Technical Report

A Systems Study of Fiber Optics for Broadband Communications

Activity No. 4
Methodology of Fiber Optics for Asymmetric Interactive Switched Visual Services

BNR Project TR6259
April 1977

Bell-Northern Research

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Asymmetric Interactive Switched Visual Services

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

LIST OF FIGURES

LIST OF FIGURES (cont'd)

1. SUMMARY AND CONCLUSIONS

1.1 OBJECTIVES

This activity forms part of a broader study concerned with the application of fibre optics to broadband communications, with special emphasis on rural areas. This study is being performed by Bell-Northern Research (BNR) for the Department of Communications of the Canadian government. The present activity considers the problems of providing asymmetric switched visual services, especially in rural areas.

1.2 OUTLINE OF THE ACTIVITY

Firstly, in order to know what transmission standards to apply to the network, it is necessary to define "asymmetric switched visual services". A discussion is presented to this end and, as a result, it is concluded that 525 line video signals with a quality slightly superior to "BP23" will suffice. In addition, the use of a "frame grabber" is recommended to provide most of the services commonly quoted in literature discussing possible broadband services.

Section 4 makes use of crude models of tree, star, and hybrid tree-star networks in rural areas, in conjunction with estimates of video traffic requirements in order to compare the amount of fibre needed for each. It is found that a hybrid tree-star configuration requires the least fibre of the three approaches.

A general discussion is presented in section 5 of parameters other than amount of fibre used which could affect the choice of networks. The principal topics are:

a) Multiplexing: Two channels per fibre using FDM is practical at present. High level multiplexing (20 or more channels per fibre) would need a major breakthrough in light source linearity or development of wavelength division multiplexing (WDM).

b) Switching: A scheme is proposed for switching two channels to each subscriber. This scheme forms the basis of more detailed design in section 6.

c) Optical Couplers: These are still in the laboratory stage, and should be the object of development work to make them suitable for use in the field.

d) Upstream transmission: A scheme is proposed for the bidirectional use of a single fibre using couplers. This needs laboratory investigation in conjunction with coupler development.

e) Noise gathering: This is not seen to be a problem in fibre systems.

Section 6 is concerned with the components needed to construct the remote switches and program centre required for a hybrid tree/star network. It presents a block diagram of these sub-assemblies, together with flow diagrams to illustrate the signalling between subscribers and these units.

Since the costs of components needed to implement fibre optics systems are largely a matter of guesswork, the present activity avoids dollar figures. Instead the components needed to implement fibre optics systems for asymmetric switched visual services are listed in detail. These "component counts" are based on the video traffic estimates of section 4 and the switching units of section 6. The figures are presented for two models of rural population distribution and for suburban and urban populations. They are performed in each case for a range of traffic requirements. The reader is given the details of each calculation, allowing him to perform his own calculations should he wish to consider traffic requirements other than those tabulated. Section 7 performs these calculations for a "near term model", with two channels multiplexed by FDM on each fibre. Section 8 performs the calculations on the assumption of twenty channels per fibre. Both WDM and FDM are considered.

Section 9 notes that the visual library services use a disproportionate amount of fibre and other resources. It is suggested that the visual library could be replaced by an expanded Pay TV network to give a considerable saving in components without causing a serious loss in grade of service. A further discussion on the comparative merits of WDM and FDM is presented, using the component count of section 8 to give a firm base to the discussion. It is recommended that investigative research should be carried out towards the development of a WDM system.

1.3 CONCLUSIONS

In the absence of reliable dollar values for components it is not possible to come to a clear conclusion on the economic feasibility or otherwise of a broadband fibre optic network for asymmetric switched visual services. However, such a network is technically feasible with a certain development effort, and the components required are detailed in the text.

The primary components needing development for a network to be installed in the near term are:

a) A compact, cheap video switching matrix.

b) Optical couplers for use in subscribers' premises and in remote switches.

For long term networks using high level multiplexing it is recommended that work be performed on:

a) Investigation of components for WDM

b) Development of a robust optical coupler for outside plant use.

In addition, for both near term and long term systems, studies should be made on:

a) The effect of cross talk on video channels passing through a switch. Specifically, is the 57 dB isolation required by BP23 for single frequency interference applicable in this case?

b) The development of a domestic receiver with a tuner capable of accepting signals in the sub-VHF band.

2. DEFINITION OF SERVICES

2.1 PREAMBLE

It will be supposed that the network under consideration will supply CATV in addition to other services. Several studies have been published in recent years discussing services which could use a broadband communications network (Refs 1 - 5). These services may be resolved into the following categories:

2.2 PAY TV

This is the simplest service covered by the title of this activity. The subscriber's interaction is limited to accepting or not accepting delivery of a program whose content is pre-ordained by the system operator. The subscriber is billed periodically on the basis of a record of his consumption of the proffered service. Whereas in urban areas this service is a convenience, removing the problems of downtown parking, cinema entrance charges, etc., in rural areas where cinemas are not densely distributed this service may offer the only way in which a subscriber can view certain programs.

2.3 VISUAL LIBRARY

This is a natural extension to Pay TV. A library of video tapes, or similar video recordings, is maintained, either at the program centre or at a location with an upstream video capability to the program centre. The subscriber can then select from a catalogue of recordings which one he wishes to view, and instruct the library to transmit it to him. Payment will probably be on a per program basis. In addition to widening the range of entertainment available by permitting minority cultural interests to be served, the service has also got significant potential for providing educational material otherwise unavailable, especially in rural areas.

2.4 SUBSCRIBER ORIGINATED VIDEO SIGNALS

Services 2.3 and 2.4 involve video signals originated by the system operator possibly in conjunction with an independent visual library. In addition, certain subscribers may wish to originate their own video programs, to be transmitted upstream to the program centre for redistribution to all subscribers or to a selected group of subscribers. Examples having equal application in urban and rural milieus include entertainment performed at local community centres; debates on matters of local interest, such as local council meetings; religions services, especially those serving a localised ethnic group. No interaction in the sense of communication from the viewer to the program originator is envisaged.

2.5 SUBSCRIBER ORIGINATED VIDEO WITH NON-VISUAL RESPONSE FROM OTHER SUBSCRIBERS.

This category is an extension of the services of section 2.4. A video program originated at one point in the network is distributed to a set of subscribers, who may react to the transmitted material by transmitting a response (vocal or numerical) to the program originator. The most obvious application of this class of service is for educational purposes. An instructor delivers his lecture, using the video link to illustrate his talk, and students may ask questions, or respond to tests using a digital path. In rural areas this service would provide educational opportunities otherwise unavailable to those unable to attend full time courses. In urban areas the market would have special appeal for the house-bound, including the physically handicapped and parents of young children.

A more contentious application is in conjunction with the broadcasting of meetings of public bodies, such as local councils, already mentioned in section 2.5. The availability of an upstream link could be used to poll public opinion on matters under consideration by the council. Interesting reflections on the impact of such a technology on the democratic process occur in ref. 2.

