive when the degree of multiplexing available allows a significant number of the signals in the system at any given time to be carried by one fibre. This is not the case here.

5.1.3 Ring Distribution

Ring distribution has not been mentioned in earlier reports, but since its use has been proposed for telephony, especially digital telephony in low density areas, it is mentioned here. Fig. 5.2(b) shows

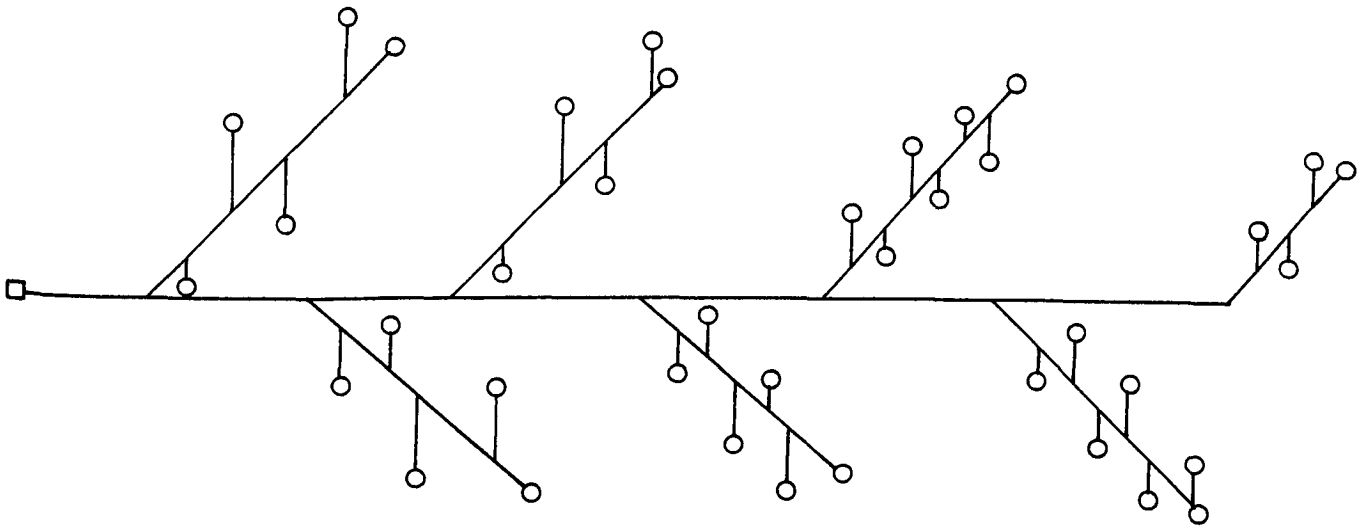


a) A Single-Node Star

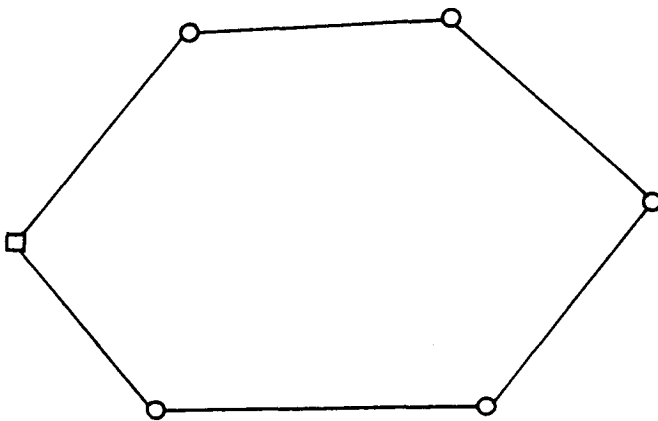


b) A Multi-Node Star

Figure 5.1: Star Networks



a) A Tree Distribution



b) A Ring Distribution

Figure 5.2: Tree and Ring Distribution

a simple ring serving 5 subscribers. The signals for all subscribers travel around the ring. Digital signals are "grabbed" from an appropriate time slot at each subscriber's premises. Analogue signals are split off using filters. Each subscriber also inserts signals into the ring which travel on to the node. Like tree networks, this distribution scheme has its maximum appeal when all the signals for all the subscribers can be multiplexed on one fibre. This is unlikely to be true in the medium term future for the range of services discussed here. It has the disadvantage that analogue signals destined for one subscriber can be tapped comparatively easily by another subscriber. Even digital signals could be tapped, although with more difficulty. A more serious objective is that an equipment failure at one subscriber's terminal would cause a loss of service to all other subscribers on the same ring. For these reasons, a ring topology is not discussed further.

5.2 TOPOLOGY FOR AN INTEGRATED NETWORK

As a result of the discussion in the previous section, the topology for an integrated network using fibre optics (INFO) will be based on that illustrated in fig. 5.3. Throughout this report, the following terms will be used to describe the sections of this network:

Central Office (C.O.): A building containing the program centre of activity report 4 together with switching facilities for data and telephony. The C.O. will be connected to other C.O.'s to make a national grid. In telephony parlance, it is a class 5 office.

Inter-office Trunks: Transmission lines connecting a C.O. to another C.O., or to a switching centre higher in the national hierarchy.

Local Trunks: Transmission lines connecting a C.O. to a remote switch.

Remote Switch (R.S.): A node remote from the C.O. to which subscribers are directly connected. Here video, data and telephony signals are separated for local re-distribution or transmission to the C.O.

Subscriber Drops: The transmission lines connecting a subscriber to a R.S.

In the sections which follow, the principal items among these will be discussed, together with the systems factors which influence their design.

5.3 THE REMOTE SWITCH

The remote switch is probably the most critical item in the whole network, especially in rural areas. The economic viability of an INFO will probably depend largely on the cost of the components in this unit.

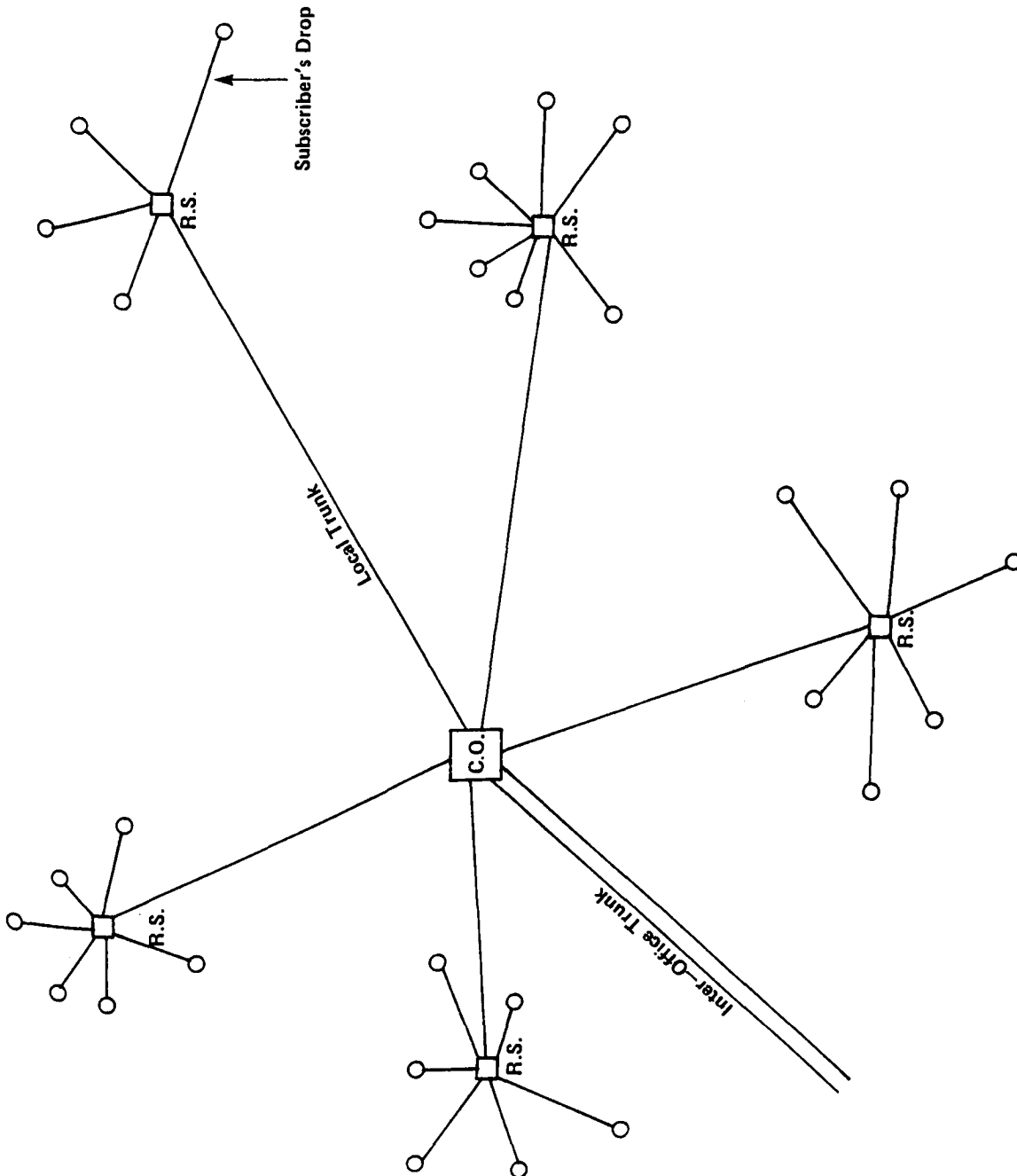


Figure 5.3: Topology for an INFO

Fig. 5.4 shows a general model of a remote switch, breaking the switch into six functional areas. These are:

- a) The video switch
- b) The telephony switch
- c) The data switch
- d) The control unit
- e) The subscriber's multiplexer and electro-optic terminals
- f) The local trunk multiplexer and electro-optic terminals.

This functional separation allows the switch to be discussed independently of the multiplexing used in the subscriber's drops or in the local trunks. Thus, the subscriber's drop multiplexer is seen by the rest of the remote switch as a "black box" with a number of input and output ports with which the other switch components must interface. In practice, the physical nature of the individual switches, especially their frequency of operation, may be influenced by the multiplexing used, but their function and capacity will remain the same. In particular the number of crosspoints needed is independent of the multiplexing schemes used.

5.3.1 The video Switch

The video switch for the present integrated network is somewhat more complicated than for the network of activity report 4. Its functional areas are illustrated in fig. 5.5. The switch has to handle three principal types of traffic, namely public access (CATV type), asymmetric private access (visual library), and symmetric private (videophone) access.

The nature of each switch will be discussed in more detail, but the discussion will be anticipated by the following comments. The public access switch (switches 1 through 3 in fig. 5.4) has a well defined number of input channels, typically 5, 12, 21 or 35, and has one output to all N_s subscribers, a second output to a fraction S of these subscribers, and a third output to a fraction T of the N_s subscribers. It is a comparatively simple switch.

The asymmetric private access switch - switch 4 in fig. 5.5 - has one output to each of the N_s subscribers. Its main function is to handle visual library services, since some of the asymmetric services of activity report 4, such as Telemedicine, will here use switch 5, the switch for symmetric operation. Others, like local community programming

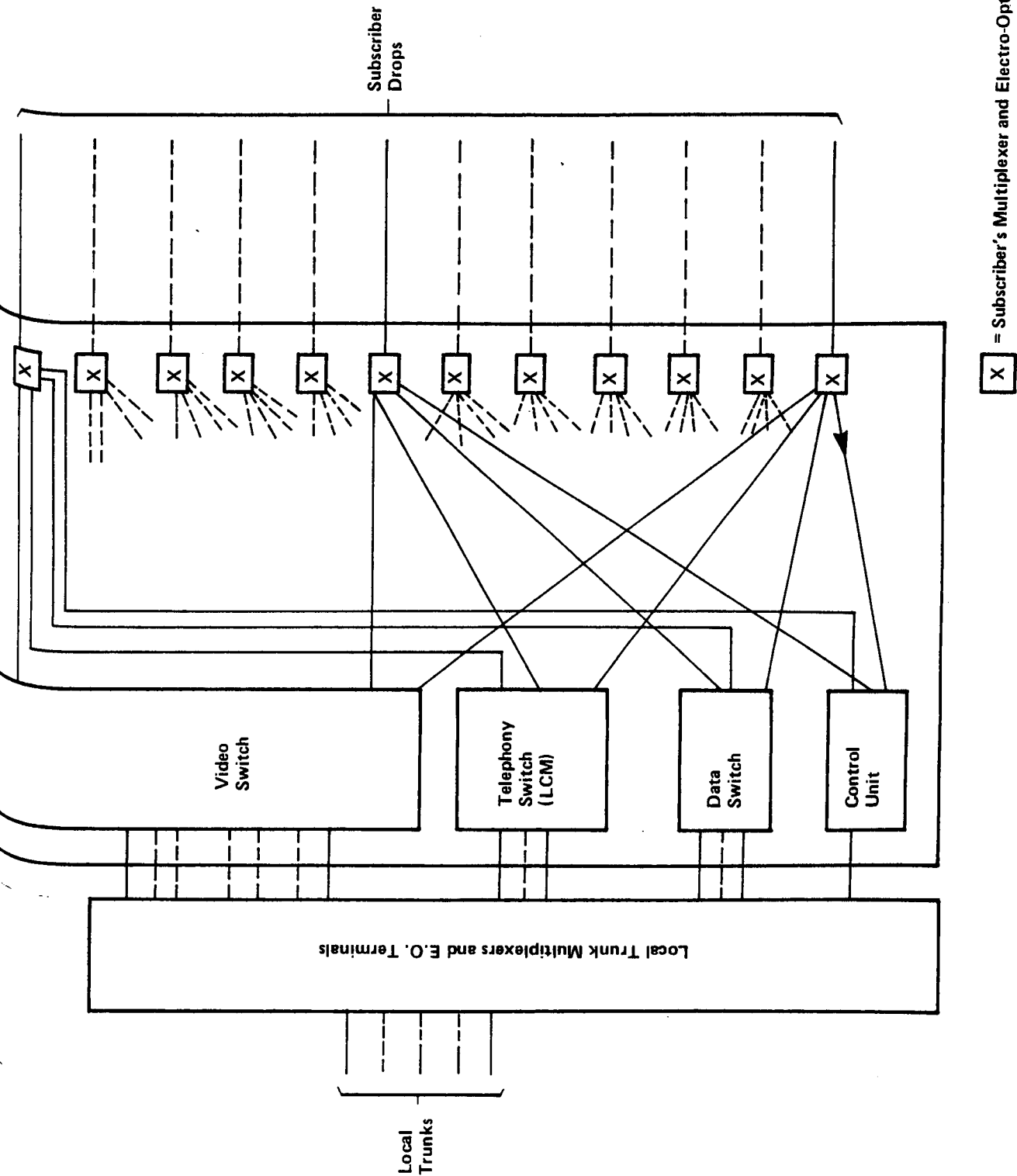


Figure 5.4: The Remote Switch

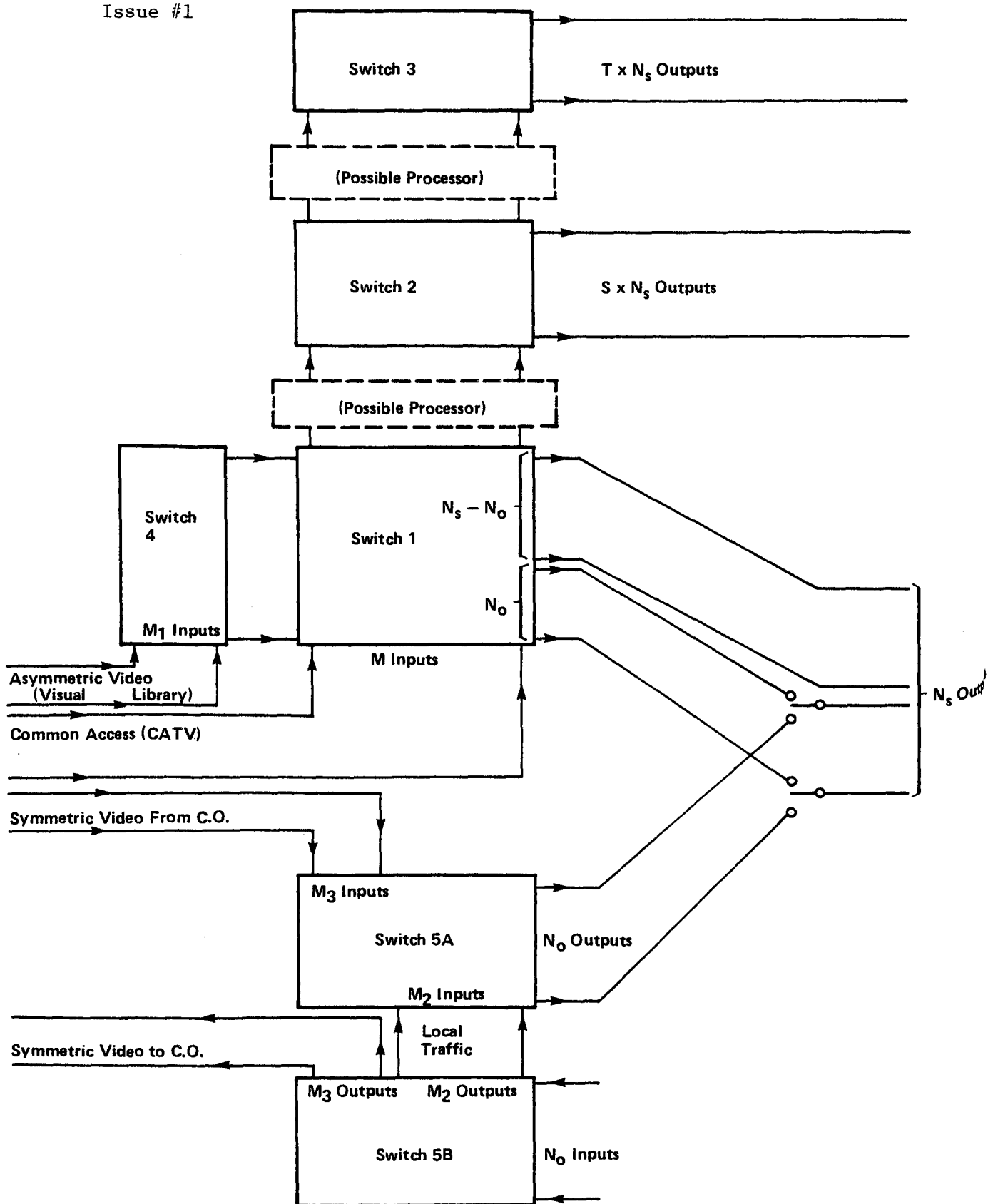


Figure 5.5: The Video Switch

are in a grey area, but will be considered to be included in the common access channels. The determination of the number of input channels needed to switch 4, and hence the number of asymmetric downstream channels to be transmitted from the C.O. to the R.S. will be based on traffic considerations, to be discussed later.

The final switch, switch 5, handles symmetric video. No subscriber is supposed to want this service. Incoming calls, as seen, can be routed locally within the switch, or routed to the C.O. although some asymmetric services may use switch 5, the number of channels between the C.O. and R.S. will be assumed to be equal in each direction. The calculation of the number of channels in each direction, and the number of local call channels, is a problem to be addressed later.

The following notation, some of which has already been defined, will be used repeatedly in this chapter and throughout the report.

- Ns: Number of subscribers per remote switch
 requiring at least one video channel.
- SxNs: Number of subscribers per remote switch
 requiring at least two video channels.
- TxNs: Number of subscribers per remote switch
 requiring three video channels.
- No: Number of subscribers per remote switch
 requiring symmetric private access video.
- M : Number of common access channels (CATV, Pay TV, frame
 grabber).
- M1: Number of asymmetric video channels from the
 C.O. to the R.S. (visual library)
- M2: Number of local (intra-switch 5) channels in
 one remote switch.
- M3: Number of symmetric video channels each way
 between C.O. and R.S.

5.3.1.1 Switches 1, 2 and 3

The general design of a switch for common access channels will first be discussed. Fig. 5.6(b) shows the simplest kind of switch capable of distributing M channels to Ns subscribers (switch 1). It can quickly be shown that use of traffic statistics to make this into a concentrator switch gives no savings due to the high traffic level encountered with this type of traffic. Traffic theory (ref. 5.1) shows

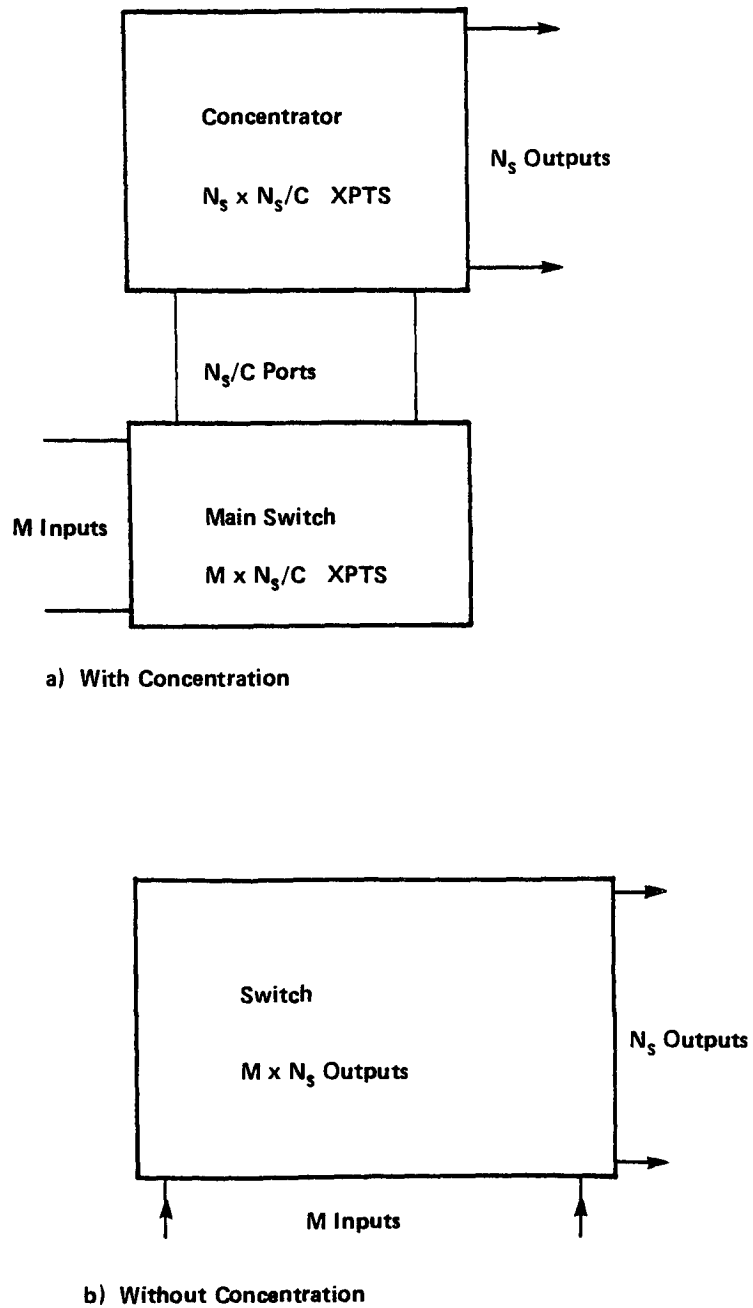


Figure 5.6: Concentration in a Public Access Video Switch

that N_s subscribers can share a number N_s/C output ports on a switch with an acceptably low probability of any subscriber being denied access. The figure C is the concentration ratio, and curves for calculating it appear in Appendix B. Typically for CATV type systems it is below 2.

A concentrator type switch is illustrated in fig. 5.6(a). The first stage, the concentrator, needs $N_s \times N_s/C$ crosspoints while the main switch needs $M \times N_s/C$ crosspoints. To compare the number of crosspoints in the simple switch and the switch using concentration, we express M (the number of common access channels) as a fraction of N_s :

$$M = K N_s$$

It follows that the ratio of the number of crosspoints in the simple switch to the number in the switch using concentration is:

$$R = \frac{K C}{1+K}$$

For R less than one, a simple switch is preferred. Since K is usually much less than unity, and C has been shown to be less than 2, the condition R greater than unity cannot occur. Hence concentration is not attractive. Further, it is undesirable to have blocking on CATV channels, since in times of emergency or during events of public importance it is very useful to have a channel available into every home.

The above argument is for switch #1, distributing the first channel into each subscriber's home. It is permissible to have a system blocking second and third channels. Whether it is economical to do so will depend on traffic statistics for these two switches. In the absence of any basis whatever for estimating this traffic, the present report will assume the use of simple non-concentrated switching for switches 2 and 3.

The division of the common access channel switch into three is partly for clarity, partly because of the different nature of the traffic through switches 2 and 3, as discussed above, and partly due to a proposal in activity report 4 to operate the three switches at different frequencies for FDM transmission. The latter scheme is shown in Appendix A to be unattractive due to problems with switch isolation. In the simple non-concentrated version of the common access channel switch, switches 1, 2 and 3 become one simple switching matrix.

One last observation is appropriate concerning the common access switch. Such switches must incorporate enough buffering to ensure that the signal level to the subscriber remains constant independent of the number of subscribers tuned to a given channel.

5.3.1.2 Switch 4

The main input for this switch is the visual library traffic, and output is to any one of the N_s subscribers. The concentration ratio used to calculate the number of input channels, M_1 , needed will be taken from graph B.1 in Appendix B, using the 1% usage rate curve.

The only way to reduce the number of crosspoints is to sub-divide the N_s subscribers into small groups. Otherwise the switch is a $N_s \times M_1$ matrix. For shorthand purposes, switch 4 will often be referred to in the text as the visual library switch.

5.3.1.3 Switch 5

No subscribers both input signals to and receive signals from switch 5. The arrangement shown in fig. 5.5 is the simplest arrangement possible to serve them. In Appendix B the traffic assumptions used by the Bell System for Picturephone are used to estimate the total traffic into the switch. A further assumption is made, based on experience within BNR on similar switching situations for telephony in rural areas. This assumption is that 60% of the total switch traffic is local. It is stressed that this is an informed "guesstimate", and could vary widely from area to area. On the basis of these two assumptions, fig. B.2 gives the concentration ratios from which M_2 and M_3 may be calculated.

Fig. 5.7 shows how two stages of concentration may be used. The N_o input channels are concentrated to $N_o/CTOT$ outputs by a concentrator. $CTOT$ is obtained from fig. B.2 of Appendix B. The main switch divides the concentrated inputs between $N_o/C60$ ($=M_2$) local outputs and $N_o/C40$ ($=M_3$) outputs to the C.O. Again, $C60$ and $C40$ are obtained from fig. B.2. This is a simplified model, and would need more rigorous treatment to be precise. The result, however, is that for all values of N_o in fig. B.1 a simple-concentrated switch with N_o ($N_o/C60 + N_o/C40$) crosspoints uses fewer crosspoints than a two stage concentrated switch, and hence the simpler switch will be assumed.

As the number of subscribers grows this one stage switching concept becomes inefficient, and a preferred approach is illustrated in fig. 5.8. The subscribers, N_o are divided into small groups, N_o' . Three groups are illustrated for simplicity. Each group N_o' has a number M_2' of local output ports and M_3' of distant output ports in the incoming section, 5b, of the switch. The outgoing section 5a of the switch is arranged in the same way. The numbers M_2' and M_3' are calculated from N_o' using the curves of Appendix B, as usual. A third switch, labelled 5c, is used to interconnect the local traffic.

From inspection of fig. 5.8 it is apparent that the N_o subscribers share between them:

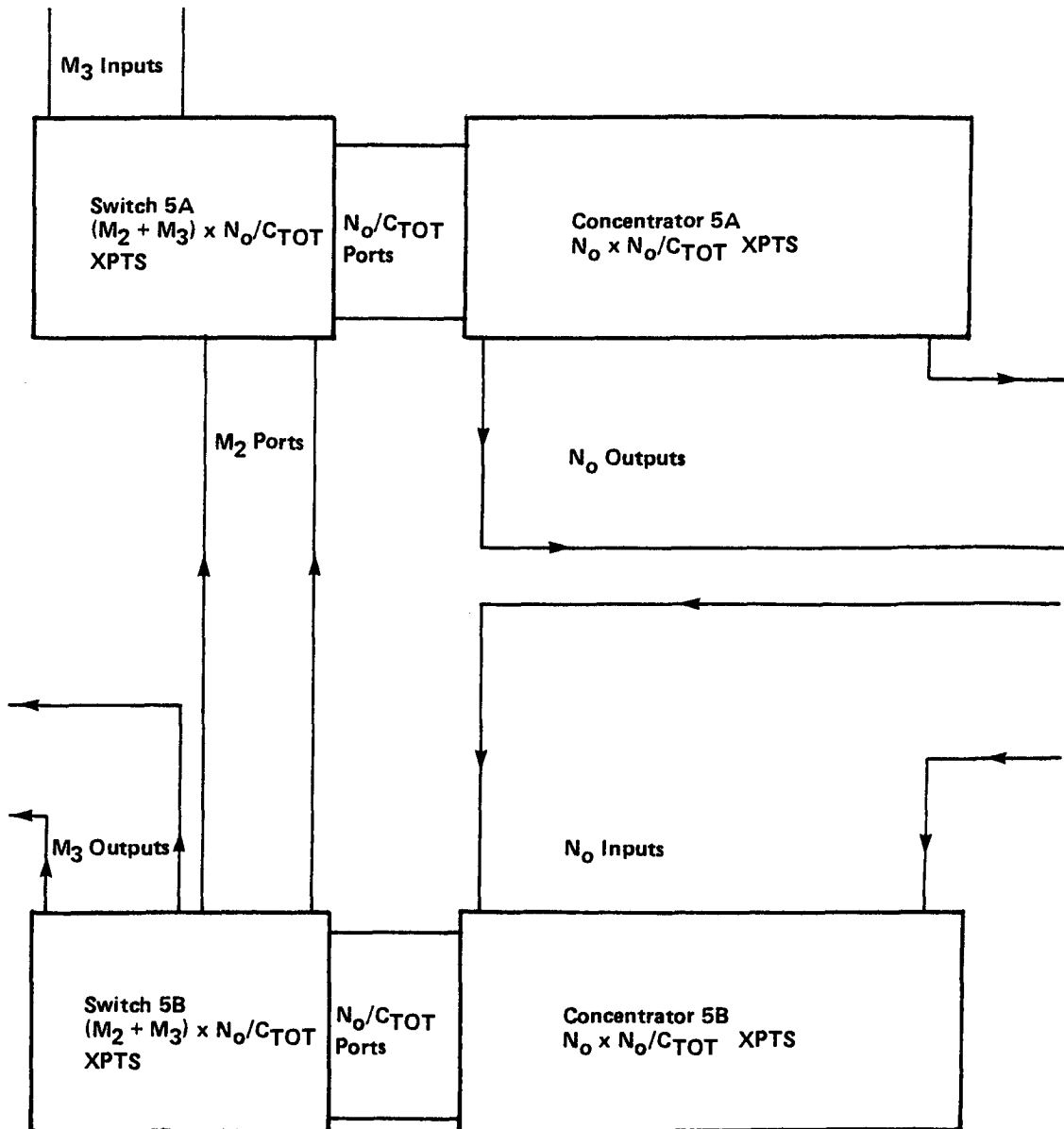


Figure 5.7: Concentration in a Private Access Video Switch

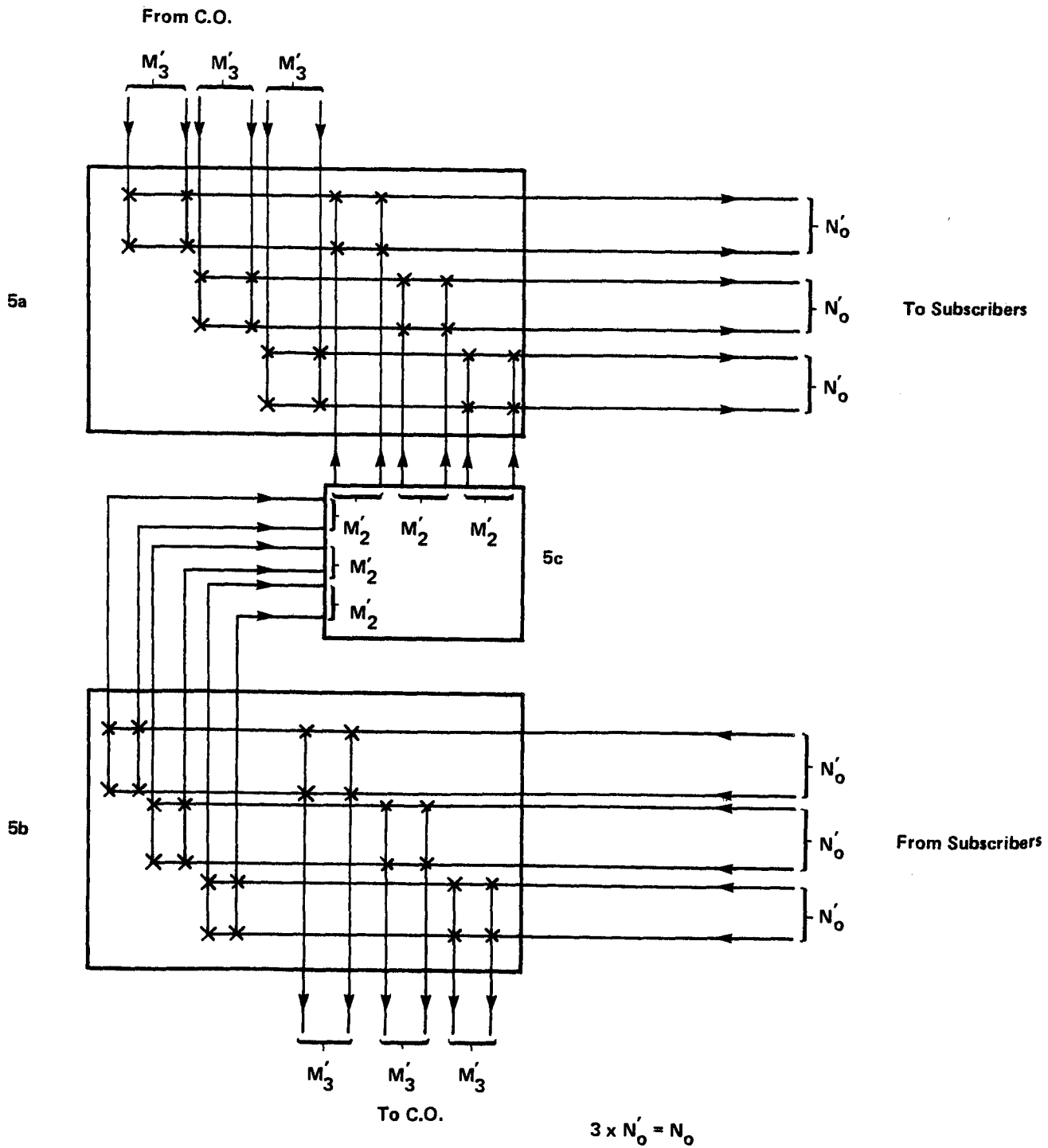


Figure 5.8: Subdivision of Subscribers to Save Remote Video Switch Crosspoints

$$2. \text{ No } x (3.M3' + 3.M2') + (3.M2' \times 3.M2')$$

crosspoints. It should be noted that, due to the nature of concentration curves, $3.M3'$ and $3.M2'$ are always greater than $M3$ and $M2$ calculated for an undivided group of N_0 subscribers.

This switch design is far from an optimised design, which would require a specialised study in itself. It serves, rather, to illustrate some of the principles which can be used to save crosspoints, albeit in this case at the expense of an increased number of local trunk channels.

Finally, for shorthand purposes, switch 5 will be referred to in the text as the videophone switch.

5.3.1.4 Influence of Signal Frequency on the Video Switch

The major performance parameter of a video switch which is affected by signal frequency is its isolation, or the extent to which it prevents crosstalk. Because the question of transmission frequency affects most aspects of the network an extended discussion of this point forms Appendix A of this report. The results of this discussion, as they relate to video switching, may be summarised as follows:

Video switches handling video signals on nominally the same carrier frequency need 57 dB isolation at the carrier frequency. Where the carrier frequencies are suitably controlled, as defined in the Appendix, the isolation requirement can be relaxed to 45 dB. Baseband colour signals need 44 dB isolation at 3.58 MHz. These figures need experimental verification, supported by appropriate regulatory approval, before they may be used in commercial systems.

These objectives, together with the decrease in isolation of 6 dB per octave increase in signal frequency, leads to the following improvements in switch isolation required at RF over the isolation required at baseband. For controlled carrier frequencies a switch operating at T7 needs 8.4 dB more isolation than one operating at baseband. Operation at T8 carries a 12 dB penalty, and T9 carries a 15 dB penalty with respect to baseband, again assuming controlled carriers in the sense of Appendix A. With uncorrelated carriers the switch improvements needed over baseband for T7, T8 and T9 are 18, 26 and 30 dB respectively. Use of non-standard frequencies, such as a 1 to 7 MHz band would need a switch 8 dB better than baseband (uncorrelated carriers) or 3.2 dB (controlled carriers).

The price penalty associated with these requirements is hard to quantify. A slight increase in isolation requirements might be accommodated by careful adjustment of a cheap technology. A great increase would mean abandoning comparatively cheap crosspoints, like cross-bar, and going to reed relays. This area is one needing much study which lies outside the scope of this report.

In the judgment of the author, baseband transmission is the most attractive approach, and is recommended. This conclusion, as detailed in Appendix A, is strongly influenced by the requirements of subscriber originated video (videophone).

5.3.2 The Telephony Switch

Until recently, telephone systems always used copper pairs carrying voice frequency signals to connect each subscriber directly to the C.O., frequently using very long lines. Due to the increasing cost of copper pairs and the decreasing cost of electronics, modern systems advocate the use of a network analogous to that of figure 5.3, especially in rural areas (Ref. 5.2). Such systems, called subscriber loop carrier systems, connect subscribers directly to a remote unit, using copper pairs operating at voice frequency. The remote unit digitizes the subscribers' analogue signals, multiplexes them and transmits them in digitally multiplexed form to the C.O., transmitting typically 24 one-way signals per copper pair. In many cases the remote unit also concentrates the traffic, by using a number of channels between the remote switch and C.O. which is less than the number of subscribers served by the remote switch. Remote units are referred to as loop concentrator multiplexers (LCMs), or remote loop multiplexers (RLMs). Various units performing these functions are commercially available, or under development. These units differ in the number of subscribers they serve, their concentration capability, and whether they are designed to work with an analogue or digital switch at the C.O.

The first decision which has to be made in selecting a telephony switch is whether concentration should be done at the remote switch or at the C.O. The argument for concentration at the remote switch runs as follows. In any system, the telephony signals will eventually undergo concentration. By moving the concentrator into the remote unit one is adding comparatively little to the total electronic requirements of the system (particularly when the C.O. switch is a digital switch). Since the number of channels between the C.O. has been reduced (typically by a factor of six) the transmission costs have been reduced - a considerable saving in rural areas.

The argument against concentration at remote switches is essentially one of flexibility. The concentration ratio at a remote switch is calculated on the assumption of certain traffic statistics for the local population. These statistics describe the number of subscribers making a call in a certain period, and the average duration of their call. Should some new service become popular among the local group of subscribers, the change in traffic could easily overload the local concentrator, and cause a loss in grade-of-service. Rectifying this would need more local trunk capacity to be installed together with more LCM units. If concentration is performed at the C.O., the much larger number of subscribers handled in total allows local traffic

fluctuations to be averaged out without affecting the grade-of-service. Should an overall trend towards increased traffic occur, then the increase can be accommodated by expanding the C.O. switch without affecting the outside plant.

In copper paired systems, extensive economic studies have shown that the use of concentrators at remote units is economically attractive, and concentration is a feature of both remote units available from or under development by Northern Telecom (the DMS-1 and DMS-100 remote unit). General consensus within BNR is that the savings from performing concentration at the remote unit outweigh the disadvantages mentioned above. In this report the limitation of the concentrator will be respected by directing data calls, with their long holding times, through a separate switch.

It has been assumed that the subscriber drops will carry telephony in an analogue mode. This is considered to be attractive since it is presently easier to digitize a collection of analogue signals at the remote unit and multiplex the resulting bit streams than it is to synchronise a group of 64 kbits/s signals originated from digital telephones in the subscribers premises. Fast evolving digital technology could well invalidate this, but the impact of this decision on the overall network is small.

Finally, as in the private access video switch of an earlier section in this report, some remote units allow local calls to be switched within the remote unit without transmitting them to the C.O. The additional cost for this feature is small, and can significantly increase the traffic handling capacity of the remote unit.

A further problem which the telephony switch must deal with is signalling and supervision. Currently detection of the off-hook condition at the subscriber's premises is achieved by an increased current flow in his copper pair tripping a relay. It is, in fact, this requirement which limits the length of copper pairs permitted in rural areas. New techniques of "in band" signaling and supervision under investigation at BNR and other laboratories could be adapted to the fibre case. The point is, however, that some kind of special interface unit at LCM must be designed in conjunction with the design of the subscriber's set when fibre is the transmission medium for telephony.

In conclusion, then, the telephony switch will be assumed to be a loop concentrator multiplexer, accepting voice frequency signals from subscribers and transmitting them in digital format to the C.O. A switching capability for the local traffic should be provided. Transmission along the local trunks will usually be at DS-1 rate (1.544 Mbits/s, or 24 voice signals). With larger remote units located more than 5 km from a C.O. it may be cheaper to use DS-2 rate (6.312 Mbits/s, or 96 voice signals) over the local trunk, as indicated by preliminary studies performed elsewhere within BNR.

5.3.3 The Data Switch

The nature of data traffic is somewhat different from both video and telephony, and needs some discussion before a data switch can be specified. Both video and telephony are accommodated fairly efficiently by circuit switching. In circuit switching a transmission path is established between two subscribers, or between a subscriber and a head-end. This path is occupied exclusively by the subscriber for the duration of his call. Although a subscriber may not use his line all the time during his telephone call, the time wasted when he takes a breath or pauses to think is not sufficiently great to make this approach unacceptably inefficient, except in cases such as transatlantic telephony where the line cost is very high. With data traffic, especially that between a human operated terminal and a computer, signals flow in short bursts with long waiting times between. In order to avoid the great inefficiency associated with circuit switching of such traffic, modern data networks use packet switching. In a packet switched network data from one subscriber are buffered and made into self-contained packages which include the address of the destination and origin. These packages are then routed by a circuit switched network to a terminal which extracts the packages and transmits them to their destination by circuit switching. The terminals performing these buffering, packaging and unpackaging functions are frequently mini-computers.