In the medical field several references are made in the literature to what has come to be known as "telemedicine". Of particular Canadian interest, an experiment has just been completed using the Hermes satellite to provide a video and high quality audio link from a hospital at Moose Factory to the university hospital at London, Ontario (700 miles away), with a high quality audio and control channel in the opposite direction (ref. 6). Among the many applications were consultation during major surgery, with the consultant in London operating the camera at Moose Factory by remote control to avoid interfering with the surgeon, and relaying advice by the audio channel. Other applications included remote diagnosis, study of X-rays, and use of the high quality audio to listen to a stethoscopic examination.

In the context of a wired (or fibred) network it is unlikely that remote supervision of operations in a rural area is practical. If a consultant is within the range of the network he would probably prefer to personally supervise the operation. Indeed, it is improbable that a rural network would encompass two physically separate locations, one housing facilities for major surgery and the other housing consultants.

Other important applications do arise in rural areas, though. The major service could well be the operation of clinics distributed through the community staffed by paramedical personnel, who would use the link to get opinions from a doctor at a central location, allowing a very effective use of limited supply of doctors. Given enough paramedical staff, several clinics could be operated in the same day unaffected by the weather condition which can render transport difficult in the

Canadian winter. In the urban context, where a large number of hospitals or medical research centres exist, it would be advantageous to be able to call an expert in for instant consultation. It is hoped that the evaluation of the Hermes project will shed more light on the requirements of telemedicine.

2.6 STILL PICTURE SERVICE

Subscribers in many instances only need a stationary visual display. Indeed, the majority of the services listed as examples of the "wired city" fall in this category. Examples are numerous, and extensively listed in references 1 through 5. A partial list is supplied here for interest:

Catalogue of programs available from the visual library.
Prices at nearby stores.
Maps, especially those showing public transport routes.
Timetables (Public transport, entertainment, church services, etc.)
Weather forecasts and road conditions.
Menus at local restaurants.
Prices of agricultural products at the market.
Transport available for agricultural products
Stock exchange information.

The subscriber would transmit a request for information and view the display on his screen, possibly changing the display quite rapidly while scanning "pages" for the specific information he is seeking.

2.7 SYMMETRIC VIDEO SERVICES

Although primarily concerned with asymmetric services, an asymmetric network could accommodate a small amount of two way symmetric video traffic. It is stressed that a full video phone service is not envisaged, but rather a limited point to point service. Examples would be in the telemedicine field, where the patient under examination in a rural clinic could benefit psychologically from viewing the doctor examining him. In remote rural areas where transport problems occur, a teleconferencing type network, with participants at a limited number of community centres, would allow easier convening of local councils. In urban areas, teleconferencing between branches of the same company, or between customers and clients is a service which may arise.

3. TRANSMISSION REQUIREMENTS

3.1 DOWNSTREAM VIDEO CHANNEL

This capability is basic to all categories of service listed and carries a video channel from the program centre to the subscriber. The difference between various services lies in the number of channels to be carried simultaneously to each subscriber, the quality required of the received signal, and the format of the signal when NTSC video is not required. On the subject of the number of channels to be supplied, opinions have been expressed that even for purely entertainment TV, simultaneous delivery of two channels to the home is desirable. With the wider range of services now proposed, such a capability becomes essential to prevent the viewing habits of one section of a household inhibiting the constructive use of the network by other members of the household. A dash between the parents' evening class and the childrens police drama (or vice versa) could seriously diminish the impact of the network. The need for more than two channels as a minimum service to all homes is dubious, since it is felt that households in possession of more than two TV receivers will remain in the minority for some time. In any case, few areas in Canada are unable to receive at least one or two broadcast TV channels for a third viewer in the household.

Thus, the network should be optimised to provide two channels per subscriber at the lowest cost possible. Any incremental costs involved in providing further channels to a subscriber due, for example, to the need for an extra fibre, will be a secondary consideration in the system selection.

The signal quality required for such a wide range of service as discussed in section 2 is not well defined. The standards of BP23, referred to in activity 2, for entertainment television are probably adequate for most purposes. The only systematic study published of the subjective acceptability of TV signal quality is that of the Television Allocation Study Organisation (TASO), which is concerned only with SNR. The impact of other degradations has not been studied in comparable fashion, but we follow privately expressed opinions from within the CATV industry that a signal meeting BP23 requirements with respect to these degradations will be judged by a viewer to be free of these degradations. With regard to SNR, however, we summarise in table 3.1 results from TASO, taken from ref 7, after converting the TASO definition of SNR to the NCTA definition used in BP23. The percentage of viewers judging a picture to be of a certain quality is tabulated versus SNR. The following are the TASO definitions:

"excellent": "A picture of extremely high quality, as good as you could desire"
"fine" : "A picture of high quality providing enjoyable viewing. Interference is perceptible"
"passable" : "A picture of acceptable quality. Interference is not objectionable"

SNR (NCTA DEFINITION)	% JUDGING PICTURE TO BE "EXCELLENT"	% JUDGING PICTURE TO BE "FINE" OR BETTER	% JUDGING PICTURE TO BE "PASSABLE" OR BETTER
40	35%	89%	over 99%
42	48%	95%	over 99%
44	60%	98%	over 99%

Table 3.1 TASO committee evaluation of effects of SNR on signal quality

Whereas the selection of a target standard must be rather arbitrary, and in practice is often decided by a posteriori arguments based on the technical capability of the system, it is proposed that a SNR of 42 dB be used as a design objective for the worst case signal. In such a system 95% of the viewers at the worst locations will consider that they have a "fine" picture - representing in most system a far higher percentage of viewers in total making this judgment.

As for the signal format, activity 2 has presented the arguments for using direct intensity modulation of the light source with an NTSC format signal (including baseband as a special case - where not specifically stated otherwise throughout this activity the expression "NTSC format" should not be construed as excluding baseband, nor should it be construed as limiting the exact choice of carrier frequencies. It is used as shorthand for a VSB analogue modulated signal of the type used in North American CATV systems or the baseband signal from which such an RF signal is derived).

Only two services among those listed above call for serious reconsideration of the adequacy of NTSC signals - namely Telemedicine and still pictures. In the case of Telemedicine the Hermes experiment is still under appraisal. However, preliminary indications are that the 525 line resolution was adequate, provided control was available to "zoom" the T.V. camera in on areas of critical interest. In view of this, and the fact that it would be unnecessarily restrictive to design a whole network for ultra high resolution (e.g. 1000 lines) video in order to accommodate a minority service, it is proposed that any future demand for special services be met by an overlay network. (The practical consequences of designing a network for higher bandwidth signals would primarily be to lower the input impedance of detectors, thereby increasing noise and shortening the permissible repeater spacing. A further decrease in repeater spacing may occur if faster light sources are needed, since the efficiency of a light source decreases with increasing bandwidth).

In the case of still pictures the use of a continuous 4.5 MHz NTSC signal is extremely wasteful. By using what have come to be known as "frame grabbers" the 4.5 MHz channel can be used efficiently, however, and domestic T.V. receivers can still be used. The principle is that, whereas NTSC transmission of a still picture results in 30 full 525 line pictures, all identical, being transmitted each second, the viewer only needs the information transmitted during 1/30th of a second. By using a "frame grabber" during that 1/30th of a second the subscriber can store all the information he needs and process it at leisure, releasing the system to transmit another frame to another subscriber. Actually, NTSC transmission sends 60 half-frames per second, and certain frame grabbers operate by storing only a half-frame of information. The resulting 260 line resolution (approximately) has been found adequate for many purposes and such a system is described in ref. 8.