With this discussion of data traffic one can now discuss the various ways in which data may be handled by the remote switch.

The first, and simplest approach is to treat low speed data like another telephone line, and assign a port in the telephony switch to each data line. Transmission through a switch like DMS-1 can easily be achieved for all data signals up to 2400 bits/s which currently use voice frequency pairs (Ref. 5.3). Although information on transmission at higher bit rates is scarce, both the previous article (Ref. 5.3) and private information (Ref. 5.4) indicate that voice frequency analogue modems operating above 2400 bits/s may encounter high error rates when used over digital channels.

Despite the fact that low bit rate voice-band data can pass through a digital LCM, it has already been mentioned that this use of the telephony switch should be discouraged unless the number of data users is very small. The following calculations give weight to this argument. Telephone conversations are usually considered as lasting three minutes on average. Data users may well have holding times of an hour or more. Thus, one data user would displace twenty telephony users. Viewed another way, one LCM under design at the moment services 480 subscribers at up to 3.1 ccs traffic per subscriber, representing 1.72 call attempts of 180 seconds holding time per subscriber per busy hour. Should ten subscribers try to access this system for data use during the busy hour,

assuming a one hour holding time, then the telephony call attempts allowed per subscriber in the busy hour drops to 1.31 - a drop of 24%. Increasing the number of data users to 20 during the busy hour reduces the call attempt telephony capacity to 0.89 - a reduction of nearly 50% in telephony capacity. Other machines will give different numbers, but the message is clear - any significant penetration of data modems severely affects the LCM's capacity.

When data forms a significant portion of the local traffic, then, it should not be routed through the LCM. A separate transmission facility should transmit data from the LCM to the C.O., and on to the nearest C.O. housing a packet switching node. This facility will be engineered to give concentration appropriate to the data traffic - here no concentration between remote switch and C.O. will be assumed. For compatibility with existing technology and terminals the data switch should resemble a LCM with no concentration. Thus, data originated by analogue VF modems operating up to 2.4 kbits/s will be sampled and converted to 64 kbits/s for multiplexing up to 1.544 Mbits/s. Digital data originated by the subscriber at 56 kbits/s can be buffered and stuffed to 64 kbits/s for insertion into a 1.544 Mbits/s bit stream. This is best achieved by having a two-stage multiplexer, one stage accepting synchronous 64 kbits/s input for multiplexing to 1.544 Mbits/s, and a second which digitizes VF input to 64 kbits/s and buffers the 56 kbits/s input from the subscriber to 64 kbits/s synchronous input to the first multiplexer. Intermediate rates - specifically 4.8 and 9.6 kbits/s analogue modems - cannot be accommodated. These rates are, however, compromise rates - faster than needed for manually operated terminals but slower than required for machine to machine communication. It is believed that with 56 kbits/s transmission available at the same price, the demand for such transmission rates will disappear. Data rates above 56 kbits/s are not widely encountered today, but it is hard to say to what extent this is due to lack of high bit-rate transmission facilities. Such transmission is perfectly feasible by fibre, but the problems associated with switching, especially in a digital switch, are non-trivial. Such high bit rate transmission will be ignored in this report.

Although the data unit is now a multiplexer rather than a switch, the term "data switch" will be maintained for consistency.

5.3.4 The Control Unit

Although all three switches - video, telephone and data - need control units to direct the switching operations, it is usual for the control signals in the latter two cases to be transmitted along with the signals to be switched, and to be decoded by units incorporated into the appropriate switches. In other words, due to the mature state of development of telephony switches and data switches, the control unit function may be regarded as being incorporated in the switch. The

control unit for the video switch is similar in function to that of the other switches, but somewhat simpler. It is simpler since all signals reaching it are control signals, and it does not have to separate control and message signals. It may also be simpler in a system where CATV type services dominate, due to the simpler nature of the switching.

Fig. 5.9 shows the functions required of the control unit, which include dialogue with the C.O. and recording for accounting purposes, as well as switching. Some of the functions on Fig. 5.9, such as broadcasting, are included as options. All these functions should be within the capability of a microprocessor.

5.3.5 The Subscriber's Multiplexer and Electro Optic Interface

Fig. 5.10 shows this unit as two "black boxes". The left hand box accepts electrical signals from the remote switch and outputs them in optical form for transmission to the subscriber. At the same time it accepts optical signals from the subscriber and outputs them in electrical form for use by the remote unit. As a consequence of the service requirements already identified, it must have up to 8 electrical input ports and 6 electrical output ports. The electrical input ports are for 3 video signals, 1 broadcast sound band, 2 telephony channels and 2 data channels, while the electrical output ports are for 1 video, 2 data, 1 video control and 2 telephony channels. It will be extremely rare for any one unit to need all these ports, but they must be available, possibly on a plug-in basis.

The second "black box" is a bidirectional unit allowing the output optical signals from the first unit and the input optical signals to it to be transmitted over the same fibre.

The composition of the first unit will now be discussed for the two possible forms of multiplexing: frequency division (FDM) and wavelength division (WDM). Time division multiplexing has been omitted since the present network includes analogue signals. Space division multiplexing has been excluded due to the cost of fibre.

By treating the mux/demux units in this way, the "component count" of later sections can simply list the number of such units required, and the reader may refer to this section for a more detailed component count, on which he may base his cost estimates.

5.3.5.1 The FDM Case

It is apparent that the complexity of the mux/demux unit in the FDM case can be traded off against switch complexity. Thus, as shown in fig. 5.5, the video switch can be organised in two ways. It can switch all channels at the same frequency and leave channel conversion to the

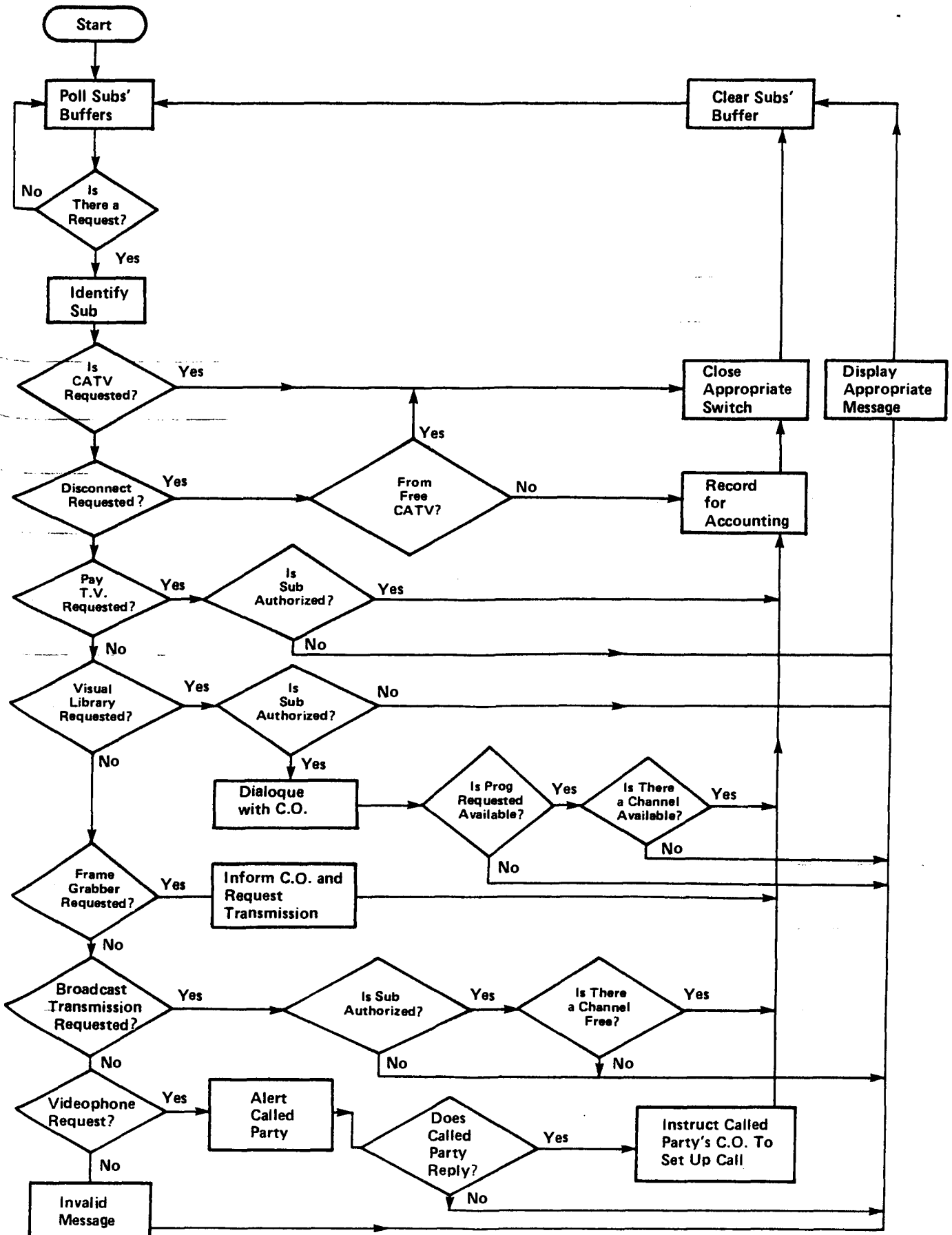


Figure 5.9 Video Switch Control Unit Functions

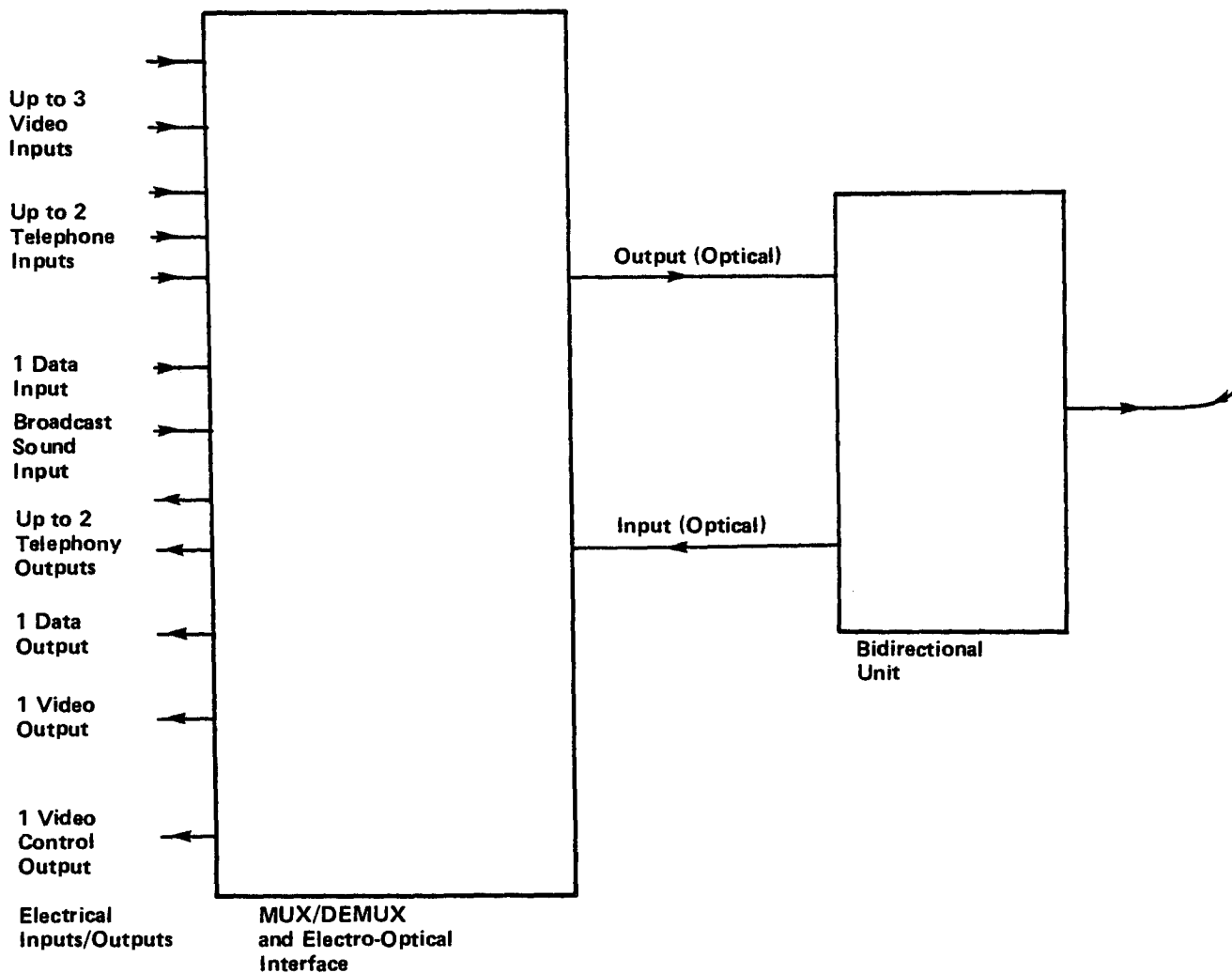


Figure 5.10: The Subscribers Multiplexer and Electro-Optic Interface at the Remote Switch

mux/demux unit. An alternative is to use the boxes marked "processor" in fig. 5.5 to perform the necessary channel conversion, with the mux/demux unit composed simply of a mixer. Unfortunately, the discussion in Appendix A shows that the latter approach, requiring switching up to channel T8, will probably make the switch unacceptably expensive. For this reason this approach will not be considered further here.

Appendix A recommends that the FDM unit be used in conjunction with a baseband switch. A possible frequency allocation when a baseband video switch is used is the following:

0	-	4.75 MHz	Video 1 (including sound)
4.85	-	5.00 MHz	Telephony 1
5.1	-	5.25 MHz	Telephony 2
5.35	-	5.36 MHz	Low bit rate data
5.45	-	5.6 MHz	High bit rate data
5.65	-	MHz	Upstream Video Control Channel
5.75	-	11.75 MHz	Video 2 (T7)
12	-	16 MHz	Broadcast sound
17.75	-	23.75 MHz	Video 3 (T9)

In this frequency allocation video channel T8 has been avoided because of possible second order beats from the T7 channel causing interference. The whole question of possible beats would need careful computer analysis before the above frequency allocation could be regarded as final.

Although the use of baseband switching is recommended, the grounds for that recommendation are open to challenge. When baseband video is not used, it makes sense to save money on the most common service - telephony, by transmitting it at baseband. This saving, it should be noted, is not in itself a strong case for always avoiding baseband video, since the cost of video modulators will be much higher than that of telephony modulators. A typical frequency allocation in this case might be:

0	-	64 kHz	Telephony 1
100	-	230 kHz	Telephony 2
250	-	260 kHz	Low bit rate data
300	-	330 kHz	High bit rate data
500	-	kHz	Upstream video control channel
1	-	7 MHz	Video 1 (non-standard)
11.75	-	17.75 MHz	Video 2 (T8)
17.75	-	23.75 MHz	Video 3 (T9)
24	-	26 MHz	Broadcast sound

Note that, in all cases, enough bandwidth has been allocated to telephony to accommodate 64 kbits/s digital telephony both at baseband and on carrier, assuming rather wasteful but cheap DSB AM in the latter case. A similar allocation has been made for high bit rate data, while low bit rate data is assumed to originate from VF modems, and hence need only 4 kHz (baseband). It is necessary to stress that these frequencies illustrate general bandwidth allocations. Selection of actual frequencies could only be made after a careful examination of relative signal levels needed, and of the levels of resulting intermodulation products.

Fig. 5.11 shows the block diagram of the FDM mux/demux unit for the case where the remote switch operates at RF, while fig. 5.12 shows the diagram when the switch is at baseband. As already mentioned, few subscribers will need all the multiplex and demultiplex options, so the unit should be of modular construction, allowing the desired units to be plugged in as required.

All the components in this FDM multiplexer and electro-optic interface are state of the art. Development would be needed, though, to reduce the cost of items such as modulators and demodulators to an acceptable level. Other items of circuitry (light source drivers and detector amplifiers) would also profit from integration, either medium scale or large scale.

5.3.5.2 The WDM Case

Following the discussion in Appendix A, in the WDM case the use of baseband switching is clear-cut, and unlikely to be questioned. The resulting block diagram for the mux/demux unit is illustrated very simply by fig. 5.13.

Unlike the components of the FDM mux/demux units, the WDM system uses components which have not yet been developed. Firstly, a range of light sources of different, accurately controlled, wavelengths must be manufactured. Further these sources must be stable in wavelength with time and temperature. Secondly, the WDM combiner and splitter must be manufactured. The use of blazed diffraction gratings for these purposes is the subject of a BNR patent application and is the basis of the analysis in activity report 5. Prisms are favoured by Japanese workers (refs. 5.5, 5.6, 5.7). The combiner could be more economically effected using the efficient power combiner developed by CRC (Ref. 5.8).

5.3.5.3 The Bidirectional Unit

Both the WDM and FDM mux/demux and electro-optic interface units require one optical output port and one optical input port. Although these could each be associated with one fibre direct to the subscriber's home, savings can be achieved by using one fibre operating in a

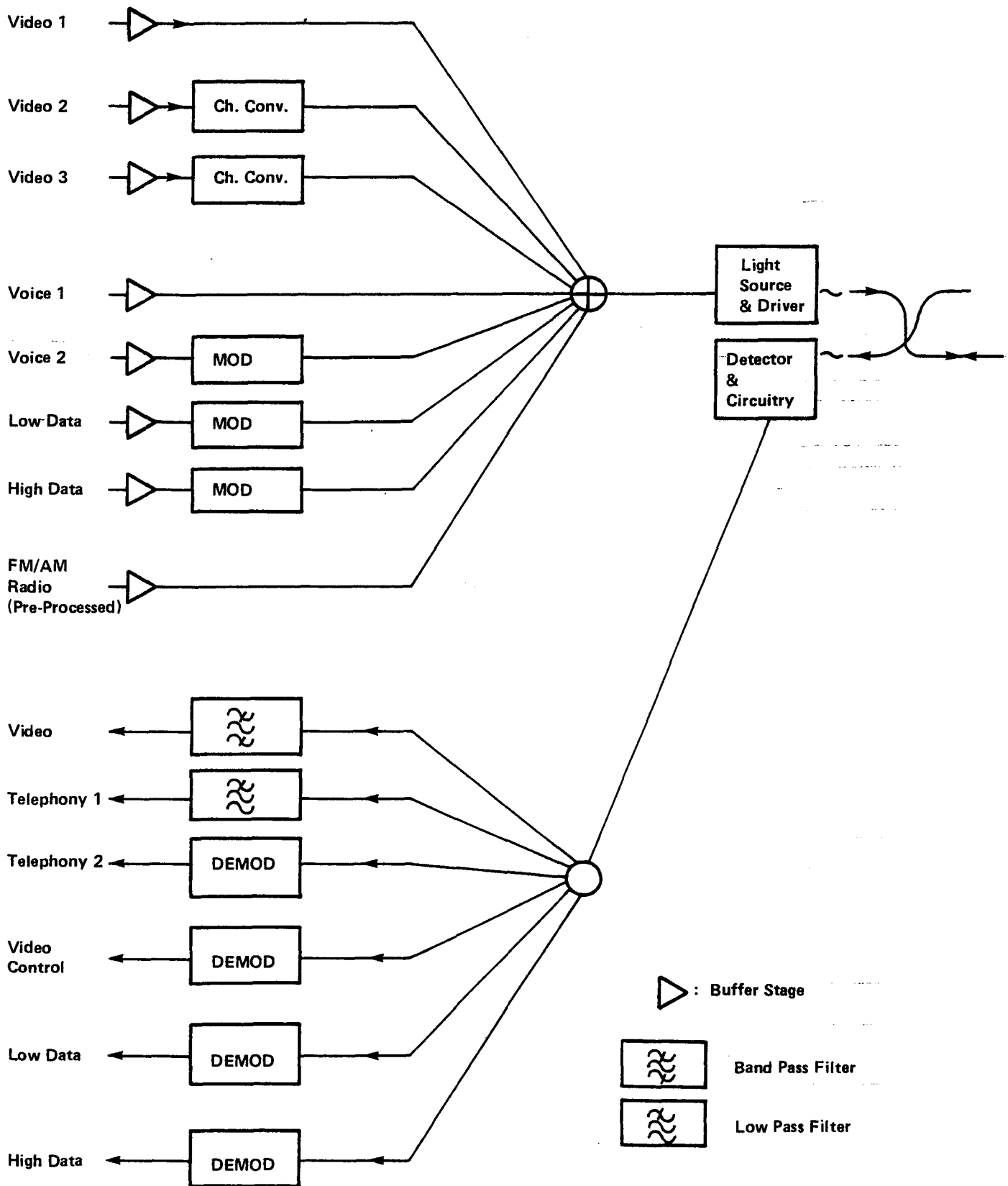


Figure 5.11: FDM MUX/DEMUX Unit When the Remote Switch Operates at RF

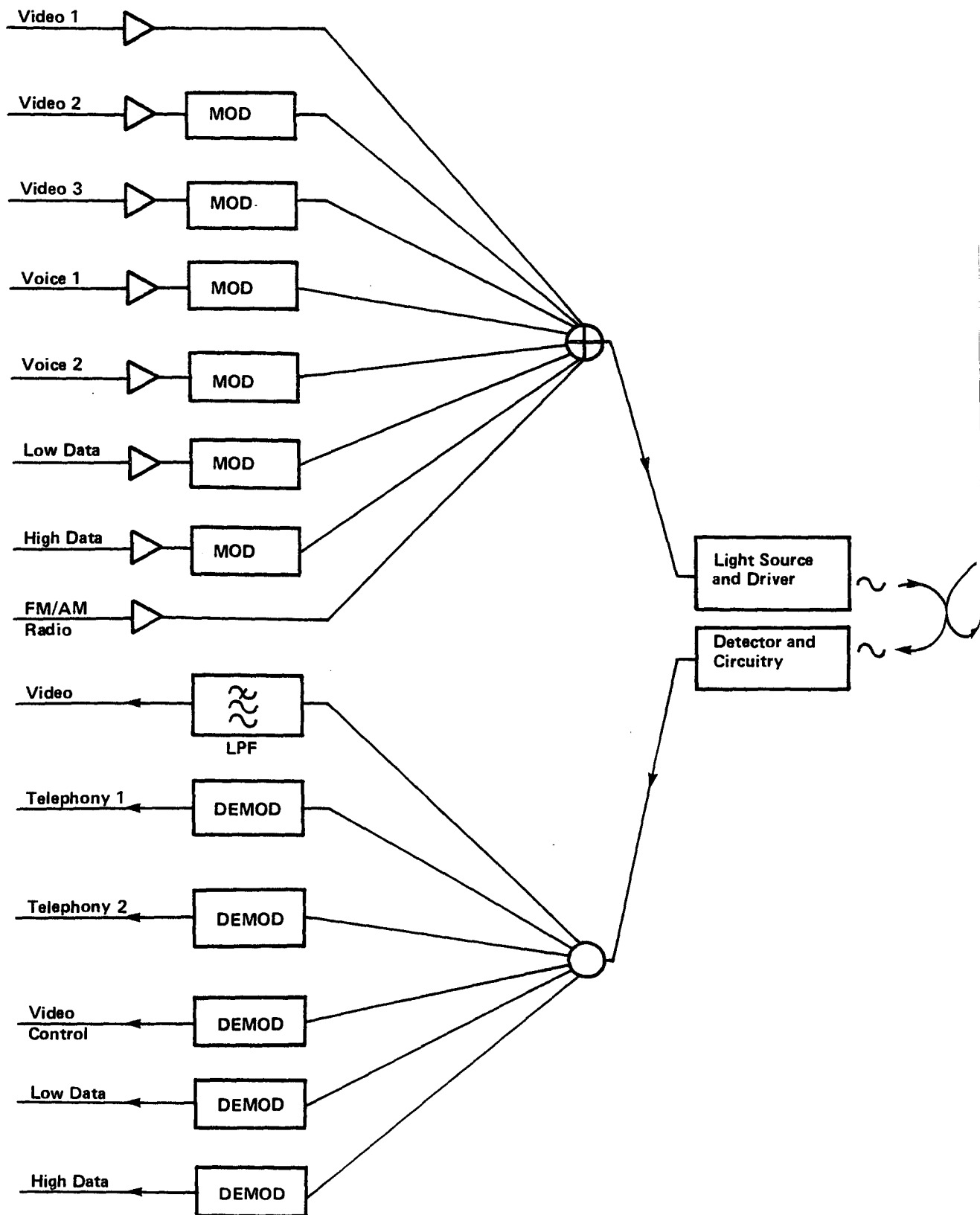


Figure 5.12: FDM MUX/DEMUX Unit When the Remote Switch Operates at Baseband

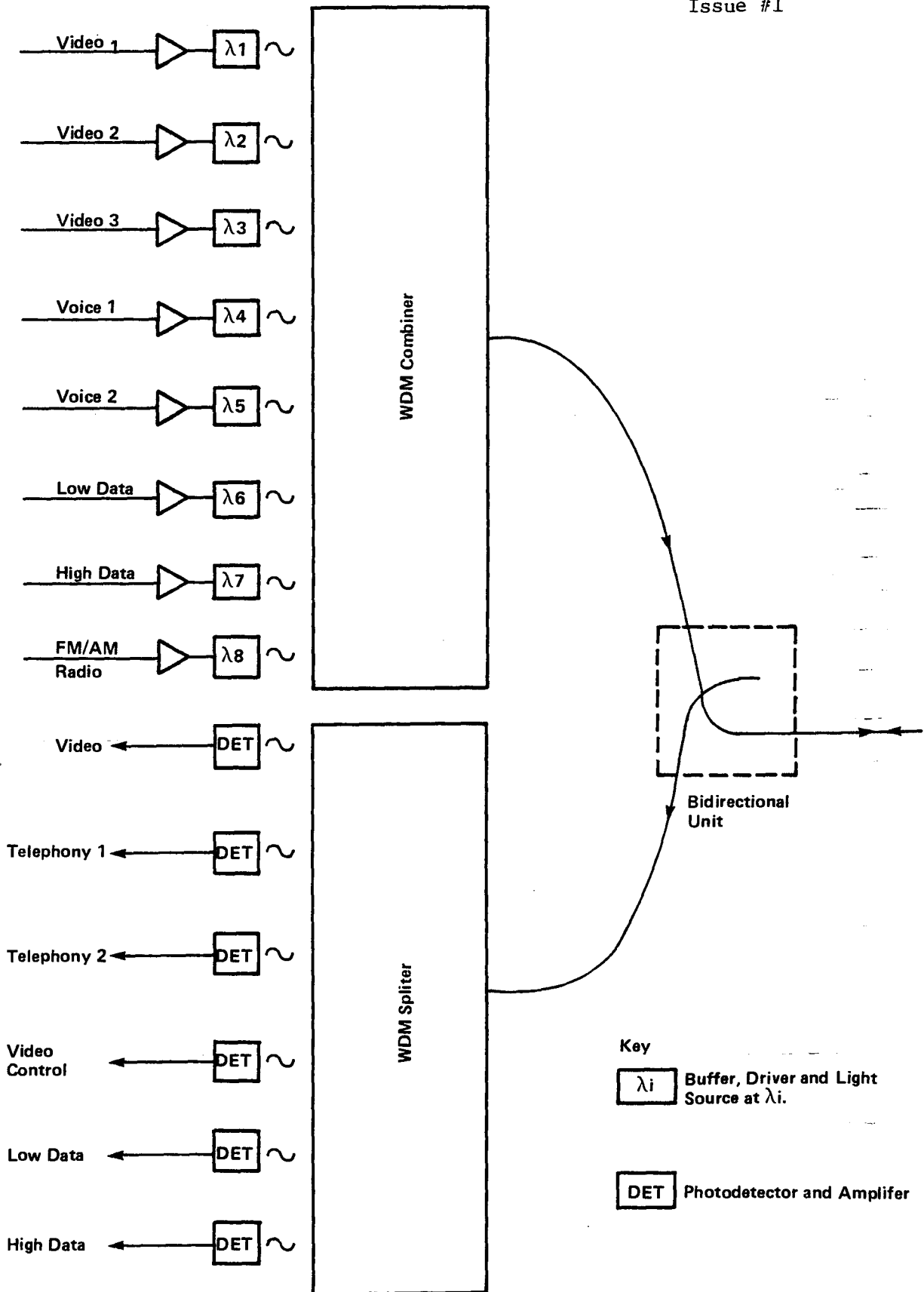


Figure 5.13: WDM MUX/DEMUX Unit

bidirectional mode to serve both ports, as illustrated in figs. 5.10 to 5.13. The use of optical couplers for this purpose was suggested in activity report 4. CRC have now demonstrated a working system in the laboratory using this principle and their highly directional optical couplers (ref. 5.9). In order to make crosstalk negligible between the most sensitive signal - the video - isolation between the two directions must be about 51 dB (baseband) or 63 dB (carrier). Both these figures are electrical isolation levels, and convert to 25.5 dB and 31.5 dB optical. These isolation requirements are derived by adding 6 dB to the switch isolation requirements, which is considered to be an adequate margin. To these figures one must add the optical attenuation due to fibre and connectors etc. between the bidirectional unit at the remote switch and that at the subscriber's terminal, plus an allowance for the tolerance permitted on transmit signal levels. Conversely, a unit having an isolation of x dB between its two directions can only be used with a fibre introducing less than y dB optical loss between subscriber and remote switch, where:

$$x = y + 25.5 + 2A \quad (\text{baseband only})$$

$$x = y + 31.5 + 2A \quad (\text{RF})$$

where A is the tolerance permitted on transmitted signal levels - in optical dB.

5.3.5.4 Component Count

Detailed component counts of this critical item in the network form Appendix C of this report.

5.3.6 The Local Trunk Multiplexer and Electro-optic Terminals

This unit is the last component of the remote switch to be discussed in this report. (The construction of the remote switch building and power supply will not be discussed here - although the latter will be dealt with in activity report 8.) Since this unit is shared by many subscribers it will be engineered for high reliability and quality, and economy will be a secondary consideration. This contrasts with the subscriber drop multiplexer, where economy is the prime consideration, and quality will be the minimum to just meet the transmission objectives.

The block diagram for this unit is simply a box with optical inputs carrying video, data and telephony from the C.O., with detectors and filters as needed to output these signals in electrical form to the video, data and telephony switches. It will also have electrical input ports, circuitry and light sources to perform the reverse operations.

Fig. 5.14 sketches such a block diagram, on which several options remain open. Firstly, video transmission is marked as "n channels/ fibre". The value of n is a function of the distance between the C.O. and the remote switch, as calculated in activity report 5. Multiplexing in this section will probably be FDM, since WDM alone loses its attractiveness when repeated transmission is encountered. This is so because the major costs associated with FDM are those of the multiplex and demultiplex equipment at each end of the link. With WDM these costs are low but, unlike FDM, a WDM mux/demux unit with all its associated light sources and detectors must be provided at each repeater.

Telephony and data transmission is indicated as 24 or 96 channels per fibre, corresponding to the digital telephony hierarchical bit rates of 1.544 Mbits/s and 6.312 Mbits/s. A third option is 48 channels or 3.152 Mbits/s, a bit rate which is becoming popular on copper pairs. On the electrical side, 96 channel systems are indicated as needing a digital mux/demux unit to interface with the data and telephony switches. It is, however, possible that future LCM type telephony switches will be capable of directly accepting and transmitting 96 channel (6.312 Mbits/s) signals. In this case, transmission will almost certainly be at the higher rate. Where a digital multiplexer/ demultiplexer is needed, the higher bit rate will only be used where the distance to the C.O. is sufficiently long to make the savings in fibre achieved by multiplexing greater than the cost of the multiplexer at both ends.

5.4 THE CENTRAL OFFICE

The functions of the C.O. are:

- a) To switch telephony to and from remote switches and other C.O.'s. This is a well-understood function, and the telephony to and from the remote switches can be converted easily to standard DS-1 format, so this function needs no further discussion.
- b) To switch data to and from remote switches and other C.O.'s. Once again, this is a well-understood function involving conventional formats of data, and needs no further discussion.
- c) To switch video signals to and from remote switches and other C.O.'s. This is a new C.O. function, and will be discussed below.
- d) To provide, or connect with, the head end of a CATV system, including the provision of Pay TV and visual library services. This, too, needs discussion.

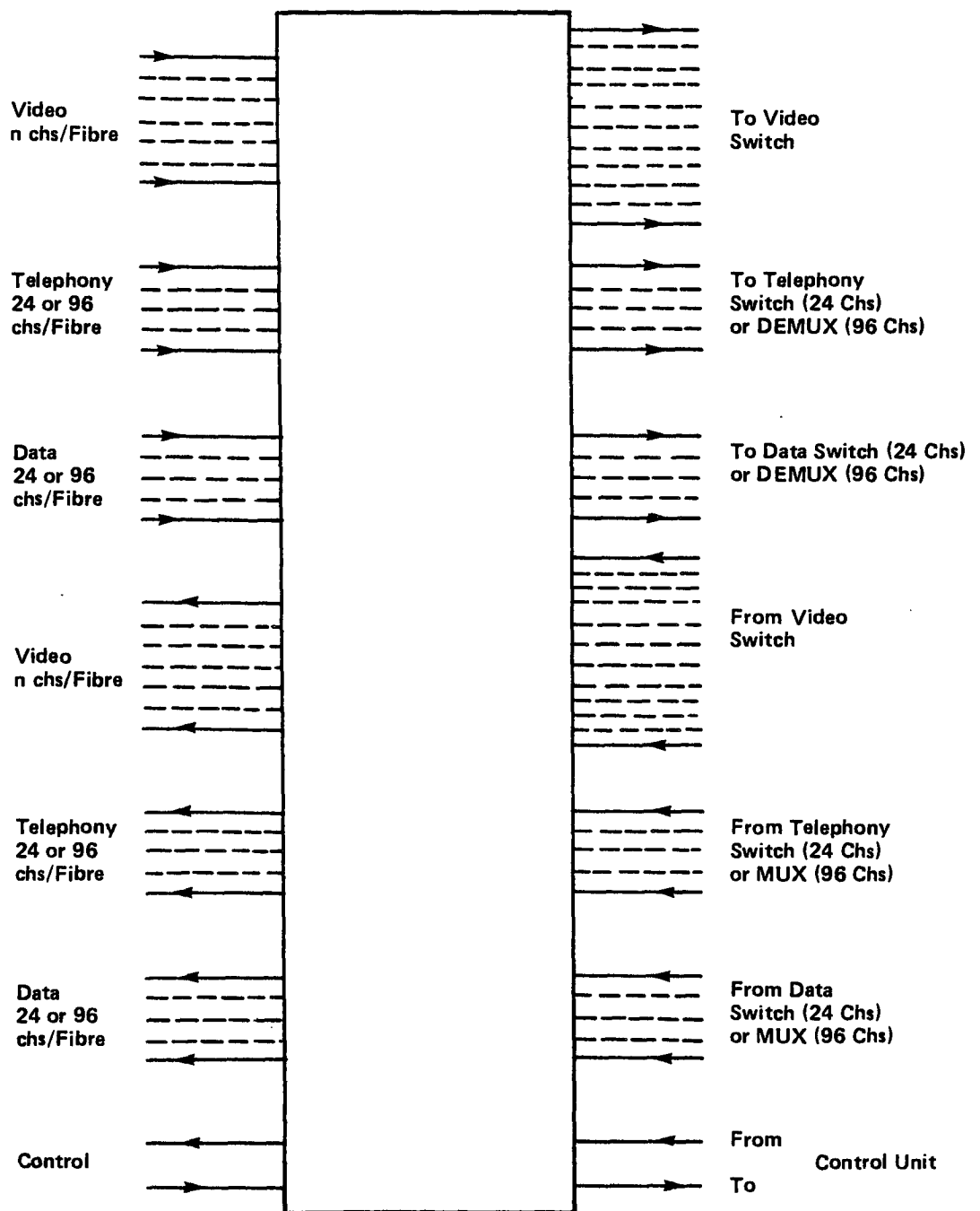


Figure 5.14: The Local Trunk Multiplexer and Electro-Optic Terminals

5.4.1 Video switching at the C.O.

If a full national grid of switched video services is to be implemented it is obvious that cascading analogue switches will lead to very stringent isolation requirements in each switch. Although this whole area needs more study than can be granted to it in the present report, it is probable that digital transmission on the inter-office network may be the solution. Ref. 5.10 points out the dangers of repeated D/A and A/D conversions, but these dangers are avoided in a system where all local trunk and subscriber drop traffic is analogue and all inter-office traffic is digital. Transmission and switching of a full NTSC colour video channel is expensive on bandwidth, although bit rate compression techniques allow considerable reductions from the 96 Mbits/s needed to encode a 6 MHz bandwidth signal at 8 bits per sample. For this reason, subscribers may settle for lower bandwidths. This subject is again too large for the present report, and the reader is referred to discussions on Picturephone Service (Ref. 5.11).

5.4.2 Origination of Video Services

The operator of the transmission system may or may not be responsible for originating the CATV, Pay TV and visual library services. It will simply be assumed that the first two are provided at high quality at the C.O., with records kept of Pay TV consumption as monitored by the remote switch control unit. Visual library services need a tape (or video-disc) library, probably manually operated, where tapes or discs are loaded in response to subscriber requests. The number of such tape decks, or their equivalent, has been severely limited in this report, compared with the figures in activity report 4, by limiting the usage rate to 1%, as discussed already. The number of units needed will not be calculated in the component count, but can be deduced from the number of channels allocated to visual library (asymmetric video) between the C.O. and R.S.

5.4.3 Comparison with C.O. in Activity Report 4

In general the block diagram for a C.O. in the present case will be simpler than in activity report 4 and is sketched in fig. 5.15. This is so because many of the asymmetric services which were manually patched in the previous report now pass through the symmetric switch. Visual library services are also much smaller, and will have dedicated non-switchable channels. The only area where manual patching can occur is when a subscriber wishes to originate local broadcasting. This would be a service restricted to very few subscribers, and could be accommodated by switching a subscriber to the "program input area" of fig. 5.15, where he could then be manually patched to a public access channel. Normally the input to this area will be from a head-end or Pay TV operation.

Data, telephony and symmetric video switches are shown in the block diagram. The data switch will be a packet switching machine or a

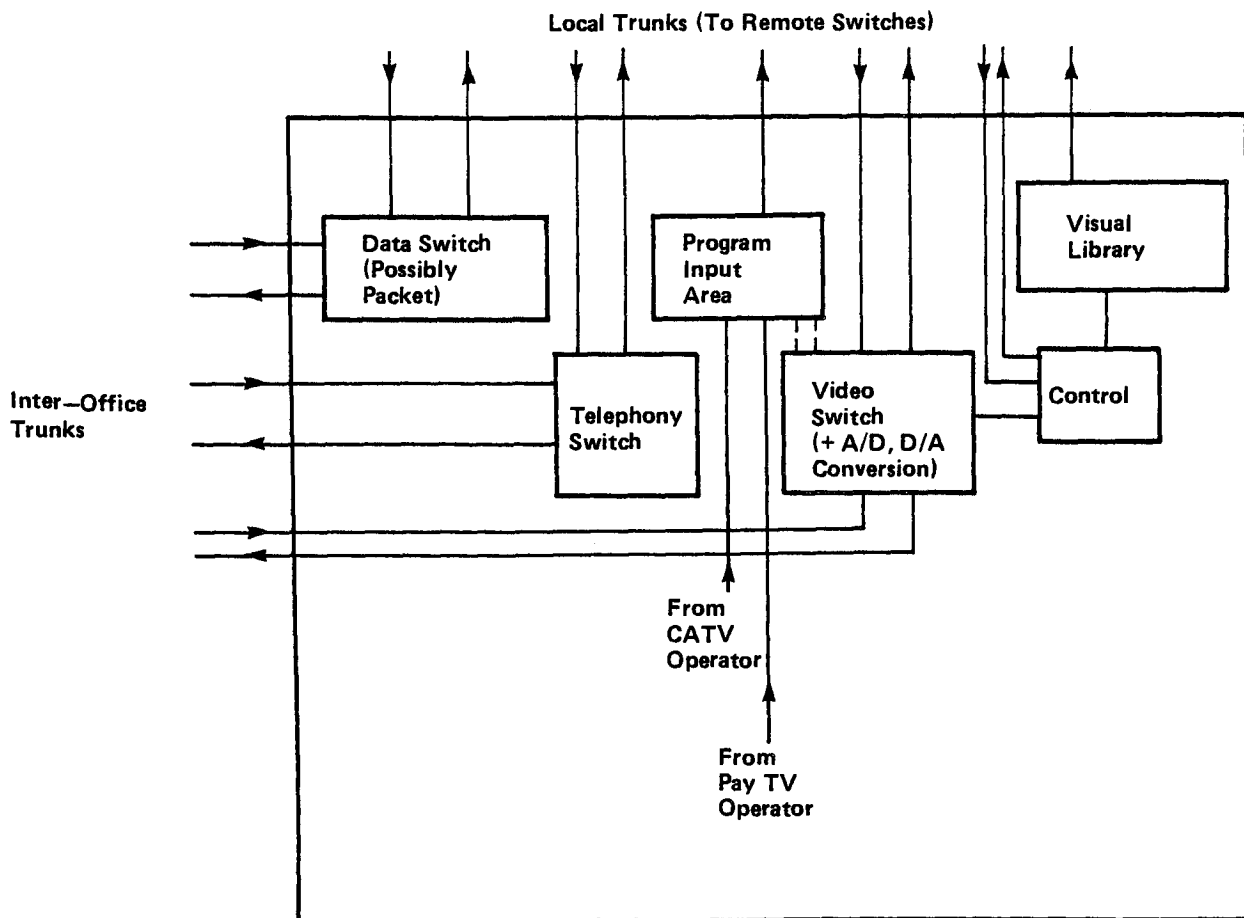


Figure 5.15 The Central Office

digital circuit switching machine routing data to a convenient packet switching centre, the choice being made by economic considerations. The telephony switch will be a conventional switch of whatever type best suits the network and its growth. The video switch has already been discussed.

5.5 THE SUBSCRIBER'S DOMESTIC TERMINAL

Each subscriber needs the following equipment:

- a) 1 TV receiver and interface per channel to be viewed.
- b) 1 telephone handset and interface per line
- c) 1 data set and interface, if data is required
- d) 1 mux/demux unit and electro-optic interface
- e) 1 signaling unit to change TV stations
- f) Emergency power supply.