The system works by transmitting a digital signal which addresses the subscribers frame grabber. A half frame of NTSC signal is then transmitted and captured by the subscriber's frame grabber. Ignoring signalling times, the system then has a capacity of serving 60 subscribers per second or, assuming that subscribers change their image every ten seconds, 600 terminals may be served simultaneously per channel, instead of one with a conventional system without frame grabber. Since the address signal can be encoded in a section of the NTSC frame unused for useful data transmission this full capacity can be realised. It is, then, recommended that transmission design assumes the use of NTSC format video signals even to deliver still pictures.

3.2 DOWNSTREAM LOW CAPACITY CHANNEL

Although this channel is included for completeness, it is only relevant to certain topologies or services. A downstream low capacity channel here means a channel for control signals: we assume the audio signal associated with a video channel is always provided. These control signals are needed in multiplexed systems offering restricted access services, where a command from the program centre enables authorised viewers to receive certain signals (e.g. Pay T.V.). An example of hardware functioning in this mode in current CATV systems is the "intelligent tap" from Delta Benco Cascade. Services which require such a downstream channel independent of system topology are those which require polling of devices at the subscribers premises. Examples here would be one mode of meter reading, monitoring of the subscriber's set status in multiplexed services either for usage sensitive billing or simply for a rating survey of programming. Since any such channel can be frequency division multiplexed with a downstream video signal, its provision will have no significant impact on system topology. Its impact on component requirements will mainly be to require an extra modulator to allow such signals to be multiplexed with the subscribers' video.

3.3 UPSTREAM VIDEO CHANNEL.

As noted in section 3.2, the object of the network is to deliver a picture with 42 dB SNR, but otherwise meeting BP23 standards (from now on referred to as BP23+) to the subscriber. Further, all signals will be of NTSC format as discussed. A very fundamental point arises in the allocation of transmission degradations to the upstream video channel, however, and it is of prime importance that its significance be appreciated by authorities implementing an asymmetric interactive video system. In a system designed for asymmetric operation the optimum configuration allocates virtually all signal degradation to the downstream direction, and demands that upstream transmission be of high quality, assuming that improved quality of transmission requires additional expenditure. The more asymmetric the network, the more asymmetric the allocation of degradations. The important implication here is that, once a system has been optimised for asymmetric use, upgrading it to a symmetric system may be expensive and will almost always result in a sub-optimal symmetric system from the economic viewpoint. To illustrate this point, let us suppose that a repeater spacing of 5 km is needed for 42 dB SNR, and 3.5 km for 45 dB. If an asymmetric system is installed with virtually perfect upstream transmission (e.g. digital), the downstream channel will have repeaters spaced by, say, 5 km. To upgrade the system means making a signal degradation allocation of 45 dB in both directions, which either involves removing all the old repeaters, re-locating all manholes and re-splicing cables or, more likely, installing extra repeaters every 2.5 km, half-way between the originals. (The spacings are not based on accurate calculations - such calculations will be performed as part of activity 5).

The precise optimum allocation of degradations will be dictated by the geography of the area to be served and by the degree of asymmetry required. The equation for determining the most economical allocation is made even more non linear by the fact that the arguments which eliminated FM and digital transmission in the downstream direction no longer apply. In the downstream case one has the constraint that subscribers have already made a substantial investment in NTSC receivers, and the network must be made compatible with them. Any unorthodox transmission scheme therefore needs a signal processor at every subscribers' premises, and this must be as cheap as possible. In the upstream direction one specifies equipment to interface with the transmission medium and may legitimately specify unorthodox and expensive systems for the limited number of transmitters in order to economise on the large number of downstream links.

In order to quantify our discussions, it is proposed that downstream transmission be designed to meet a 43 dB SNR, and upstream be designed to meet 49 dB SNR (giving a total performance of just over 42 dB), with a proportional allocation of other degradations. The design of an optimum network would then proceed as follows. The downstream video distribution, program centre switching and upstream low capacity channel would be optimised to give 43 dB over the video channel. The upstream requirements would then be studied for 49 dB SNR. If one was near a "quantum leap", for example if 49 dB needed very expensive digital systems while 48 dB could be accommodated by conventional NTSC means, a re-allocation of degradations would be made. By doing this, and essentially making upstream optimisation a secondary process, one has much more flexibility in system design than trying to simultaneously optimise the whole system.

3.4 UPSTREAM LOW CAPACITY CHANNEL.

All services which fall under the definition of asymmetric interactive switched visual services need an upstream channel to justify the word "interactive", and it is the capacity of this channel which justifies the word "asymmetric". The services defined in section 2 fall neatly into two categories: those needing video upstream (symmetric) and those for which audio bandwidths carrying either audio or digital signals suffice. The advantages to be gained by allowing higher speed digital signalling appear to be insignificant. To specify this link, therefore, we propose a minimum standard comparable to that of telephony. For this a flat frequency response from 300 Hz to 3200 Hz is more than adequate - there is no universally agreed specification for this bandwidth in the telephony world. Digital signalling at 300 baud will be the design objective, with an acceptable error rate of 1 in 10^6. This bit rate is chosen as one for which data terminals already exist, so that new circuitry need not be designed. The error objective, comparable to that demanded on digital telephone networks, is considered to be easily met. It is not considered necessary to provide higher quality (i.e. larger bandwidth) upstream audio - the only service among those listed which would profit from such a capability would be Telemedicine. However, Telemedicine service already implies the existence of an upstream video channel, which has associated with it an F.M. audio channel in conventional NTSC video transmission.

4. VIDEO TRAFFIC STATISTICS : THEIR INFLUENCE ON AMOUNT OF FIBRE NEEDED

4.1 GENERAL PRINCIPLES

Having identified the services to be offered, and the capacity and quality required in both directions over the network to supply them, we now turn to the problem of designing a network which will accommodate them.

Networks fall naturally into two categories: those where every subscriber has a dedicated channel (or, in our case, two channels) connecting him to the Program Centre and those where subscribers have access to a common highway of substantially fewer channels than there are subscribers. With the former "star" network the subscriber always has his own private channel to the P.C. (program centre), with the latter "common highway" network he only has a channel if one is free on the highway. A channel is defined as a pathway capable of transmitting a message independently of the messages carried elsewhere on the system - it may be a single fibre, a frequency slot in a FDM signal carried on one fibre, a single wavelength in one fibre (WDM) or a mixture of all of these. Its nature does not affect the discussion of traffic which follows, but it does have considerable impact on the components needed to implement the scheme.

For a preliminary comparison of networks we generalise even further, and compare the networks in terms of "channel-kms", by multiplying the length of each section of the network by the number of channels it is carrying. The weaknesses of this approach have been exposed in activity 2 - as one changes the multiplexing technique, so one alters critical parameters such as repeater spacings. These parameters control the points at which it is possible to locate taps, and hence determine the length of the drops. However, the present approach will reveal broad trends in the amount of fibre needed to implement various systems. It is the only method of making this comparison without specifying the multiplexing to be used.

4.2 VIDEO TRAFFIC ESTIMATES

Due to the mixed nature of the traffic on the asymmetric switched video network, the channels serving a group of subscribers must be divided into two classes, namely private access and public access. Any of the common access channels can be accessed at any time by any subscriber (CATV type service), whereas private access channels are only available to one subscriber (or, conceivably, a small group of subscribers) at any given time. Frame grabbing services, it will be recalled, use common access channels.

Although it would be possible to provide a dedicated private channel to every subscriber, thereby assuring him of access at all times, to do so would be most uneconomical. It would need a very large amount of fibre - essentially needing a star network, and also it would need one video source per subscriber at the program centre to allow each person to watch an independent program. Fortunately this is not necessary. The determination of the number of private channels needed to serve a given number of subscribers with a low risk of any subscriber being denied access is the problem traffic theory sets out to solve. This ratio of the number of channels to the number of subscribers is a function of the amount of traffic and of the acceptable probability of blocking. Traffic is measured by the product of the average call length in hundreds of seconds by the number of calls initiated during the busiest hour of the busiest day, giving a unit of a "hundred call seconds" (CCS). Blocking is defined as the probability P of not finding a free line when required.

Two traffic models are appropriate for the video network - Poisson and Erlang C. In the latter the reasonable assumption is made that once a subscriber has accessed a channel (equivalent to getting a dial tone in telephony), then his calling time is independent of the time he had to wait for his channel. The Poisson model assumes that the caller has a certain period of time available, and that every second he waits to access a channel is subtracted from his call holding time. In practice the two models give virtually identical results for low blocking probabilitics ($P < 0.1$), and any differences are completely negligible compared with the uncertainty associated with the assumptions which follow. In this activity Poisson statistics were used, since such tables are more widely available. In passing, we note that the third common traffic model - Erlang B - is not applicable, since it assumes that subscribers denied access to one of the channels under study have access to some alternative route.

The real problem, however, comes not from the choice of model, but from the estimate of traffic. In telephony one has statistics based on many millions of observations, and even then introduction of new services such as credit card verification and radio talk shows can wreak havoc with switching requirements. With video services one has no statistical base at all - all one can offer is a, hopefully, intelligent guess, and then study the impact of varying the parameters so guessed.

The first parameter for which an estimate is needed is the average holding time of a channel - i.e. for how long will a subscriber use a channel on average? Taking a balance between visual library type services and telemedicine or educational programs an average of one hour seems a generous estimate. (Remember that the comparatively long CATV and Pay T.V. viewing times and the short frame grabbing services are supplied over public access channels and do not affect the private access channel traffic statistics). The next figure needing estimation is the number of calls which will be originated each hour during the busiest period of the busiest day. This is a figure for which absolutely no data exists - but it is most unlikely to involve more than 25% of the subscribers using one channel for private access, remembering that CATV and Pay T.V. are, presumably, catering for majority entertainment. Finally, it is necessary to set a value for P - here P = 0.01 has been taken as a reasonable target.

Figure 4.1 plots the relationship between the number of subscribers and the number of channels needed to serve them for the above values of holding time and P, varying the percentage of subscribers wanting to access one private channel per hour. An interesting difference exists between these curves and normal telephony curves, due to the large holding time - the curves are nearly linear over much of their range. In telephony one is often on the knee of the curve and halving the number of subscribers does not give a proportionate saving in trunks, whereas in our case dividing 1000 subscribers sharing N trunks into, say, two groups of 500 subscribers sharing M trunks does not greatly increase the total number of trunks. This property can be used to advantage in some networks, as will be shown later.

Over the linear portion of the curves the number of channels N can be related to the number of subscribers by:
$N = AS + C$, where A and C for various values of percentage usage are as follows:

Percentage Usage	"A"	"C"
5	0.059	10
10	0.132	12
15	0.171	12
20	0.226	12
25	0.288	12

Thus, 1000 subscribers at 20% usage need:

$$1000 \times 0.226 + 12 = 238 \text{ channels.}$$

These linear relations hold for numbers of subscribers in excess of about 400.

4.3 SIMPLE NETWORK MODEL

Figure 4.2 shows in schematic form the three principle networks which can be used, namely a tree, a hybrid tree/star and a star network. Figure 4.2 (a) shows a modified tree structure, more suitable for rural applications than a normal tree. The trunk is subdivided, here into four sections, and private access channels are apportioned among these sections using the curves of figure 4.1. In addition common access channels run the full length of the trunk. Feeders, four of which only are shown, access the private access channel bus serving their region, and the public access bus as shown, resulting in a large number of channels in the feeder/drop network.