The TV receivers, telephone handsets and data set will not be included in the component count for a fibre system, since they are common to copper based and fibre systems. The TV interface unit is either a channel converter or modulator. By assuming the availability of baseband inputs, modulators are not required, and channel converters are again common to both systems, and so are not included. The telephone and data set interfaces are mainly needed for signaling and supervision. For data sets they represent no great problem and may be assumed to be incorporated in the set at construction, and hence ignored. For telephony, a unit to allow a conventional 500 set to interface with the fibre system could represent a significant cost compared to the cost of the basic 500 set. Other network constraints may lead to the evolution of in-band signaling or, eventually, digital telephony, where the interface problem is simplified. For the purposes of the component counts this item will be ignored.

The remaining items, then, which must be included in any components count which will form the basis of a costing exercise are:

The mux/demux unit and electro-optic interface

The signaling unit to change TV stations.

Emergency power.

The first of these units is complementary to the unit at the remote switch. It's components are detailed in Appendix C.

The signaling unit may be a touch-tone pad or, if cheaper, a dial pulse generator, with a modulator to a suitable frequency, such as those suggested in section 5.3.5.1.

Emergency powering will be discussed in more detail in activity report 8. In the absence of a conductive path from a C.O. some form of trickle charged device is needed to ensure that failure of the electricity mains does not deprive the subscriber of telephony service. Since television receivers and data modems rely on the hydro supply in all current systems, they may be permitted to fail. The amount of protection needed by a telephone system is hard to define. Eight hours protection is one objective, but physical back-up devices are usage dependent as well as time dependent, so some usage rate during that eight hours would need to be defined. This report will evade the question by stipulating eight hours reserve for use at "normal usage rates". Regulatory bodies, or subscribers themselves, may demand some more rigorous requirements.

5.6 ALTERNATIVES TO THE SWITCHED NETWORK

As the latest results from activity report 5 indicate that high level (12 channel) multiplexing on the local trunks and subscriber drops using a linearised laser cannot be totally ruled out, this section gives a preliminary glance at the way in which low subscriber densities can be accommodated without switching. This idea may be expanded in the revised issue of this activity report. Fig. 5.16 shows the remote unit (which has hardly any switching), serving 24 subscribers. Assuming 50% of the subscribers want videophone service, the 12 videophone inputs can be at different frequencies, which can be combined into one trunk fibre. Similarly the telephone channels could be at different frequencies, and also be combined on the same fibre. The video control signal will be extracted to control the visual library switch, and to control videophone switching by commands relayed to the C.O.

It is repeated that this concept will be developed more carefully in the final version of this report, and contains obvious weaknesses in its present form.

5.7 SUMMARY

This chapter has provided some details of the major components which will make up an INFO. In some cases options are open which can only be resolved after development work has been performed. The description of the components, including options, is believed to be a good basis on which an economic analysis of the system can be made. The next chapter will apply the network of the present chapter to various model areas.

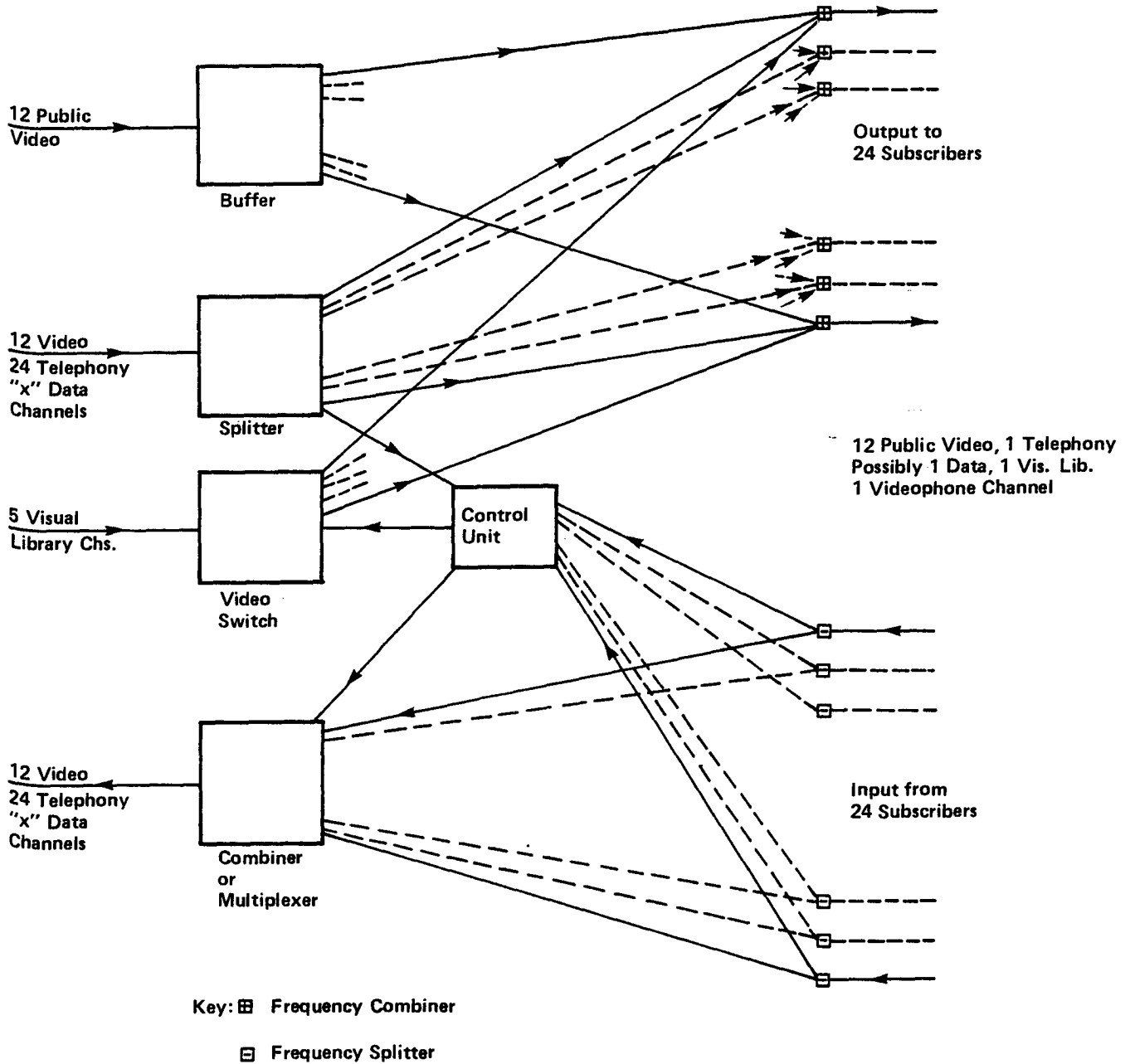


Figure 5.16: Remote Unit for Few Subs, High Multiplexing

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6. APPLICATION TO MODEL POPULATION DISTRIBUTIONS

6.1 INTRODUCTION

This chapter will apply the network model of chapter 5 to four types of population distribution, namely a rural strip type distribution and a rural, a suburban and an urban grid type distribution. The chapter will start by listing the components needed for each subscriber irrespective of the population distribution, and will then detail the extra components needed per subscriber in each model area.

6.2 COMMON EQUIPMENT NEEDED

Based on the discussion of the previous chapter, each subscriber needs the following equipment, in addition to his basic TV receiver(s), telephone, and data set, irrespective of the distribution topology:

a) At his home:

- i) Mux/demux unit and electro-optic interface,
as detailed in Appendix C
- ii) Video channel selection unit
- iii) Emergency powering

b) At the remote switch

- i) Mux/demux unit and electro-optic interface,
as detailed in Appendix C.

In addition, each group of subscribers served by a remote switch must share the cost of:

- a) A building to house the remote switch, and a power supply.
- b) The video switch, comprising a control unit and rack, shared by all subscribers, and a number of crosspoints which depends on the number of subscribers, and which will be calculated for each case.
- c) The telephony and data switches. The sizes of these units will largely be determined by what is commercially available, and will obviously depend on the number of subscribers.
- d) Local trunks, electro-optic interfaces and mux-demux units.

Finally, each group of subscribers must share some of the cost of equipment at the C.O. and beyond.

This report, however, will limit itself to discussing in detail only the components in the remote switches and domestic terminals together with the fibre needed to connect them. Care is needed, though, since a cheap remote switch can sometimes be bought at the expense of an expensive C.O.

6.3 THE POPULATION DISTRIBUTION MODELS

Four different population distribution models were used in activity reports 2 and 4, based on a survey of population densities used in various other studies. The same models will be used here. Two rural models are used - a grid distribution model, and a strip distribution model. In the former, subscribers are located on a square grid, with a separation of 320 meters between them (fig. 6.1a), while in the latter, subscribers are distributed along a road at 160 metre intervals, at a distance of 160 metres from the road (fig. 6.1b).

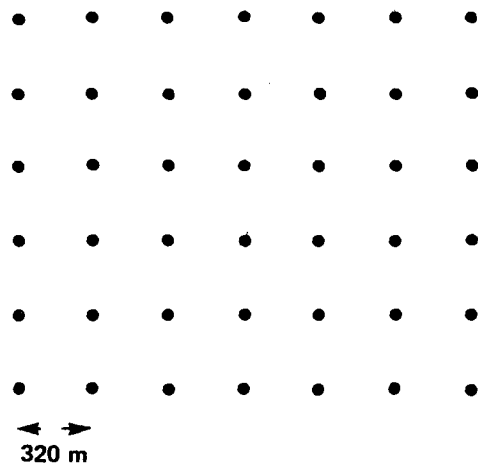
This staggered distribution of houses makes little difference at the present level of discussion, but it will affect the practical problems of breaking out drops from a cable.

The final two distribution models are for suburban and urban areas. The model is again a grid, as in fig. 6.1(a), with spacings between the suburban subscribers of 58 metres, and between the urban subscribers of 14 metres.

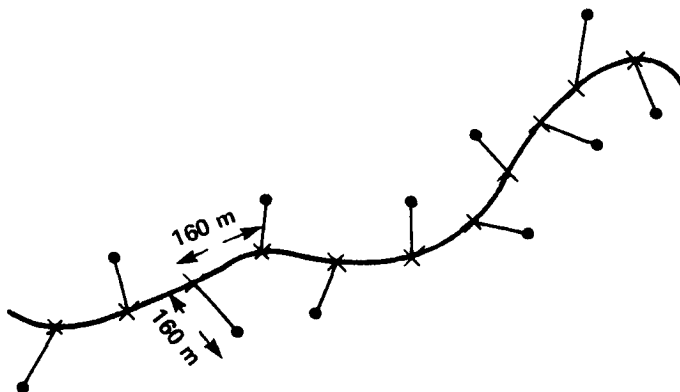
The population densities in the three grid models are approximately 10, 300 and 5000 subscribers per square kilometre in the rural, suburban and urban areas respectively.

6.4 GRID MODELS

The population in all models must be broken down into small serving areas of subscribers served from a remote switch, and into larger serving areas of remote switches served from a C.O. The maximum serving area for a remote switch is determined by the maximum fibre length over which the required multiplexed signals can be transmitted without repeaters. The most economical size depends on population density and the relative cost of switching, outside plant (cable, fibre, trenching, etc.) and terminal hardware. The necessary costs are not available for this report, so the choice of serving area is based on judgment which may later be proved false. The upper limit on the C.O. serving area is determined by the maximum length of repeatered line to feed the remote switches. Again the optimum cannot be determined here.



a) Section of Grid Distribution



b) Section of Strip Distribution

Figure 6.1: Rural Population Distribution

Fig. 6.2 shows a remote switch serving area. The diamond shape allows serving areas to combine easily to cover a large total area. If the distance from the remote switch to the nearest subscriber is "d", and from the remote switch to the furthest subscriber is "Nxd", then it can be shown that the total route length to join each subscriber to the remote switch by a rectilinear route is:

$$2.N(N+1)(2N+1) d/3 \quad (6.1)$$

By a rectilinear route is meant that fibre must be laid parallel or perpendicular to the diagonals of the diamond, a restriction imposed by roads and rights of way.

The number of subscribers in such an area is:

$$2N(N+1) \quad (6.2)$$

Fig. 6.3 shows a C.O. serving area. Each small diamond is a remote switch serving area, and the total of the solid and dotted serving areas is another diamond. This shape has the advantage that all the furthest remote switches are the same distance from the C.O., following a rectilinear route, and the total route length to join each remote switch to the C.O. by a rectilinear route is given by:

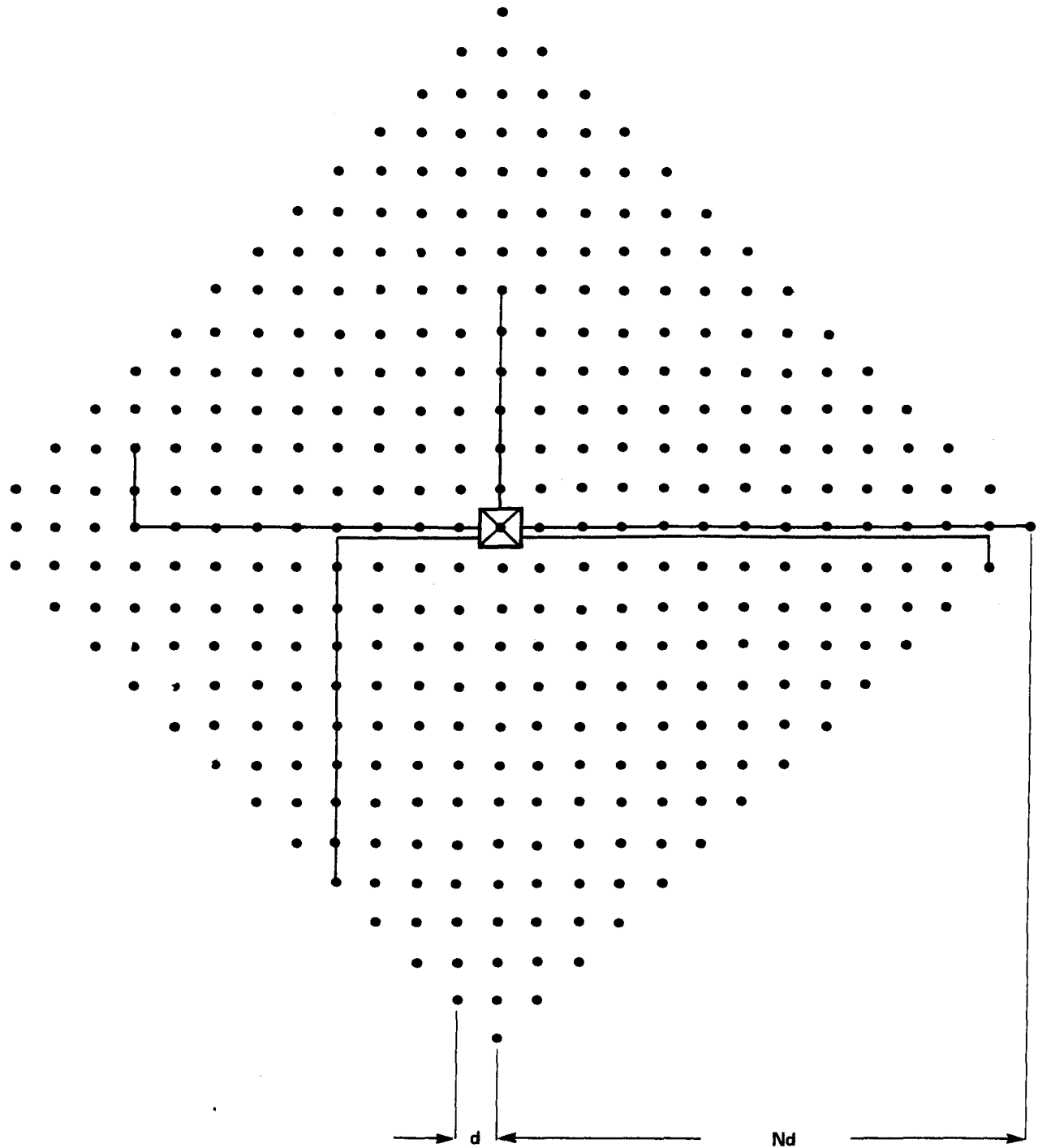
$$4. NMAX(NMAX+1)(2.NMAX+1) a/3 \quad (6.3)$$

where "a" is the distance from the C.O. to the first remote switch along a diagonal, and NMAX.a is the distance to the furthest remote switch.

Although the diamond shaped serving area is a logical one, the discussion of activity report 4 was based on an area encompassed by a circle. Fig. 6.3 shows how the R.S. serving areas marked with solid lines approximate a circular serving area. The statistics for the new area can obviously be quickly obtained by subtracting those for the R.S. serving areas marked with dotted lines from the whole diamond.

6.5 THE RURAL GRID DISTRIBUTION

The distance d in fig. 6.2 has been fixed at 320 metres by our distribution model. The maximum range, Nd, was taken as 4.16 km in activity report 4, i.e. N=13. In that report one fibre was only required to carry two video channels. In this report, three channels are needed together with telephony and data. Neglecting the telephony and data, activity report 5 shows that one baseband and two RF channels chosen to avoid problems due to harmonics can just be transmitted 4 km using LEDs, but can easily meet that range using lasers. With three RF frequencies a laser is needed. All these figures assume 5 dB/km fibre loss (including cabling loss, splice and connector loss), and LED and laser characteristics derived from the state of the art review (activity report 1).



No. of Subscribers: $2N(N + 1)$
Total Drop Length: $\frac{2}{3} N(N + 1)(2N + 1)d$

Figure 6.2: Remote Switch Serving Area

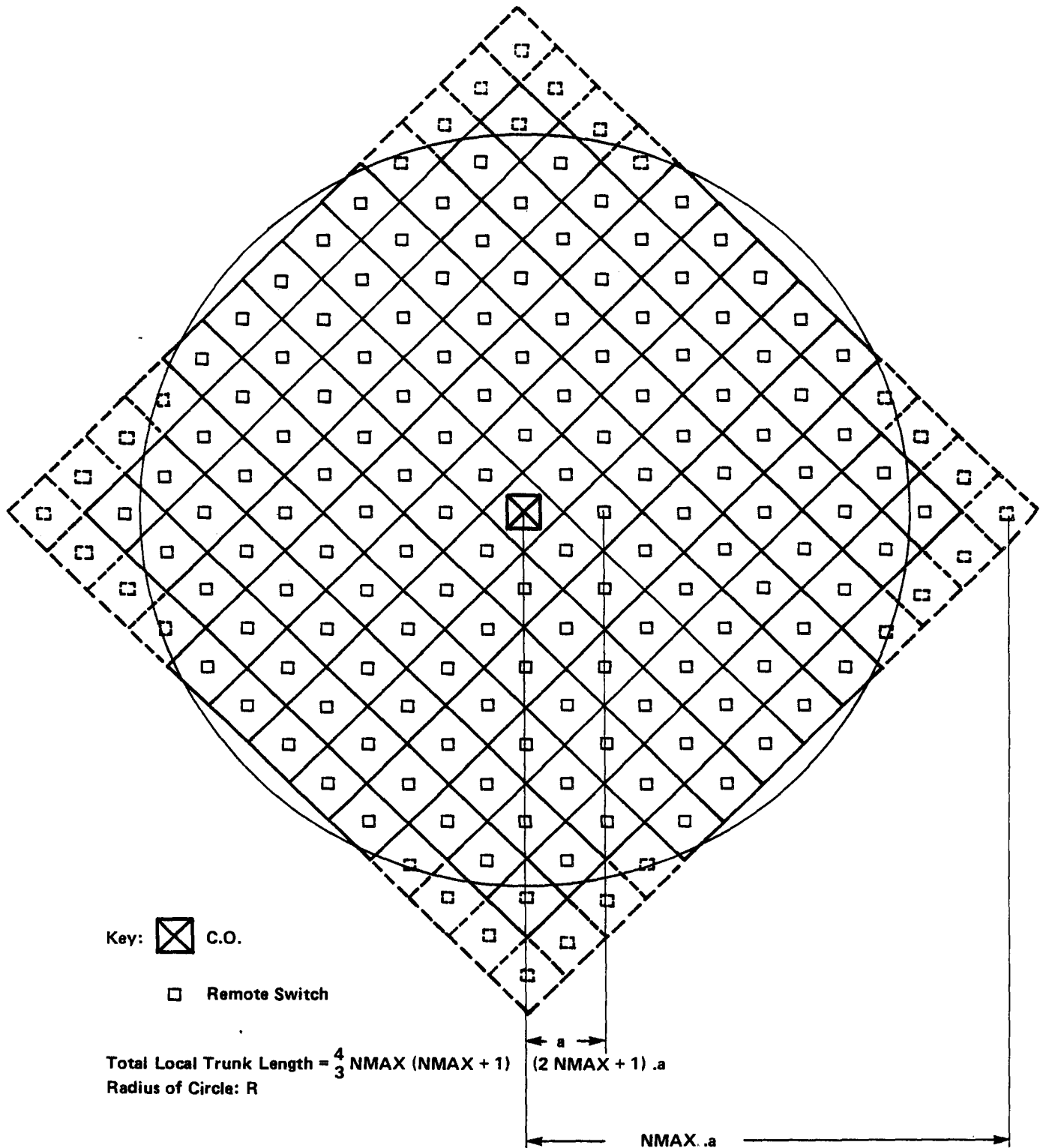


Figure 6.3: Area Served by G.O.