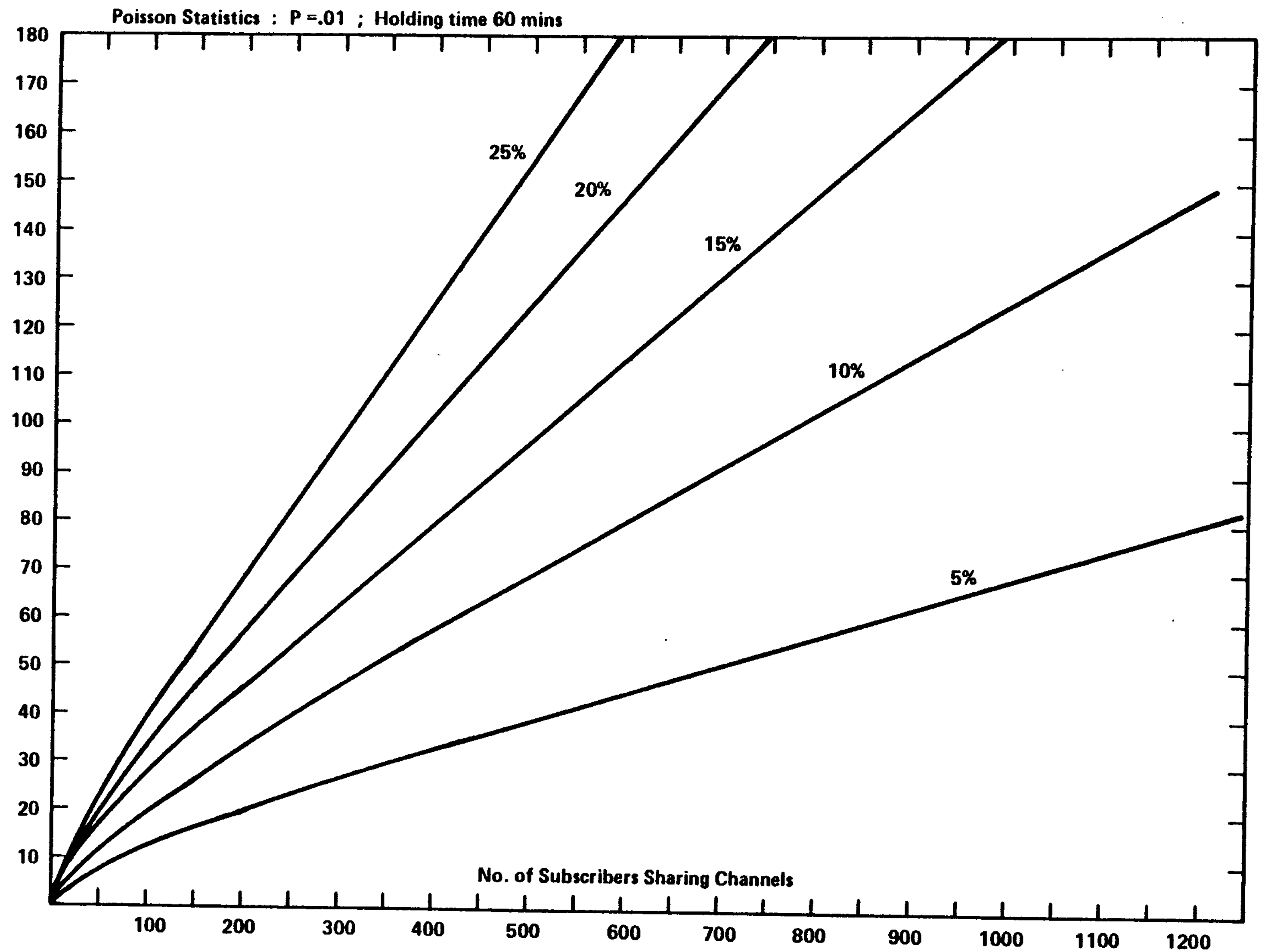
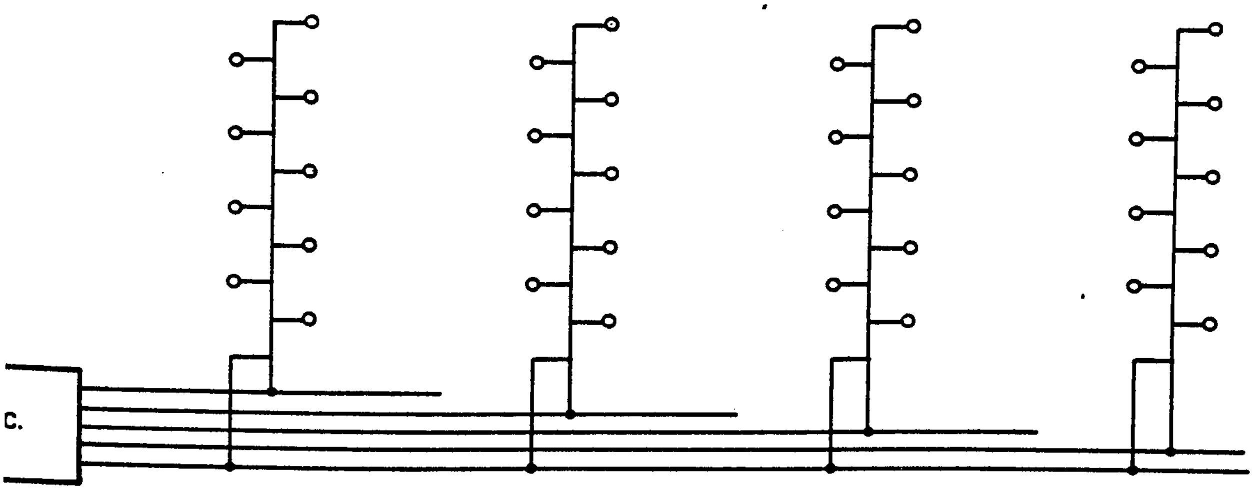
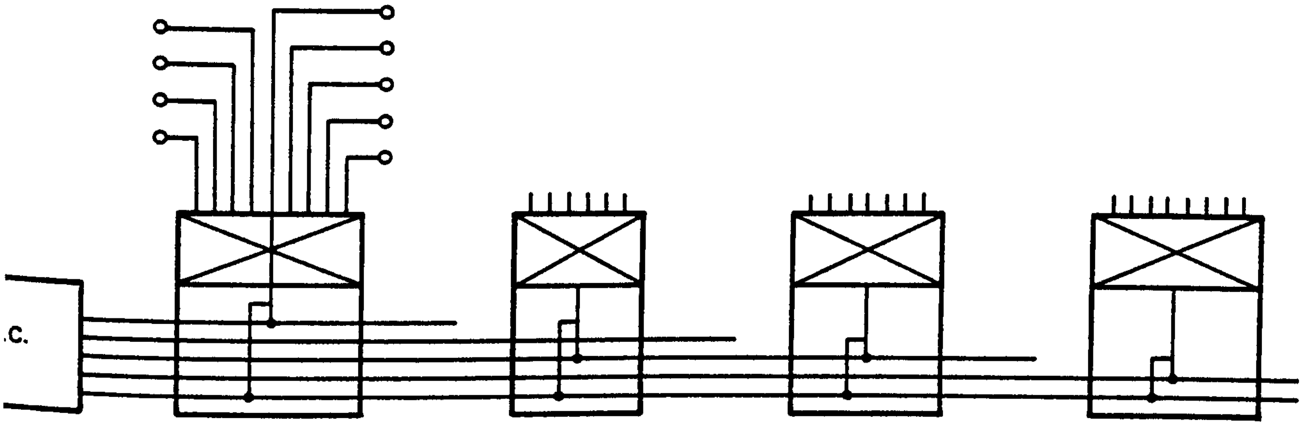


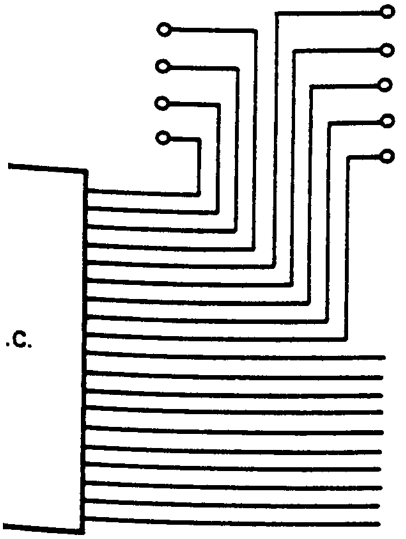
Figure 4.1 — Channel Requirements for Video Traffic



A) Modified Tree Network



B) Hybrid Star/Tree Network



C) Part of a Star Network

Figure 4.2 Illustration of Tree, Star, and Hybrid Star/Tree Networks

Figure 4.2 (b) shows a hybrid tree/star network. Again the division of the trunk is used, although the savings so gained are comparatively small. This time each subscriber has a two channel path to a switching unit at the feeder/trunk interface which can assign any two channels chosen from the appropriate private access bus and the public access bus to him. (Only one feeder array is shown).

Figure 4.2 (c) shows a star network: each subscriber has a two channel capacity running all the way from his home to the P.C. For simplicity of drawing only the first route is shown.

Figure 4.3 presents a very simple model of a rural population distribution. As in activity 2, a mean spacing of 320 metres between subscribers is assumed, and they are distributed on a staggered grid. The lines represent highways and other rights-of-way which transmission lines will be constrained to follow. By superimposing the three models of figure 4.2 on this map, ball-park comparisons of the three networks can be made. Further, the impact of changing the traffic statistics on the network requirements will be demonstrated. In the light of the results of these comparisons the network meriting the most study will be selected for a more detailed analysis later in this activity.

The area of figure 4.3 serves 1488 subscribers, distributed along 124 branches of length 1.92 km each, each of which serves 12 subscribers. These lengths have been chosen as being well within the range of a single fibre running from the trunk in a tapped system. The precise figure of 1.92 is dictated by the need to serve an integral number of subscribers.