On this basis, and assuming improvements in light source performance will provide an improved safety margin, the 4.16 km maximum serving length from a remote switch will be maintained. The number of subscribers within this area follows from expression 6.2 above with $N=13$. It is 364. Similarly, from expression 6.1 above, the total route length to supply one fibre to each home is 1048.32 km, or 2.88 km per sub.

6.5.1 The Video Switch

The main subscriber - dependent component in the remote switch (ignoring the telephony and data switch) is the video switch. For 364 subscribers the 1% curve of fig. B.1 shows that a concentration ratio of 38.2 is needed, i.e. 10 lines must be provided for visual library type services. The number of channels needed for videophone depends on the percentage of subscribers assumed to require this service, and is obtained from the 60% and 40% curves of fig. B.2. For example, at 50% penetration, 182 subscribers want the service. Fig. B.2 shows that a concentration ratio of 4.65 is appropriate for local traffic, and 6.35 for distant traffic, or 40 and 29 channels respectively.

As discussed in section 5.3.1.3, the simple switch design for symmetrical video is far from optimum. It is beyond the scope of this report to optimise the switch design, but a subdivision of the subscribers into 3 groups, as shown in fig. 5.8, gives some saving in crosspoints, at the expense of increased trunking. The results of this subdivision will be included in the table below.

The final problem in estimating the number of switch crosspoints is how to calculate the number of crosspoints needed for common access video. This could be handled by assuming some arbitrary distribution of subscribers having second and third channels. The present report prefers to tabulate the number of switch crosspoints needed to supply one channel per subscriber only, and note that subscribers needing extra channels need to be supplied with M crosspoints for each such extra channel, where M , as before, is the number of common access channels.

Table 6.1 shows the number of video crosspoints per videophone subscriber needed for various values of M (the number of public access channels) and various percentages of symmetric video (videophone). Also shown are the total number of one-way video channels needed between the C.O. and remote switch. The term one-way video channel needs explanation. Public access video channels need only be transmitted from the C.O. to R.S., thus one CATV channel needs one one-way video channel on the local trunks. Videophone will need two-way transmission, so one videophone channel needs two one-way video channels.

The figures in table 6.1 are presented for both the case where a simple videophone switch is used and the case where a subdivision of the subscribers into three groups, as in fig. 5.8, is used.

TABLE 6-1

Total Number of Crosspoints Per Videophone Subscriber, and
Number of One-Way Trunk Video Channels
(Standard Rural Grid Distribution)

No. of Public Channels	Percentage Penetration of Videophone Service			
	5%	10%	20%	50%
5	47	61	87	153
12	54	68	94	160
21	63	77	103	169
35	77	91	117	183

a) No. of crosspoints (simple videophone switch)

No. of Public Channels	Percentage Penetration of Videophone Service			
	5%	10%	20%	50%
5	46	60	70	93
12	53	67	77	100
21	62	76	86	109
35	76	90	100	123

b) No. of crosspoints (3-way division of videophone switch)

No. of Public Channels	Percentage Penetration of Videophone Service			
	5%	10%	20%	50%
5	29	35	45	73
12	36	42	52	80
21	45	51	61	89
35	59	65	75	103

c) No. of one way channels in local trunks (simple videophone switch)

No. of Public Channels	Percentage Penetration of Videophone Service			
	5%	10%	20%	50%
5	45	57	69	93
12	52	64	76	100
21	61	73	85	109
35	75	87	99	123

d) No. of one way channels in local trunks (3-way division of videophone switch)

Inspection of fig. 5.5 shows that the following relationships hold for a simple videophone switch:

No. of crosspoints per videophone subscriber:

$$= M+M1 + 2 (M2+M3)$$

No. of one way video channels in the local switch:

$$= M+M1+2M3$$

The terms are all as defined in section 5.3.1. In the case of the subdivided switch the relevant relations are set out in section 5.3.1.3. Subscribers not requiring videophone service, of course, only need $M+M1$, crosspoints, with $M1=10$. It is also repeated that these numbers are to provide only one public channel per subscriber.

6.5.2 Other Remote Switch Components

The 364 subscribers served by a remote switch could use a 480 input RLM unit for telephony. This is one of the proposed standard RLM sizes, with either 48 or 96 telephony channels between the unit and the C.O. The extra VF inputs could be used to supply second lines to subscribers wanting them.

Data can be handled by one 24 VF channel multiplexer, with the option of substituting a 56 kbit/s input for any VF input, as required. Further modules may be added as needed.

Each local trunk needs an interface unit. The number can be calculated from the local trunk channel capacity calculated, and from the above data and telephony units.

6.5.3 Local Trunk Length

Application of the relationship 6.3 to the total C.O. serving area within approximately a 40 km radius of a C.O. (as illustrated in fig. 6.3, with $a=8.64$ km, $R=40$ km), the per subscriber trunk length to connect all R.S.'s to the C.O. is .094 km.

In view of the fairly large number of channels needed over these trunks, however, the length of fibre per subscriber in these trunks can be quite high. Thus, from table 6.1 d), assuming only 2 channels multiplexed per fibre, each subscriber needs nearly 6 km of fibre in the local trunks to meet the highest level of usage on the table. Some savings can be got by running the public channels (not visual library) from one R.S. on to the next, tapping off the channels electrically at each R.S. Even assuming this makes the fibre per subscriber negligible for public channels, however, still means that slightly over 4 km of fibre is needed per subscriber in trunking. Increasing the multiplexing

obviously decreases the amount of fibre needed and the latest results from activity report 5 hold out some hope in this direction. Decreasing the radius served by the C.O. also decreases the local trunk length per subscriber, while at the same time permitting a higher degree of multiplexing. This solution, of course, increases the cost of the C.O. per subscriber. The final solution is to decrease the bandwidth and quality of the videophone channel, and hence increase multiplexing.

Without using some method to reduce the local trunk requirements, the cost of these trunks dominates the transmission costs associated with the network, especially since local trunks, being repeatered, have a higher cost per unit length than drops.

6.6 EFFECT OF LOWER SUBSCRIBER DENSITIES

6.6.1 General Approach

The effect of changing the separation between subscribers from 320 m to three new values, namely 480, 640 and 1280 metres, is studied here. These new figures correspond to population densities of about 4.3, 2.5 and 0.6 subs/sq. km. These new separations can be fitted to the diamond shaped serving area of fig. 6.2, using $N=8$ for the 480 m spacing, $N=6$ for the 640 m spacing, and $N=3$ for the 1.28 km spacing. The maximum drop length in all three cases is 3.84 km. Table 6.2 compares the number of subscribers and average drop length with that in the 320 m separation

TABLE 6-2

Drop Lengths and Subscriber Numbers Within a 4 km Serving
Area for Low Population Densities

Spacing	Max. Length Of Drop	No. of Subs In Area	Average Length of Subs' Drops
320 m	4.16 km	364	2.88 km
480 m	3.84 km	144	2.72 km
640 m	3.84 km	84	2.77 km
1280 m	3.84 km	24	2.99 km

case. The most interesting feature of this table is the comparative insensitivity of the average drop length to the density. As will be seen later, though, the per subscriber trunk length increases substantially with decreasing density.

With the very low subscriber densities encountered here, the videophone switch design of section 5.3 is inefficient. For the lowest densities of videophone subscribers (10 or less per remote switch), virtually no concentration is possible. Thus, lines from these subscribers will simply go straight to the appropriate local trunk mux/demux and electro-optical interface units, as shown in fig. 5.16.

As the number of subscribers increases slightly the gains to be had by concentration become attractive, but the division of local and distant traffic is not efficient. For example, 20 subscribers would need 10 local channels (M_2) and 8 distant channels (M_3) or a total of 12 channels (MTOT) when no division is made. These figures come from the "60%", "40%" and "total" curves of fig. B.2, Appendix B. Thus, use of a switch which divides local and remote traffic needs 36 crosspoints per videophone subscriber, ($=2.(M_2+M_3)$), and 16, ($=2.M_3$), one way channels in the local trunks shared by 20 subscribers. Use of a simple concentrator with no division of local from remote traffic, means that 24 crosspoints ($=2.MTOT$) per videophone subscriber and 24 one way channels between 20 subscribers are needed.

In addition, the logic circuitry to control the switch which does not separate local from distant traffic is simpler than that of a switch with intra-call facilities.

The cross-over points between no switch and a simple concentrator switch, and between a simple concentrator switch and a switch with intra-call facilities depend on the relative costs of switching and transmission. Further, they depend on the average trunk route length, which depends on the subscriber density. Once costs are available these cross-over points will be simple to calculate, but here, somewhat arbitrarily, 10 videophone subscribers per switch will be taken as the break even point for a concentrator switch, and 30 as the point where a call with intra-call facilities proves attractive.

Applying these principles, tables 6.3 through 6.5 show the number of crosspoints per videophone subscriber, and the number of trunk channels needed. The tables are arranged as follows. Firstly the nominal percentage penetration of videophone is given. The actual number of subscribers, with integer round-up, follows. The type of videophone switch is next identified, using the above principles. "Conc." means a concentrator switch, while "simple" implies a switch with intra-call, but where the subscribers have not been subdivided into small groups. From the relationships in the preceding paragraph the number of crosspoints per subscriber needed in the videophone section of the switch are next tabulated together with the number of one way trunk channels for

TABLE 6-3

Crosspoints and Channels for Subscribers at 480 m Spacing

Nominal % Penetration of Videophone	5%	10%	20%	50%
Actual no. of videophone subscribers	8	15	29	72
Type of videophone switch	NONE	CONC.	CONC.	SIMPLE
No. of videophone XPTS per vid. sub.	0	18	28	70
No. of videophone one-way trunk channels	16	18	28	30
"M1" (as defined in 5.3.1: see text)	5	5	5	5
No. of common access XPTS per sub.	M	M	M	M
No. of common acc. 1-way trunk channels	M	M	M	M

No. of subscribers: 144

Length of fibre needed in R.S. serving area: 391.68 km =
2.72 km/sub.

TABLE 6-4

Crosspoints and Channels for Subscribers at 640 m Spacing

Nominal % Penetration of Videophone	5%	10%	20%	50%
Actual no. of videophone subscribers	5	9	17	42
Type of videophone switch	NONE	NONE	CONC.	SIMPLE
No. of videophone XPTS per vid. sub.	0	0	20	52
No. of videophone one-way trunk channels	10	18	20	22
"M1" (as defined in 5.3.1: see text)	4	4	4	4
No. of common access XPTS per sub.	M	M	M	M
No. of common acc. 1-way trunk channels	M	M	M	M

No. of subscribers: 84

Length of fibre in R.S. serving area: 232.96 km = 2.77 km/sub.

TABLE 6-5

Crosspoints and Channels for Subscribers at 1.28 km Spacing

Nominal % Penetration of Videophone	5%	10%	20%	50%
Actual no. of videophone subscribers	2	3	5	12
Type of videophone switch	NONE	NONE	NONE	SIMPLE
No. of videophone XPTS per vid. sub.	0	0	0	16
No. of videophone one-way trunk channels	4	6	10	16
"M1" (as defined in 5.3.1: see text)	3	3	3	3
No. of common access XPTS per sub.	M	M	M	M
No. of common acc. 1-way trunk channels	M	M	M	M

No. of subscribers: 24

Length of fibre needed in R.S. serving area: 71.68 km =
2.99 km/sub.

videophone, using the curves of fig. B.2. The value "M1", calculated by applying the 1% curve of fig. B.1 to the total population served by the R.S., is the number of visual library switch crosspoints needed per subscriber, as well as the number of one way video channels on the trunk needed for visual library service. Finally, the reader is reminded by the Tables to add his own value "M" for the number of channels needed for public access TV and hence for the number of public access crosspoints per subscriber. As before, subscribers wanting second or third channels need M extra crosspoints per extra channel, and subscribers not wanting videophone only need M+M1 crosspoints each.

To summarize, the number of crosspoints needed per videophone subscriber is obtained from the tables by adding the number of videophone crosspoints tabulated to the value tabulated for M1 plus the value supplied by the reader for M. The reader will note that, elsewhere in the report, M was allowed to have the values 5, 12, 21 and 35. The second parameter which may be obtained from the tables is the total number of one way channels needed on the trunk, which again is obtained by adding M1+M to the figure for the videophone channels.

6.6.2 Results

The least dense model, as detailed in table 6.5, will be considered first. The remote switch can be very simple. The video switch is mainly needed for the public access channels. Thus, a 12 public access channel system only needs 360 crosspoints (12 public access + 3 visual library for 24 subscribers), assuming 20% or less videophone penetration. Telephony and data could be accommodated by two 24 V.F. channel multiplexers (no concentration). This whole unit with power and control could fit into a pillar box. The problem area, however lies with the local trunks. Using the formulae already presented the total trunk length to fit the circular serving area of fig. 6.3 is 5017.6 km, or an average of 1.483 km per subscriber. At the 20% videophone penetration level 13 channels plus the common access channels must cover this distance. Thus, the economy of this very low density area will be critically dependent on the amount of multiplexing available in the trunks. At the time of writing the latest results for activity report 5 allow cautious optimism to be expressed about multiplexing up to 12 channels on one fibre, using linearised lasers and harmonically related carriers (H.R.C.).

In the case of a 640 m spacing, a remote switch serving area covers 84 subscribers. Their telephony needs could be met by a 128 subscriber RLM - for example the ITT DM32S unit, which is commercially available. Data will use one or more 24 input multiplexers without concentration. For less than 10% penetration of videophone service the video switch requirements are virtually the same, per subscriber, as for the low density model. Again the whole remote switch could possibly be designed to fit in a large pillar box. The per subscriber trunk length in this case is 0.393 km. Of the order of 24 private channels must

cover this distance, plus the public channels, so once again a high level of multiplexing is desirable.

The 480 m spacing situation gives rise to 144 subscribers per remote switch. For telephony, RLM's are currently available for 128 subscribers (DM32S) and 256 (Northern Telecom DMS-1), so the number 144 is somewhat awkward to serve. Data services, as before, will be catered for by using as many 24 channel input non-concentrating multiplexers as needed. Table 6.3 shows that the video switch may need a large number of crosspoints - 10800 for 35 public channels and 50% videophone, 2718 for 12 public channels and 10% videophone. This will probably mean that something larger than a pillar box is needed. The per subscriber trunk route length is 0.225 km, and the maximum channel capacity, from table 6.3, is 35 plus common access channels. Multiplexing is less critical than for the lower densities, but still attractive.

To summarise the results for very low subscriber densities, the subscriber's drop and remote switch do not appear to become inordinately expensive, assuming the cost of land and remote switch power and housing can be kept low. The local trunks, however, can only be kept to a reasonable cost by using a high level of multiplexing. As discussed in section 5.6, a simplified remote unit can be used if high multiplexing is possible, when a small number of subscribers are served by the remote unit. The design of section 5.6, as sketched in fig. 5.16, applied to the 24 subscriber situation (1.28 km subscriber spacint) needs four trunk fibres or 5.93 km of fibre per subscriber, and only 5 crosspoints per subscriber at the switch. It is stressed, though, that the multiplexing here makes assumptions which have yet to be verified.

6.7 THE RURAL STRIP MODEL

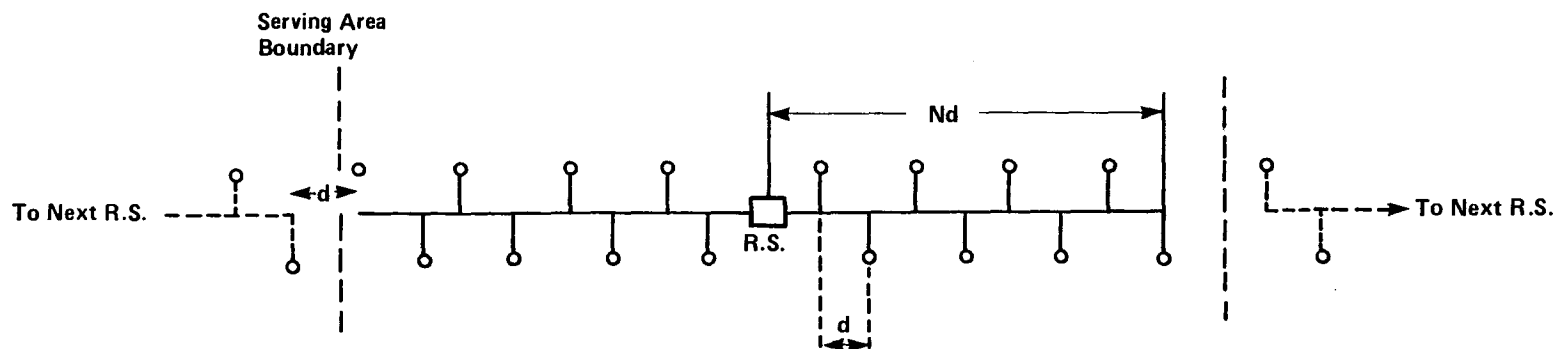
6.7.1 General Relationships

A remote switch serving area like that of fig. 6.4, serving $2N$ subscribers, has a route length of $N(N+1)d + 2Nl$ km, where d is the distance in km along the strip (road) between the foot of subscribers' drops, and l is the drop length in km. As before, the route length is the length of fibre needed to run one fibre from each subscriber to the remote switch, running along the road and down the drops.

The trunk route length needed to run one fibre from each R.S. to the C.O. is: $NMAX(NMAX+1) \times a/2$, where a is the separation between remote switches. Inspection of fig. 6.4 shows that:

$$a = (2N+1)d$$

$NMAX$ is the number of remote switches served by the C.O. along one strip. (Note that one C.O. may serve several strips).



No. of Subscribers: $2N$

Total Drop & Lengths: $N(N+1)d + 2NL$, Where L = Drop Length

a) The R.S. Serving Area



$a = (2N + 1)d$

Total Trunk Route Length = $NMAX(NMAX + 1) \times a/2$.

b) Distribution of Remote Switches

Figure 6.4 The Rural Strip: R.S. Serving Areas and Their Distribution

6.7.2 The 320m Population Distribution Case

For a population separation of 320 m, $d=160$ m and $l=160$ m in the above model. By taking a value of $N=25$ a maximum drop length of 4.16 km is obtained, as in the grid distribution case. Taking $NMAX=6$ gives a maximum local trunk length of 48.96 km.

Applying the general formulae of 6.7.1, the per subscriber drop length from a remote switch can be calculated as 2.24 km, and the per subscriber trunk route is 0.53 km. Each remote switch serves 50 subscribers.

Making the same assumptions as in the low density grid case, table 6.6 shows the component count for a remote switch serving 50 subscribers. The video switch is comparatively small, from inspection of table 6.6. Telephony could be served, albeit wastefully, using a DM32S unit, with a separate mux/demux for data, or data and telephony could share three 24 channel input mux/demux units.

Consideration of the 0.53 km per subscriber and the channel requirements of table 6.6 shows that multiplexing is about as critical as in the grid case of similar population density. In a strip development, it is easy to run the public channels through all the switches, instead of running M channels along dedicated fibres to each switch. Inspection of fig. 6.4 shows that 0.15 km of fibre is needed per subscriber to run one fibre through all the switches sequentially.

6.7.3 Low Population Density Strip

Table 6.7 shows the effect of increasing the separation between subscribers to 480 m, 640 m and 1280 m. (Due to the straggled nature of the subscribers these correspond to separations between drops along the strip of half these values.) The drop lengths in all cases are kept at 160 m.

The constraints in fitting these densities to the model were that the maximum drop length should be approximately 4 km, and the maximum trunk length is approximately 45 km. Imposing these constraints leads to values for N (fig. 6.4) of 16, 12 and 6 respectively, and to a value for $NMAX$ of 6 in all cases. Application of the formula in fig. 6.4 leads to the results of table 6.7

It is obvious that the long trunk lengths per subscriber in the low density rural strip distribution make multiplexing important.

TABLE 6-6

Crosspoints and Channels for Subscribers at 320 m Spacing
Strip Distribution

Nominal % Penetration of Videophone	5%	10%	20%	50%
Actual no. of videophone subscribers	3	5	10	25
Type of videophone switch	NONE	NONE	NONE	CONC.
No. of videophone XPTS per vid. sub.	0	0	0	26
No. of videophone one-way trunk channels	6	10	20	26
"M1" (as defined in 5.3.1: see text)	6	6	6	6
No. of common access XPTS per sub.	M	M	M	M
No. of common acc. 1-way trunk channels	M	M	M	M

No. of subscribers: 50

Length of fibre in R.S. serving area: 112 km = 2.24 km/sub

TABLE 6-7

Drop and Trunk Lengths for Various Density Rural Strip Models

Separation Between Subscribers	No. in R.S. Serving Area	No. in C.O. Serving Area*	Average Length of Drops	Per Subscriber Trunk Length
320 m	50	325	2.24 km	0.53 km
480 m	32	208	2.20 km	0.80 km
640 m	24	156	2.24 km	1.08 km
1280 m	12	78	2.40 km	2.24 km

* This is the number along one strip. A C.O. may easily serve several strips, nearly always at least two.

6.8 THE SUBURBAN CASE

In the suburban population distribution model, subscribers are separated by 58 m, on a grid. Activity report 4 has discussed the problems of deciding on the size of serving area for a remote switch. Use of a maximum drop length of 4 km or so, as in the rural area, gives a serving area of over 11,000 subscribers with an average drop length of nearly 3 km (see table 7.11 in activity report 4).