We proceed in the next section with the comparison of the channel-km capacity needed for each of the three model networks, ignoring such problems as upstream signalling.

4.4 CHANNEL-KM CAPACITY OF A TREE MODEL

If one superimposes the model of figure 4.2a on the population distribution of figure 4.3, one finds that the four private access lengths of trunk serve 372 subscribers each. From figure 4.1 one can read off the number of channels needed to serve this number of subscribers for the five usage rates of 5%, 10%, 15%, 20%, and 25%. In addition the common access channel bus is assumed to have four alternative design objectives, namely 5, 12, 21 and 35 channels. Thus, for example, for 10% usage, each of the four sets of private access channels must have 55 channels (from figure 4.1). For the case of 21 common access channels, each feeder and each drop must have 76 channel capacity. Table 4.1 shows the total channel-km capacity needed for a range of usage percentages and common access channels. Note that taps have been permitted anywhere on the trunk and feeders. Although this is improbable, it serves to give a simple model adequate for the purposes of this section.

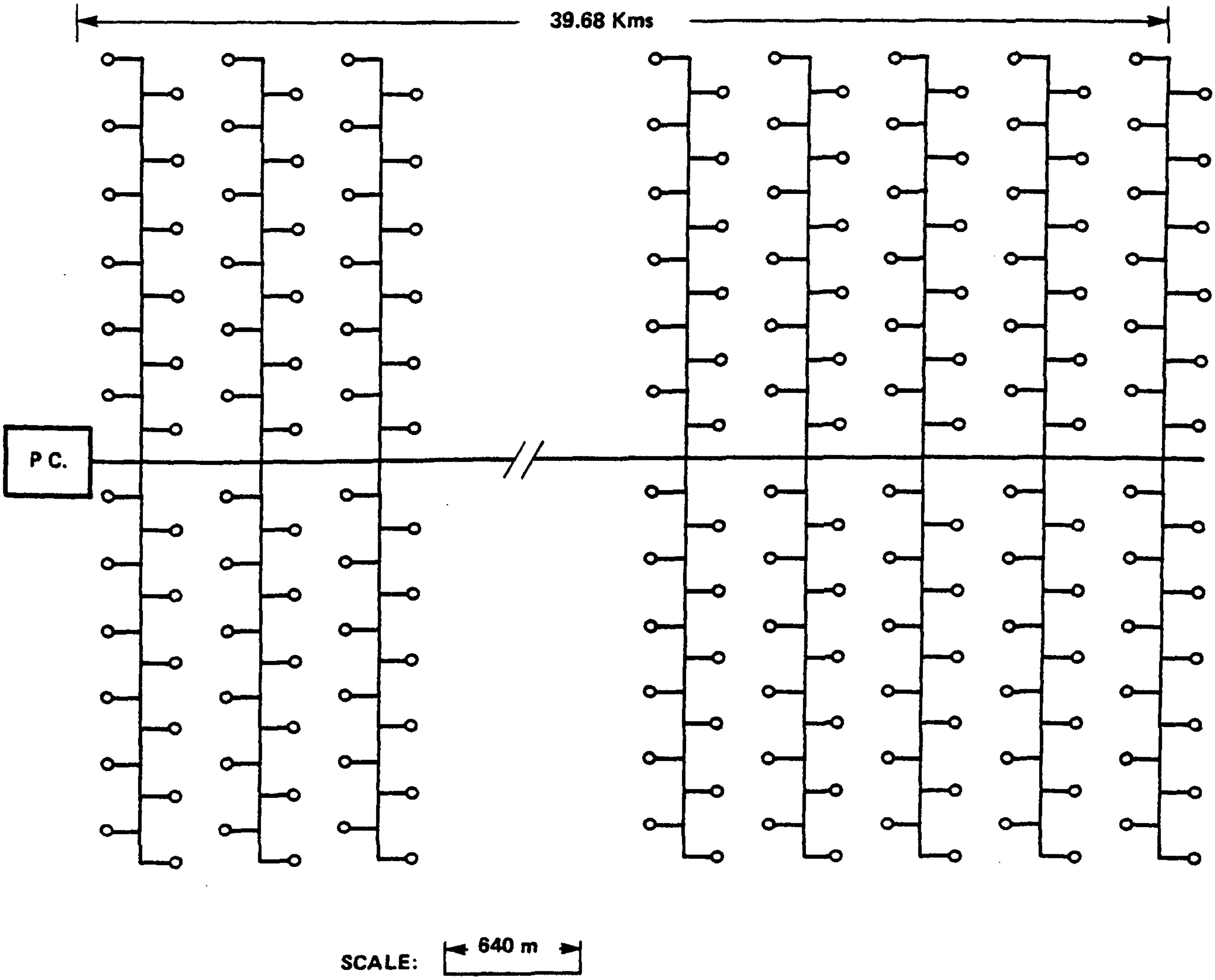


Figure 4.3 – Model for Rural Grid Population Distribution

A/Tree Model: Common highway from P.C. to each subscriber. 1488 subscribers divided into 4 groups of 372. All units in channel-kms.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
	5%	10%	15%	20%	25%
5	20 430	34 250	45 770	58 440	70 530
12	24 040	37 860	49 380	62 050	74 140
21	28 680	42 500	54 020	66 690	78 780
35	35 900	49 720	61 240	73 910	86 000

B/ Hybrid tree/star model: Common highway from P.C. to trunk/feeder interface where remote switches interface with two channel drops to each subscriber.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
	5%	10%	15%	20%	25%
5	7 160	9 550	11 550	13 740	15 830
12	7 860	10 250	12 250	14 440	16 530
21	8 750	11 140	13 140	15 330	17 420
35	10 150	12 540	14 540	16 730	18 820

C/ Star model: Two dedicated channels per subscriber all the way from the P.C

Channel capacity required: 63 570 channel-kms,independent of traff

NOTE: All figures rounded to the nearest 10

Table 4.1 Channel capacities for various networks (simplified model)

4.5 CHANNEL-KM CAPACITY OF A HYBRID TREE/STAR MODEL

One now superimposes the model of figure 4.2 b on the population distribution of figure 4.3. Once again the trunk is divided into four sections, each serving 372 subscribers with private access channels, and one section serving all subscribers with common access channels. Every 640 metres on the trunk a remote switcher is located (again it is stressed that this is not a realistic model). Every subscriber has his dedicated two channel path to the remote switcher, which can provide him access at any time to any channel on the public access channel, or access to any private channel which is free. It should be noted that altering the percentage usage by subscribers and the number of common access channels affects the number of channels (and hence channel-kms) on the trunk only, making the network less sensitive to traffic than that of section 4.4. The resulting channel-km capacity required for the range of usage probabilities and common access channels already discussed is also presented in Table 4.1.

4.6 CHANNEL-KM CAPACITY OF A STAR MODEL

If one superimposes the model of figure 4.2c on the population distribution of figure 4.3 it is easy to calculate the number of channel-kms capacity needed. The figure is 63,570 channel-kms independent of traffic.