It is interesting to consider the trade-offs between using many small remote switches and few large remote switches. Using the terminology of section 6.4, and the formulae presented there, diamond shaped R.S. serving areas of N equal to 25, 50 and 75 are compared. The per-subscriber drop lengths within these R.S. serving areas are 0.99 km, 1.95 km and 2.92 km, respectively. In order to compare local trunk lengths, 36 of the small serving areas, serving 46,800 subscribers are compared with 9 of the medium, serving 45,900, and 4 of the large units, serving 45,600 subscribers. In the first two cases, the C.O. is co-located with a R.S., in the latter case it is not. By applying concentration curves, as usual, a comparison can be made of the amount of fibre needed in the local trunks for various levels of multiplexing. Table 6.8 shows the results, where the number of video channels for videophone is derived from the 40% concentration curve of fig. B.2, which is assumed to tend asymptotically to 10; the number of visual library services comes from the 1% curve of B.1; 35 public channels are assumed, and, finally, 4 fibres per thousand subscribers are allocated for telephony. (The use of the 60% - 40% traffic division in suburban areas is open to question. It should be regarded only as an illustration.)

The result from table 6.8 is that, for low levels of multiplexing, the combined drop length and per subscriber local trunk length varies little between the three schemes although small R.S. areas use slightly less fibre. For high levels of multiplexing the saving in drop lengths to be gained from using a small R.S. becomes more significant.

In a suburban area the cost of real estate may well limit the number of remote switches one would want to use, so the remote switch serving 5100 subscribers appears to be a good compromise between long drop lengths and too high an investment in real estate.

Due to the large number of subscribers served by each switch, the videophone switch will divide the 5100 subscribers into small groups. It is beyond the scope of this report to actually calculate the optimum value for this division. Division into groups as small as in the rural case would lead to a great increase in channel requirement in the local trunks over the case where no such division is used. For interest, but with no suggestion of optimality, table 6.9 shows the number of videophone crosspoints needed in two cases - the first with 20 groups of

255 subscribers, the second with 50 groups of 102. Also shown is the increased local trunk channel capacity caused by subdivision. Inspection of the table shows that too small a subdivision is totally useless - the number of crosspoints rises due to the switch to interconnect local channels (a glance at fig. 5.8 should make this clear), and the number of trunk channels increases. The optimum design of this switch, once all the cost trade-offs are known, could be performed by applying standard design guidelines.

TABLE 6-8

Comparison of Amounts of Fibre (in km. per Subscriber) in
the Local Trunks for About 45,000 Suburban Subscribers

% Penetration of Videophone	5%	10%	20%	50%
Multiplex: video channels per fibre				
2	0.36	0.42	0.47	0.86
3	0.25	0.30	0.33	0.59
4	0.21	0.23	0.25	0.45
5	0.17	0.20	0.21	0.37
6	0.15	0.17	0.18	0.32
9	0.11	0.13	0.14	0.23
12	0.10	0.11	0.11	0.18

a) 36 R.S. serving areas of 1300 subscribers each.

% Penetration of Videophone	5%	10%	20%	50%
Multiplex: video channels per fibre				
2	0.13	0.16	0.22	0.35
3	0.10	0.12	0.15	0.24
4	0.08	0.09	0.12	0.19
5	0.07	0.08	0.10	0.16
6	0.06	0.07	0.09	0.13
9	0.05	0.05	0.07	0.10
12	0.04	0.05	0.06	0.08

b) 9 R.S. serving areas of 5100 subscribers each.

% Penetration of Videophone	5%	10%	20%	50%
Multiplex: video channels per fibre				
2	0.10	0.12	0.16	0.29
3	0.07	0.09	0.11	0.20
4	0.06	0.07	0.09	0.15
5	0.05	0.06	0.07	0.13
6	0.04	0.05	0.06	0.11
9	0.04	0.04	0.05	0.08
12	0.03	0.03	0.04	0.06

c) 4 R.S. serving areas of 11,500 subscribers each.

TABLE 6-9

Effect on Crosspoints and Channels of Sub-Dividing a
5100 Subscriber Videophone Switch

Percentage Penetration of Videophone	20%	50%
No subdivision	580(240)	1360(510)
20 groups of 255	173(520)	256(880)
50 groups of 102	328(900)	343(1300)

Units: Crosspoints per videophone subscriber.

In parentheses: No. of videophone channels needed in local
trunks.

6.9 THE URBAN MODEL

Subscribers in urban areas are modelled as being distributed on a grid with a 14 metre spacing. Expanding the diamond shaped remote switch serving area of section 6.4 to $N=150$, 45,300 subscribers can be served from one centre, using a maximum drop length of 2.10 km, with a mean drop length of 1.41 km.

In view of this comparatively short drop length, there is little motive to install remote switches, and the problem becomes one of C.O. organisation, with video switch design as the dominant feature.

6.10 CONCLUSIONS

In rural areas a higher level of multiplexing than 2 or 3 video channels for a 40 to 50 km range, with SNR of 46 dB, is needed to reduce the amount of fibre needed in the local trunks to a reasonable level. This high multiplexing may require the use of low bandwidth, or monochrome, or both for the videophone service. In suburban areas trunking is less critical, and there is no trunking in urban areas. Very careful switch design, however, will be needed to reduce the number of crosspoints from those in the simple switch models of this report.

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7. EVOLUTION OF A FIBRE OPTIC INTEGRATED NETWORK

As shown in this report, and others in the series written under the present contract, the critical areas in implementing a fibre optics network are video switching and, in rural areas, trunk multiplexing. Another critical section is the subscriber's terminal equipment, both at the remote switch and at his home. The component count for this terminal equipment has been given, but the cost of the equipment will be very dependent on the level of circuit integration achieved. This chapter suggests the way in which a fibre optic network could be implemented, starting with devices capable of being developed in a short time. The proposals are mainly intended for rural areas.

In the first phase, an area having no television service, or a poor television service, and having poor telephone service (multi-party) is selected. The area is divided into remote switch serving areas as described in the present report. Each remote switch location is joined by a fibre trunk to the C.O., and subscribers are joined to the remote switch location by single fibre drops. Although, in the initial phase, only two to five CATV channels, plus telephony, will use the local trunks, it is probably economical to install more capacity at this stage to allow for the needs of the later phases. In this first phase, no video switching is used. Instead, all the CATV channels are multiplexed over each subscriber drop. The number of CATV channels in the system, therefore, is limited by the number which can be multiplexed over the longest subscriber drop. In this phase, multiplexing will be by FDM, either using one light source with electrically multiplexed input or, for longer drops, several light sources operating at different electrical frequencies, and combined by a power coupler. Telephony will be provided by a RLM at the remote switch location, as described in the present report. In this phase the development of the necessary telephone interface units could determine the speed of progress. It may be necessary to first install the CATV network, and later provide telephony.

The first phase could be installed by the early nineteen eighties, possibly without the telephony service. While it is being planned and installed, development work will proceed on video switching and multiplexing, as needed for the later phases. In the second phase an expanded CATV service with Pay TV will be introduced. Also available will be a limited (1% penetration) visual library service. Upstream transmission will be for very few selected subscribers, using dedicated channels to the C.O., where the signals are distributed by a CATV channel. Technically, this phase sees the introduction of a video switch with its control unit at the remote switch, together with a signaling device in the subscriber's home. At this phase the availability of baseband input on the subscriber's television set is desirable.

The second phase could be installed by the mid to late nineteen eighties. The final phase will be the installation of the symmetric video services, loosely referred to as videophone in the present report. For this phase a high level of multiplexing on the local trunks together with a cheap video switch is needed. Also, aspects such as market demand and picture quality required need to be investigated. It seems reasonable to suppose that the technical problems associated with this third phase could be solved by the late eighties.

APPENDIX A BASEBAND VIDEO V RF CARRIER VIDEO

A.1 GENERAL

The decision on whether to use baseband or RF video transmission affects all of the following areas of an integrated distribution network:

- a) Repeatered trunk transmission
- b) Video switching
- c) The subscriber's multiplex unit in the remote switch
- d) The maximum permissible range of the subscriber's drops
- e) The interface at the subscriber's set.

Some of these effects are fairly trivial, some are serious. More important, although some can be quantified in terms of a dollar penalty, some cannot yet be so quantified. This Appendix sets out to quantify the trade-offs as far as possible, and to indicate the questions which must be answered in order to optimise the final network design.

A.2 REPEATERED TRUNK TRANSMISSION

The main impact of the use of baseband on repeatered trunk transmission is to require repeaters to have excellent low frequency response, or to require DC clamps to be fitted periodically. This problem area has been addressed by the CCIR (Ref. A.1). CCIR meetings have revealed two trends in baseband transmission - Europeans are using good low frequency amplifiers, while in North America clampers are more widely used - typically one for every five or six amplifiers.

Since trunk transmission will almost certainly use FDM, the choice of baseband as one of the frequencies to be multiplexed has a relatively minor effect on repeater spacing. If WDM were to be used, however, the effect would be significant.

The decision to use baseband or not in the trunk can be made independently of the decision to use it elsewhere in the network with relative impunity, since the trunk interfaces to convert the frequencies are shared by many subscribers. This is not true, though, in very low population density areas.

A.3 VIDEO SWITCHING

The most critical frequency-dependent property of a video switch is its isolation, or protection offered against crosstalk between adjacent channels. This isolation must be paid for in dollars, either by going from a comparatively cheap technology to a more expensive technology, or by labour intensive "conditioning" of the cheaper technology. The fundamental rule here is that, for any given switch, isolation falls off at 6 dB per octave increase in signal frequency.

This rule will be invoked in the calculations which follow.

The first question to be posed is: what isolation is needed in a switch? The answer will first be derived in terms of an RF modulated signal. In BP23 it is stated that single frequency interference at or near the video carrier or colour sub-carrier must be 57 dB down with respect to the video carrier.* This requirement is stated more precisely in graphical form - see fig. A.1. It follows from this, at first sight, that two RF video signals at the same nominal frequency should be isolated by 57 dB to avoid unacceptable interference at the video carrier. This observation is supported by Ref. A.2.

It is possible, however, to relax the isolation requirements by careful control of the video carrier frequencies. The most obvious procedure is to use the phase-locking approach adopted in FDM systems to minimise the interference due to intermodulation (Ref. A.3). However, although direct crosstalk, between video carriers is no longer a serious problem, the crosstalk between the first sidebands due to the line frequency is. These first sidebands are at least 6 dB down with respect to the video carrier, and therefore need a worst case switch isolation figure of 51 dB to ensure that crosstalk is 57 dB down with respect to the video carrier.

The only system known to the authors which makes widespread use of RF switching for the direct distribution of television is the Rediffusion system. They have carefully studied the problem of minimising isolation problems by careful control of video carrier frequencies. In ref. A.4 they conclude that a significant gain can be achieved by off-setting the video carriers on adjacent switch buses by one third of a line frequency. (The more obvious one-half of a line frequency is not available, since colour sub-carrier sidebands fall there.) In their experience, such an arrangement results in the need for 45 dB isolation at the video carrier.

* In Activity report 4, (first version) an error occurred. It was not realised that the single frequency interference at the colour sub-carrier is expressed in terms of the video carrier.

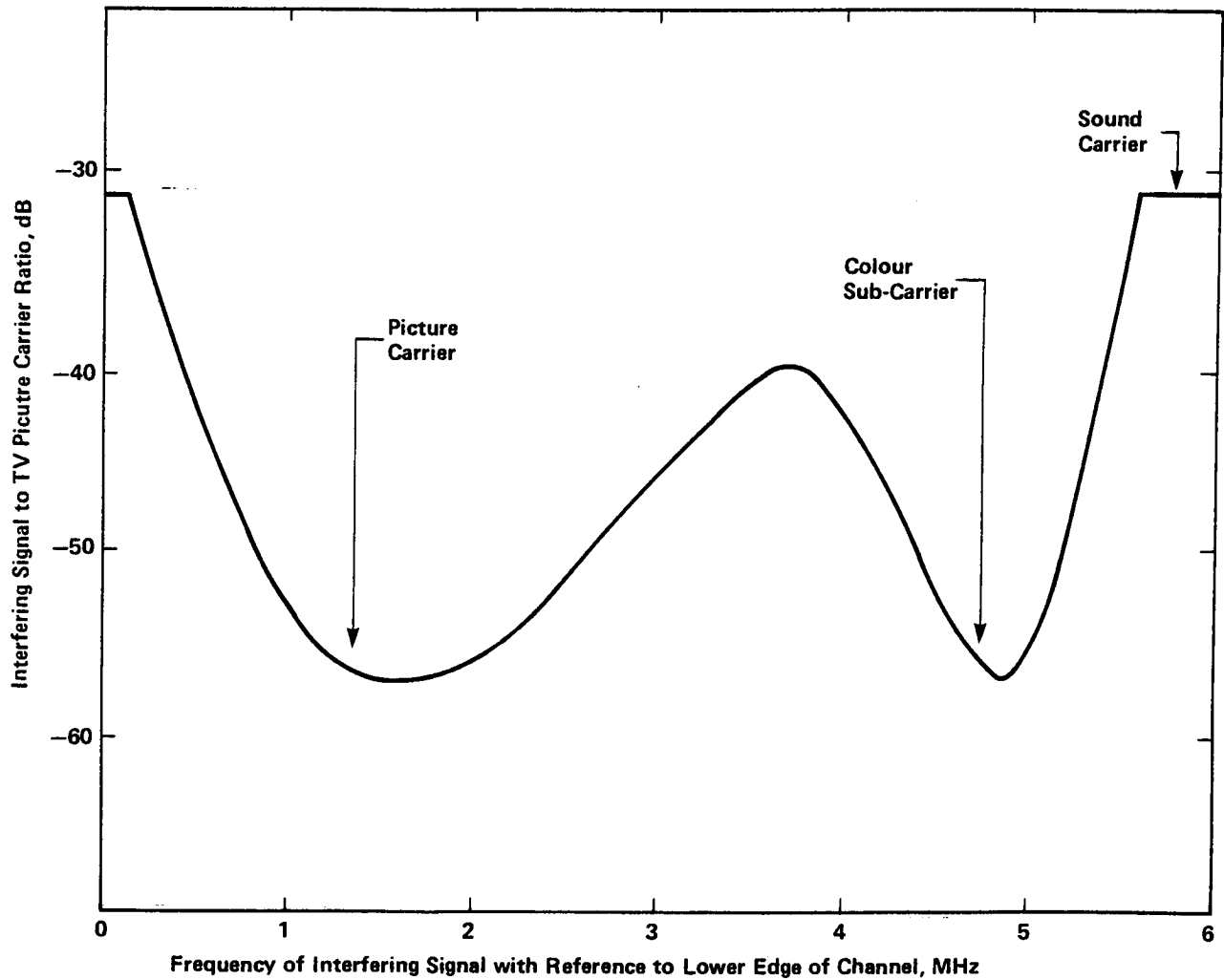


Figure A.1: BP23 Single Frequency Interference Requirements

Some consideration is needed of the crosstalk requirements at the colour sub-carrier frequency. As shown in fig. A.1, crosstalk from the colour sub-carrier of signal A into signal B must be 57 dB down with respect to the video carrier of signal B. In order to calculate the crosstalk isolation needed, it is necessary to know the relative levels of the colour sub-carrier and the video carrier. Standard NTSC modulation of a TV signal can be expressed by:

$$V(t) = A(1+0.77 S(t)) \cos Wct$$

where $S(t)$ is the baseband signal, normalised to be between 0 (white) and 1 (sync). The 0.77 factor assures that the relative levels, as set out in ref. A.5, of the NTSC signal will be met. On the 0 to 1 scale, the colour sub-carrier varies between 0 for a white picture and 0.6 for saturated red or cyan (Ref. A.5). Substituting 0.6 for $S(t)$ above, the amplitude of the two colour sub-carrier sidebands is 0.23 times the video carrier, or about 13 dB down. (One of the two sidebands, of course, is rejected by the VSB filter.) The result of this is that 44 dB isolation is needed in the worst case at the colour sub-carrier frequency to ensure a 57 dB interference level relative to the video carrier. Since the colour sub-carrier frequency is an integral part of the broadcast signal, it is not possible to control it in the same way as the video carrier. Even if this were possible the gains would not be as great as in the video carrier case, since the phase of the colour sub-carrier carries information.

The above discussion can be summarized as leading to the following switch isolation requirements for RF modulated video:

Case A: Uncorrelated signals:	57 dB isolation at carrier
	44 dB isolation at colour sub-carrier
Case B: Controlled carrier frequencies:	45 dB isolation at carrier
	44 dB isolation at colour sub-carrier

For baseband video one can assume that the same colour sub-carrier isolation of 44 dB is needed. In fact, ref. A.4 refers to 45 dB as the required isolation between two "video frequency", or baseband, signals. This 45 dB requirement is interpreted by the author as applying at the colour sub-carrier frequency, and will be used here as the standard.

In addition to the above single frequency interference levels, it is necessary to specify the total crosstalk at all frequencies which may

be tolerated. Again, using the rediffusion system as a reference, they specify that the ratio of signal level to the sum of induced voltages from all other program should be not less than 40 dB. (Ref. A.6.)

Having specified the cross-talk objectives one can now apply 6 dB per octave rule to compare the performance required of a baseband switch with that required of a switch carrying video on an RF carrier. As noted, a baseband switch must have 45 dB isolation at 3.58 MHz (colour sub-carrier). The lowest standard RF channel is T7, with video carrier at 7 MHz, colour sub-carrier at 10.58 MHz. For Case A (uncorrelated signals), 57 dB isolation at 7 MHz is needed. This is equivalent to 63 dB at 3.58 MHz - i.e. the switch must be 18 dB better than a baseband switch. For case B (carrier controlled), the isolation required is equivalent to 56.5 dB at 3.58 MHz, meaning that the switch must be 8.4 dB better than a baseband switch.

The same calculations applied to T8 and T9 channels, whose carriers are at 13 and 19 MHz respectively, give the following results. With case A assumptions the switch requirements are 26 dB (T8) and 30 dB (T9) better than baseband, and with case B assumptions the figures are 12 dB and 15 dB respectively.

The high penalty implied in using RF carrier can be reduced by using a non-standard frequency below T7. The exact specification of such a frequency must be made with care, involving the calculation of possible intermodulation products. Further, the practical problems of modulation and demodulation at such a frequency must be studied - (Ref. A.4). For the sake of illustrating the savings in switch requirements a channel in the band 1 to 7 MHz will be considered. If the other considerations mentioned above allow, a carrier could be located at 2.25 MHz, colour sub-carrier at 5.83 MHz and sound carrier at 6.75 MHz. Case A assumption mean a switch isolation requirement 8 dB better than for a baseband switch, while case B assumptions give a figure of 3.2 dB. Should experiments indicate that colour sub-carrier cross-talk is more critical than carrier cross-talk, one could follow Rediffusion in using lower sideband transmission with, for example, carrier at 5.5 MHz, colour sub-carrier at 1.92 MHz and sound at 6.75 MHz.

To summarize, the effect of using RF modulated carrier for video is to require increased isolation in the video switch. A worst case isolation requirement is 57 dB at video carrier frequencies. Less isolation is required with frequency controlled carriers. The exact isolation needed in this case needs study, but 45 dB at video carrier and 44 dB at the colour sub-carrier appears to be conservative. The impact of these figures, combined with the frequency at which they are required to be met, is to need a switch whose isolation is either 18 or 8.4 dB better than a baseband switch, depending on which of the assumptions about carrier frequency control is made. These figures are for the lowest standard RF video channel, T7. Use of a non standard channel

could reduce the increased isolation requirements to 8 dB or 3.2 dB, again depending on which assumption is made concerning the isolation required.

A.4 THE SUBSCRIBER'S MULTIPLEX UNIT IN THE REMOTE SWITCH

A.4.1 The FDM Case

An FDM multiplexer must convert the input signals to suitable non-overlapping frequencies for input to a mixer. When the input signals are on RF carrier this conversion is achieved by using channel converters; when the input signals are at baseband, modulators are needed. Cost comparisons between currently available channel converters and modulators are not a valid basis for determining the cost penalty of using baseband. This is so because channel converters are available as mass-produced low quality consumer goods, while modulators are studio quality low quantity items. Thus, at a recent NCTA conference, channel converters were available at \$17 (U.S.) each, while a Jerrold Commander modulator sells for over \$2000 (Canadian price). A reasonable way to assess the difference between two units of comparable quality is to look at the extra components needed for a modulator over those required for a converter. The most expensive of these is a VSB filter, which could cost between \$25 and \$50 in quantity. (These are "guesstimates" based on similar components in telephony devices.) Although SAW filters could reduce these prices significantly, they are only practicable at frequencies over about 50 MHz, where light source efficiency is poor, and therefore they are not likely to be used in fibre based systems. The next item needed in most modulators is a sound modulator. Modulators like the Jerrold Commander are designed to accept baseband sound input and modulate it to RF. Although normal Bell System practice (Ref. A.7) is to transmit audio separately, the integrated network could transmit sound frequency modulated on a carrier through the video switch. In this case the modulator would need to separate the sound from the video after frequency conversion to avoid unacceptable attenuation by the VSB filter. This could cost between \$5 and \$10 for a separation filter. Finally, because of the low frequency carriers being used, modulation would probably have to be a two stage process, as is normal in all high quality modulators. Without accurate circuit design any estimate must be very approximate, but a combination of all the above factors would indicate an incremental cost of between \$50 and \$100 for a cheap mass-produced modulator over the price of a cheap channel converter.

If the video switch were to operate at baseband, every subscriber requiring 3 channels would need two modulators at the remote switch, if FDM is the multiplex scheme used on his drop.