5. OTHER FACTORS IN THE SELECTION OF A NETWORK

5.1 MULTIPLEXING APPROACHES: STATE-OF-THE-ART

To help compare possible networks the channel-km figures of section 4 must be used in conjunction with the other criteria which follow below. Consideration must first be given to multiplexing, repeating in the process some of the discussion of activity 2 and anticipating some results of activity 5. To transmit more than one analogue channel over a fibre one must use either frequency division multiplexing (FDM) or wavelength division multiplexing (WDM). Since wavelength and frequency are obviously related, some workers object to the term WDM instead of FDM. However, we make the distinction that, semantically, one talks of the wavelength of light more often than its frequency, and of the frequency of an electrical signal more often than its wavelength. Thus, we elect to use WDM to mean multiplexing of several light sources of different optical wavelength, and FDM to mean multiplexing of several electrical signals of different frequencies. (We assume time division multiplexing is ruled out due to the expense of the terminals and bandwidth requirements).

WDM offers many potential advantages, and preliminary calculations indicate that, using a diffraction grating coupler (possibly of holographic construction) something in the order of 20 sources may be used in the range 800 to 900 nm if each source has a full spectral width at 1/e intensity of 2 nm. (These sources, of course, could themselves use FDM). However, sources with sufficiently well defined spectra having uniform modulation characteristics are not available, nor are they likely to be in the next five years. Also the diffraction coupler (ref. 9) although perfectly simple in concept, needs development. Other simple approaches (i.e. not integrated optics) to WDM using filters introduce unacceptable losses for a high degree of multiplexing. Approaches using integrated optics are promising, but not for near term implementation. Although we will study the savings to be gained from developing a WDM system in order to evaluate the profitability of an investment in R. & D. in this area, we eliminate WDM from the discussion on systems for near term implementation.

In the case of FDM the limit on multiplexing is imposed by a combination of the interdependent variables of source linearity, power and bandwidth - calculations based on any one alone will be erroneous. Full calculations will be presented in activity five, but preliminary results indicate that there is no clearly defined cut-off allowing one to make a statement that x channels can certainly be transmitted y kms but x + 1 cannot. Based on devices currently available in the laboratory one can state with confidence that two channels can be transmitted over 56 km at the required 43 dB SNR and meeting other BP23 requirements. Predictions on higher degrees of multiplexing can be made with varying levels of confidence - one of the tasks in activity five will be to tabulate the device characteristics needed to achieve such multiplexing. For the present, however, we can only state with confidence that two channels can be multiplexed over the distances needed for rural areas.

5.2 EFFECT OF MULTIPLEXING ON SWITCH COMPLEXITY

The only criterion used so far for the selection of the optimum network has been the amount of fibre needed, which in general is minimised by multiplexing. In a hybrid tree/star network some thought must be given to the impact of multiplexing on the remote switch.

The simplest switching scheme which supplies 2 channels to each subscriber for an FDM trunk is that of figure 5.1(a). Here each subscriber is equipped with two fibres from the remote switch. The subscriber's fibres are simply switched via an electro-optic interface to two fibres on the trunk which carry the desired two channels plus others. Although simple, this scheme has many disadvantages. Firstly, to prevent the subscriber from accessing channels he is not authorized to view, some device must be provided at his premises, acting under control of the program centre or remote switch. Secondly, high level FDM on the trunk would require the switch to maintain its isolation between inputs at high frequencies. Thirdly most of the fibre in a network is in the distribution, thus doubling the amount of fibre there effectively doubles the total amount of fibre in the system. Finally, this approach is not compatible with WDM in the absence of a purely optical switch.

An alternative system which is convenient for the case where subscribers' feeders carry two channels each is shown in figure 5.1 (b). Here, purely for the purposes of the illustration, three channels per trunk fibre have been assumed. All channels coming into the switch are duplicated at the two frequencies used on the subscribers' feeders. Two spatial switches are provided per subscriber, allowing him to independently select his high and low channel signal. Thus, no matter what trunk multiplexing is used, all that is needed is two channel converters per incoming channel, whose cost is divided between all the subscribers sharing the switching machine, plus a spatial switch. This approach will be incorporated in the design of a remote switch in section 6, with two modifications. Firstly, private access channels will not be duplicated - a subscriber may only access one at a time. Secondly, a slight saving arises when the trunk also uses two channel FDM at the same frequencies as the subscribers' feeders - in this case some channel converters can be replaced by filters.

Switching on a full FDM network (all channels on one fibre) could be effected by a bank of frequency converters with no spatial switching. This point will be returned to briefly in section 6, but is likely to be expensive.

Finally, WDM as envisaged now, would best be switched by de-multiplexing and spatial switching.

Section 6 will discuss in more detail the components needed for switching and their assembly into suitable units. This discussion has merely been to highlight switching as a factor which is affected by multiplexing.