Thus, such subscribers would need two modulators at the remote switch were to operate at RF.

A.4.2 The WDM Case

When WDM is the chosen modulation technique there is no difference in the equipment needed at the remote switch multiplex unit whether the switch operates at baseband or RF.

A.5 THE MAXIMUM PERMISSIBLE RANGE OF THE SUBSCRIBERS' DROPS

As is shown in activity report 5, a light source driven to a certain peak current by a baseband signal can transmit over a link having 10 dB more optical loss than can the same light source driven to the same peak current by an RF signal, assuming the same detector and the same transmission objectives in each case.

In WDM and single channel systems, this means that, with 5 dB/km fibre, the range of a system using baseband is 2 km more than using carrier.

With FDM, the advantage of using one baseband and two RF carriers over three RF carriers is slight - of the order of 2 dB more optical loss may be tolerated in the former case.

A.6 THE INTERFACE AT THE SUBSCRIBER'S SET

There are two possibilities here: either demand is adequate to justify manufacturers providing a baseband input or it is not. If baseband - input sets are available, then no additional costs are associated with baseband transmission. In the extreme case, manufacturers might produce baseband-only domestic sets at a price less than that of current receivers. It may be noted that Rediffusion experience has been that they have been able to offer their subscribers a saving by supplying them with cheaper TV receivers tuned only to the Rediffusion HF carrier signal (ref. A.6), so the case may be made strongly that medium scale production of tunerless TV sets would give a cheaper product than a conventional set. Even the inclusion of, say, T7 and T8 tuners for an FDM set could well give a cheaper set.

Where a baseband input set is available, obviously baseband transmission carries no cost penalty. In fact, in one scenario where TV sets have only got baseband inputs, the use of RF carrier carries a cost penalty since a tuner must be supplied. Where a baseband input is not available, the subscriber must be provided with one or more modulators, whose cost has already been estimated above.

In the absence of a baseband TV set input, use of FDM in conjunction with a baseband video switch means that the subscriber needs one modulator for his first channel at his home, in addition to the one modulator per extra channel already mentioned at his remote terminal. This assumes FDM of one baseband and two RF signals. Use of three RF signals means that no modulators are needed at the home, but an extra one is needed at the remote terminal. In the WDM case, baseband transmission means that one modulator is needed per channel at the subscriber's set, when that set does not have a baseband input. The comments made so far are summarized in table A.1.

A.7 THE EFFECT OF WIDESPREAD SYMMETRIC VIDEO

It has been shown above that the penalties associated with switching of video at RF can be minimised by careful control of carrier frequency, taking for granted the control of colour sub-carrier and line frequency. When subscriber originated video transmission is encountered, such accurate control may not be possible. It could only be achieved by precise extraction of carrier and colour sub-carrier information from the CATV type signals the subscriber receives. Even then, much of the gain in switch isolation arises from controlling the frequencies on alternate busses of a switch. The signal from a subscriber can end up on any bus in the switching network, and hence this approach is not available.

It follows that networks accommodating subscriber originated video should work at baseband. It can quickly be seen that with switches having intra-call facilities it is not practical to operate upstream at baseband and downstream on carrier, so the introduction of symmetric video would mean that all video should operate at baseband.

Further, even at baseband, the isolation requirements in the video switch are affected by the accuracy with which the colour sub-carrier is controlled. Subscribers should be required to lock their colour sub-carriers to the national standard, or to originate their programs in monochrome. This, in practical terms, may mean a considerable difference to the cost differential between a colour and monochrome transmitter.

A.8 OTHER FACTORS AFFECTING ACCEPTABLE SWITCH ISOLATION

All of the above isolation figures assume that the video signals pick up all their single frequency interference while passing through one switch. Three corrections must be made to these figures. Firstly, transmission by FDM will introduce single frequency interference due to intermodulation and WDM will do the same due to insufficient isolation.

The amount depends on the linearity of the light source and its power level (FDM) or on the spectrum of the light source, and the nature of the WDM splitter (WDM). These figures can be calculated from the equations in activity report 5. Addition of the degradations from the two sources (switch and transmission) will be on a power basis.

TABLE A-1

Summary of Conclusions of Appendix A

			Domestic Terminal	
Subscriber Drop		Remote Terminal	BB and RF Inputs on Domestic TV	RF Input Only on Domestic TV
FDM: 1BB, 2RF:			BB and RF Inputs	RF Input Only
A) RF Switch:	2 dB longer than Ref. A	1 Demod, 2 Ch. Convs. (1)	2 Ch. Convs.	1 Mod.; 2 Ch. Convs.
B) BB Switch:	2 dB longer than Ref. A.	2 Mods.	2 Ch. Convs.	1 Mod.; 2 Ch. Convs.
FDM: 3RF				
A) RF Switch	=Reference "A"	2 Ch. Convs.	3 Ch. Convs.	3 Ch. Convs.
B) BB Switch	=Reference "A"	3 Mods.	3 Ch. Convs.	3 Ch. Convs.
WDM: 3BB				
BB Switch:	10 dB longer than Ref. B	-	-	3 Mods.
		-	-	3 Mods.
WDM: 3RF				
RF Switch:	=Reference "B"	-	3 Ch. Convs.	3 Ch. Convs.

Notes

1. This figure assumes a non-standard RF whose spectrum overlaps baseband.
2. Reference lengths A and B are arbitrary. The relation between them depends on the loss in the WDM mux/demux. See activity report 5.
3. Abbreviations: RF: radio frequency carrier; BB: baseband; Mods: modulators; Demods: demodulators; Ch. Convs.: Channel Converters.

The second correction which must be made to the above isolation figures is for the tolerate range of signal levels. Thus if x dB of crosstalk is allowed, but the level of signals is allowed to vary by $\pm y$ dB, it follows that the switch must afford $x+2Y$ dB isolation to cover the case of crosstalk from a signal having the maximum permissible level into one having the minimum permissible level.

The final correction is for the cascading of switches. The common access channels (CATV, Pay TV, Visual library) can be arranged to never pass through more than one switch. Symmetric video, however, may pass through several switches - one at the transmitting subscribers remote switch, one at the receiving subscriber's remote switch and, possibly, several C.O.'s in between.

The use of N switches in cascade means that the isolation of each switch must be increased by something between $10 \log N$ and $20 \log N$ dB, depending on whether crosstalk adds on a power or voltage basis. This penalty may be minimised by the use of digital transmission in the inter-office network, leading to a maximum cascade of 2 analogue switches, and an increased switch isolation of between 3 dB and 6 dB.

A.9 FURTHER ASSUMPTIONS AND CONCLUSIONS

The major simplifying assumption that will be made here is that baseband inputs will be available on domestic sets. In view of Rediffusion experience with the marketability of non-standard TV Sets in star distribution networks (ref. A.6) this is not unreasonable.

The major conclusion that can be made from the above discussions is that baseband switching and transmission over subscribers' drops has many advantages. The only situation where it carries a penalty is when FDM is used in the subscribers' drops, and where a large number of subscribers want second and third channels. This disadvantage is considered insufficient reason to avoid baseband, especially when symmetric video forms a substantial part of the network traffic.

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APPENDIX B VIDEO TRAFFIC

This appendix presents curves from which the concentration ratios used in the discussion of switches and the calculation of local trunk capacity are taken. In all cases Poisson statistics are used, as discussed in activity report 4.

The first curves will be presented for CATV type traffic, characterised by long holding times. A mean holding time of one hour is used. This may well be an under-estimate for CATV as such, but may be reasonable for visual library type services. The curves of fig. B.1 show the concentration ratios which may be used for various usage rates in order to ensure a blocking probability of 1%. The usage rate is defined as the percentage of subscribers who initiate a demand for service during the busiest hour of the busiest day. The curves are similar to those of activity report 4, with the addition of 50% usage rate and a 1% usage rate. The former is to simulate ordinary first-channel CATV usage, while the latter is for visual library. Activity report 4 concluded that visual library services were very wasteful on resources, even at 5% usage rates. The 1% figure is a response to comments from DOC. In order to keep the usage rate this low, either the service must be made expensive or regulated in some way. Throughout the report the 50% curve will be used for CATV and the 1% will be used for visual library.

Fig. B.2 is used for the design of private access switches. The usage rate and holding time of fig. B.1 are combined in a traffic estimate of 8.5 ccs per subscriber. This figure, corresponding to about 24% usage on fig. B.1, is derived from published estimates for the Bell System "Picturephone" traffic (Ref. B.1). The curve marked "Total" is the concentration ratio permitted to give 1% blocking probability for this traffic. For a switch it is necessary to estimate how much of this traffic is local, and how much is destined for the C.O. Experience within BNR on the design of telephony switches (RLM's) indicates that, in rural areas, 50% of the traffic can be local. This figure varies from region to region obviously, but will be used for illustration here. The curve "60%" shows the concentration ratio which may be tolerated for the local traffic, while the 40% curve applies to the rest of the traffic, destined for the C.O. The dotted curve - marked "60% + 40%" shows the effective concentration rate when traffic is divided into a 60% and a 40% section.

B.1 REFERENCES

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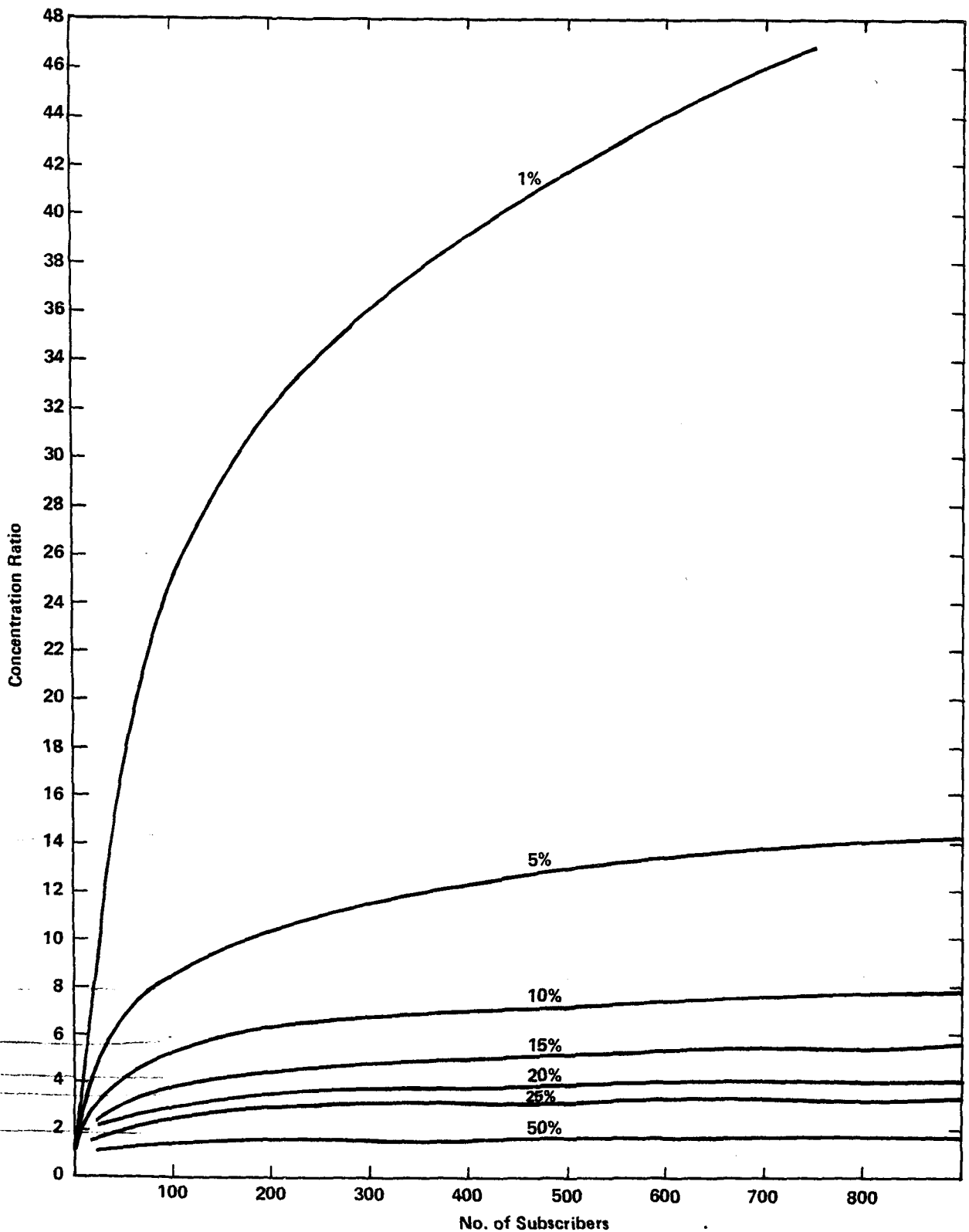


Figure B.1: Concentration Ratios Available for Long Holding Time at Different Usage Rates

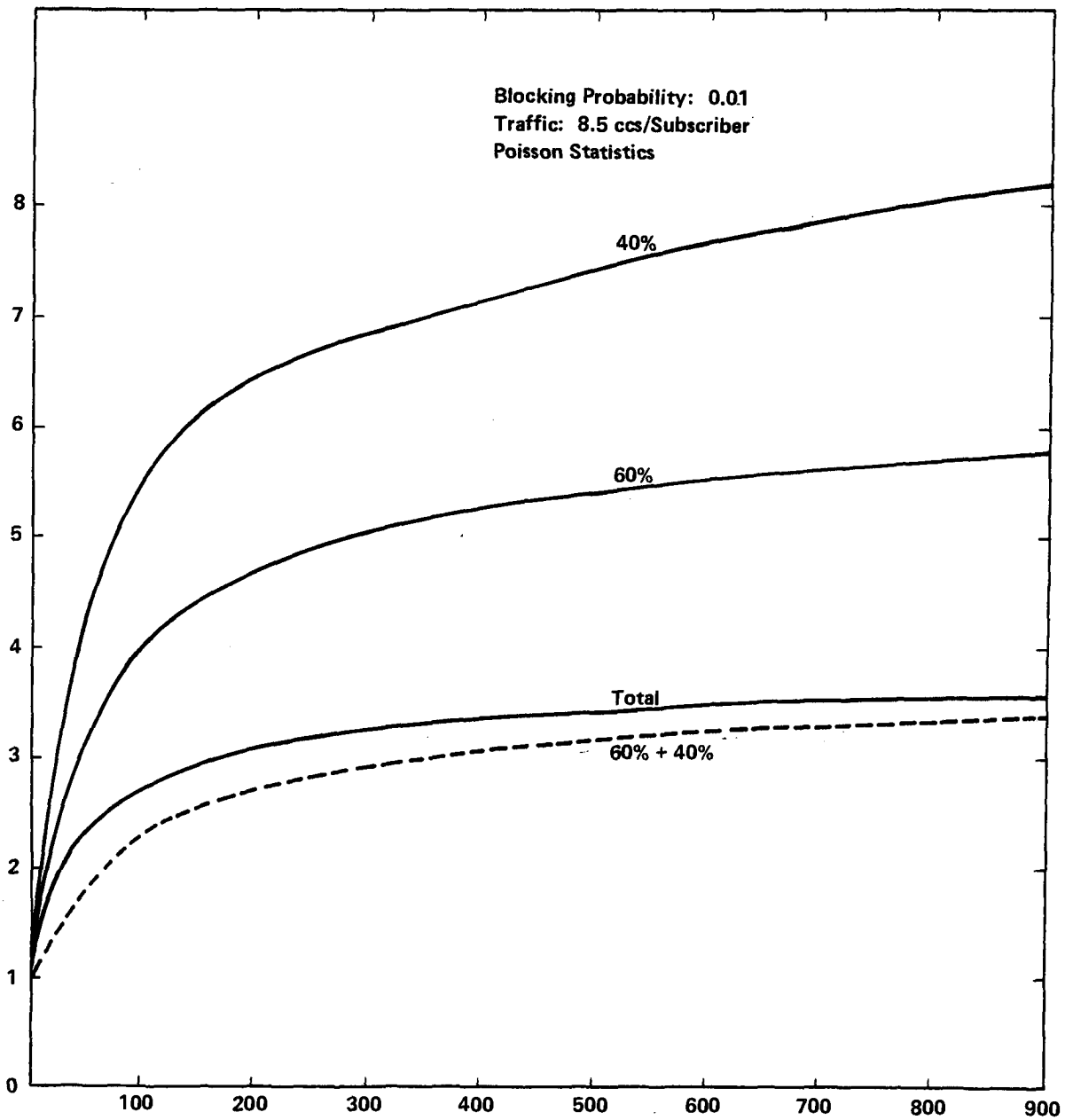


Figure B.2: Concentration Ratios, Assuming Picture Phone Traffic Levels

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APPENDIX C COMPONENT COUNT FOR THE SUBSCRIBER'S MUX/DEMUX
AND ELECTRO-OPTICAL INTERFACE UNITS

C.1 DESIGN PRINCIPLES

All the schemes here use the same design principle, whereby each subscriber has a terminal unit at the R.S. equipped to transmit one video channel and one telephony channel, and to receive one telephony channel and one video control signal channel. This unit is designed to accept plug-in units to transmit a further two video channels, a further telephony channel, two data channels and a broadcast radio channel, as well as plug-in units to receive a second telephony channel, one video channel, and two data channels. By interchanging the words transmit and receive, one arrives at a description of the subscriber's domestic terminal.

C.2 BASEBAND SWITCHING AND FDM

With reference to figure 5.12, the basic unit at the R.S. will consist of:

- i) A light source and linearising driver circuitry
- ii) An 8-port mixer (probably resistive)
- iii) A three-input video buffer (Note 1)
- iv) A VF modulator
- v) A photodetector (PIN) and circuitry
- vi) A 6-way splitter
- vii) A baseband video low pass filter
- viii) A telephony demodulator
- ix) A video control demodulator
- x) A bidirectional unit (DOC coupler)
- xi) Packaging with room for plug-in units

Note 1: It is probable that a 3-input buffer on one I.C. can be made for little more than a single input unit, hence it is included as a basic item.

In addition to the basic unit, the following plug-in options should be available:

- i) One video modulator per extra video channel (max. of 2)
- ii) 1 extra telephony modulator
- iii) 1 modulator for low bit rate data, already on an analogue carrier

- iv) 1 modulator for higher bit rate baseband data
- v) 1 buffer for broadcast radio (Note 1)
- vi) 1 extra telephony demodulator
- vii) 1 demodulator for low bit rate data on an analogue carrier
- viii) 1 demodulator for higher bit rate baseband data.

Note 1: This item might be incorporated into the video buffer chip.

The subscriber's domestic multiplex unit has the following changes from the basic unit at the R.S.:

- ii) Becomes a 6-port mixer
- iii) Not required
- vi) Stays a 6-way splitter, since 3 TV channels can be split off together
- vii) Not required
- ix) Becomes a video control signal modulator
- xi) Packaging will have to be aesthetically pleasing for use in the home

The plug-in options for use at the subscriber's premises are:

- i) 1 extra telephony modulator
- ii) 1 modulator for low bit rate data on an analogue carrier
- iii) 1 modulator for higher bit rate baseband data
- iv) 1 extra telephony demodulator
- v) 1 demodulator for low bit rate data on an analogue carrier
- vi) 1 demodulator for high bit rate baseband data

C.3 R.F. SWITCHING AND FDM

With reference to fig. 5.11, the changes needed to the basic R.S. unit for baseband switching are:

- iv) Not required, or may be replaced by a buffer
- vii) Becomes a bandpass filter
- viii) Becomes a low pass filter

The change needed to the R.S. plug-in units for baseband switching is:

- i) Becomes one video channel converter per extra channel.

C.4 USE OF MULTIPLE LIGHT SOURCES FOR FDM

An approach, mentioned quickly in the text, which may be used to increase the maximum drop length is to modulate several light sources at different frequencies and combine their optical outputs in one fibre. The effect on the component count is quite simple to see. At the ultimate, each input port needs its own light source and driver, with no electrical mixer. Compromise with, say, one source per video channel, and all other signals combined on a fourth source are more attractive. Thus, the only items affected in the counts above are the number of light sources and drivers, and of mixers.

C.5 WDM

A WDM unit is unaffected by the use of R.F. or baseband video switching, except by the frequency response of the light sources, which is a small effect ignored here.

With reference to fig. 5.13, the basic R.S. unit consists of:

- i) An 8 input port power combiner
- ii) A light source and driver for a video signal
- iii) A light source and driver for a telephony signal
- iv) A 6-output WDM splitter, such as a blazed diffraction grating
- v) A photo-detector and circuitry for telephony
- vi) A photo-detector and circuitry for the video control signal
- vii) A bidirectional unit (DOC coupler)
- viii) Suitable packaging

Extra plug-in units are simply a light source and circuitry per signal transmitted, and a detector and circuitry per signal received.

All light sources, of course, operate at different, precisely defined, wavelengths. One type of detector is assumed to have adequate spectral response to cover all wavelengths used.

The basic domestic unit consists of:

- i) A 6 input port power combiner
- ii) A light source and driver for a telephony signal
- iii) A light source and driver for the video control signal
- iv) An 8-output WDM splitter
- v) A photo-detector and circuitry for video
- vi) A photo-detector and circuitry for telephony
- vii) A bidirectional unit (DOC coupler)
- viii) Aesthetically acceptable packaging for domestic use

The same comments as for the R.S. unit apply to the plug-in units required.

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