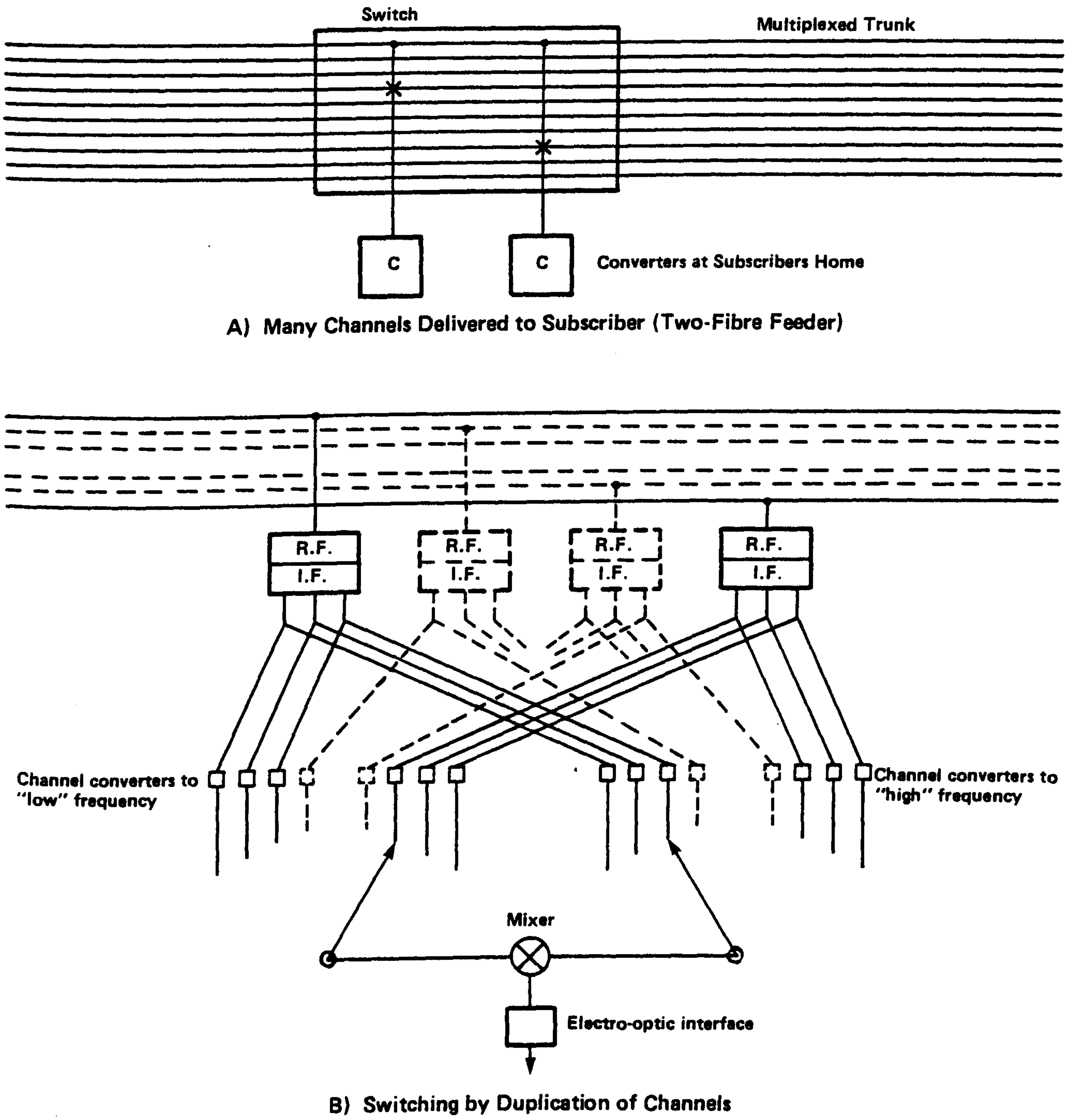


Figure 5.1 – Two Possible Switching Approaches Providing Two Channels Per Subscriber

5.3 COUPLERS AND TAPS

As has already been stated, highly multiplexed systems save fibre. Point to point links, such as trunks from a program centre to a remote switch, can effectively use multiplexing without any added requirements on couplers. However, it is the distribution area of a hybrid star/tree network which uses most of the fibre. If one departs from a one fibre per subscriber approach and, instead, multiplexes many channels on one fibre with each subscriber allocated his own wavelength or frequencies (or both) the fibre saving is great, but optical couplers must be used widely in the system. Such systems will be considered in detail in section 8.

It was noted in the state-of-the-art review (Activity One) that optical couplers are still in an early stage of development. It is recommended that development work on couplers suitable for field use should be started as early as possible if a field trial is planned in the next five years. For highly multiplexed (WDM or FDM) systems of the future such couplers will be indispensable and their availability will be assumed in section 8 of this activity, entitled "Model networks suitable for long term implementation".

Even in systems with one fibre per subscriber, couplers can play a very useful role by permitting bidirectional use of the fibre, as discussed in the next sub-section (5.4).

5.4 UPSTREAM TRANSMISSION

So far all discussion has centred on the downstream video channel (with the implicit assumption that, where necessary, downstream low capacity control signals would follow the same path, using FDM). Upstream video, as discussed in section 3, will always be considered a minority service, to be provided in optimum fashion as an overlay on the optimised downstream network. An extra fibre per subscriber plus special repeaters would be permitted. However, upstream "audio" (using this term to mean the low bandwidth channel of section 3.4) has to be supplied to each subscriber. The first approach that could be suggested would be the use of existing telephone pairs. However a quick calculation based on just one of the functions of this channel, namely channel selection in a tree/star or star configuration, shows that this method is not feasible. A modern digital telephone switching machine serving 50,000 subscribers has a capacity of 350,000 call attempts per hour. If 50% of these subscribers were to make an attempt to change channels within 3 minutes (including many who will make several attempts to "scan" the channels), one has a rate of 500,000 call attempts per hour during that 3 minute period. If to this one adds the background calling rate of two attempts per hour (3.6 ccs/hr of average duration 180 secs) one has a total of 600,000 attempts per hour - 70% above the machine's maximum rating, which is totally unacceptable.

This telephony blocking problem arises partly because a machine designed to efficiently couple any of N subscribers to any other subscriber is being asked to connect any of N subscribers to one subscriber. In theory several approaches could be used to bypass this, such as putting control signals over the telephone pairs at some frequency such as 5 kHz and filtering these out at the telephone switching centre for delivery to the video program centre for buffering and processing. Since space is very restricted in telephone switching centres, and the increasing introduction of digital transmission and digital multiplexing may make such schemes difficult, this approach cannot be recommended. A suggestion, patented by BNR, for using telephone pairs for such applications as meter reading or opinion polling is the "Votaphone", (ref. 10) which operates by inducing longitudinal earth return currents in the telephone pairs, and detecting simultaneously the current in a hundred pairs. Unfortunately the highly peaked traffic statistics of our traffic again makes this approach impractical in its present form, and detection of longitudinal currents in smaller groups of pairs is difficult due to lack of space in telephone offices.

Having discounted the use of the telephone pair one has the choice of installing a special upstream medium (fibre or copper, whichever is cheaper) or using the existing fibre in a bidirectional manner. For the star/tree hybrid introduction of an extra fibre on the trunk for signalling between the remote switch and P.C. would not have a large percentage effect on the amount of fibre needed, but another fibre per subscriber in the feeders would. The arrangement of figure 5.2 shows a solution which one could be confident of implementing with a modest development effort. Couplers are used at the switch and at the subscribers premises. Upstream control signals are transmitted at a frequency incapable of interfering with the video signal, thus reducing the isolation requirements of the subscribers' coupler. Development of this system is identified as a task needing attention some years before any field trial. As implied above, low bandwidth signals from a remote switch to the program centre could be multiplexed together over a dedicated fibre without greatly adding to the cost per subscriber.

With multiplexed tree structures, upstream transmission involves coupling FDM or WDM signals into an upstream fibre, with some risks due to noise gathering, as discussed in the next section.

5.5 NOISE GATHERING

Much attention has been given in articles on upstream coaxial cable based broadband communications to the problem of "noise gathering" (ref. 11). This phenomenon occurs in FDM systems, especially those using large numbers of cascaded repeaters. The problem for a coaxial cable system is illustrated in figure 5.3. Many subscribers, Sij, transmit signals by repeatered coaxial cable to the point marked C.O. The system has been compared to a large funnel, since noise entering at any point on the network reaches C.O., whereas in the downstream path only noise

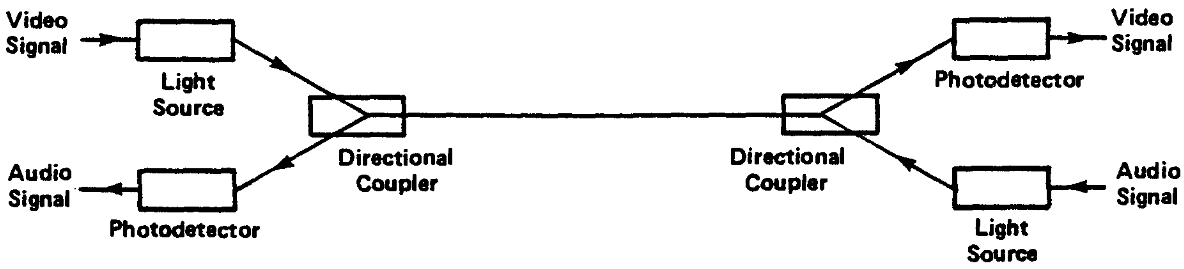


Figure 5.2 — Bidirectional Operation of a Fibre

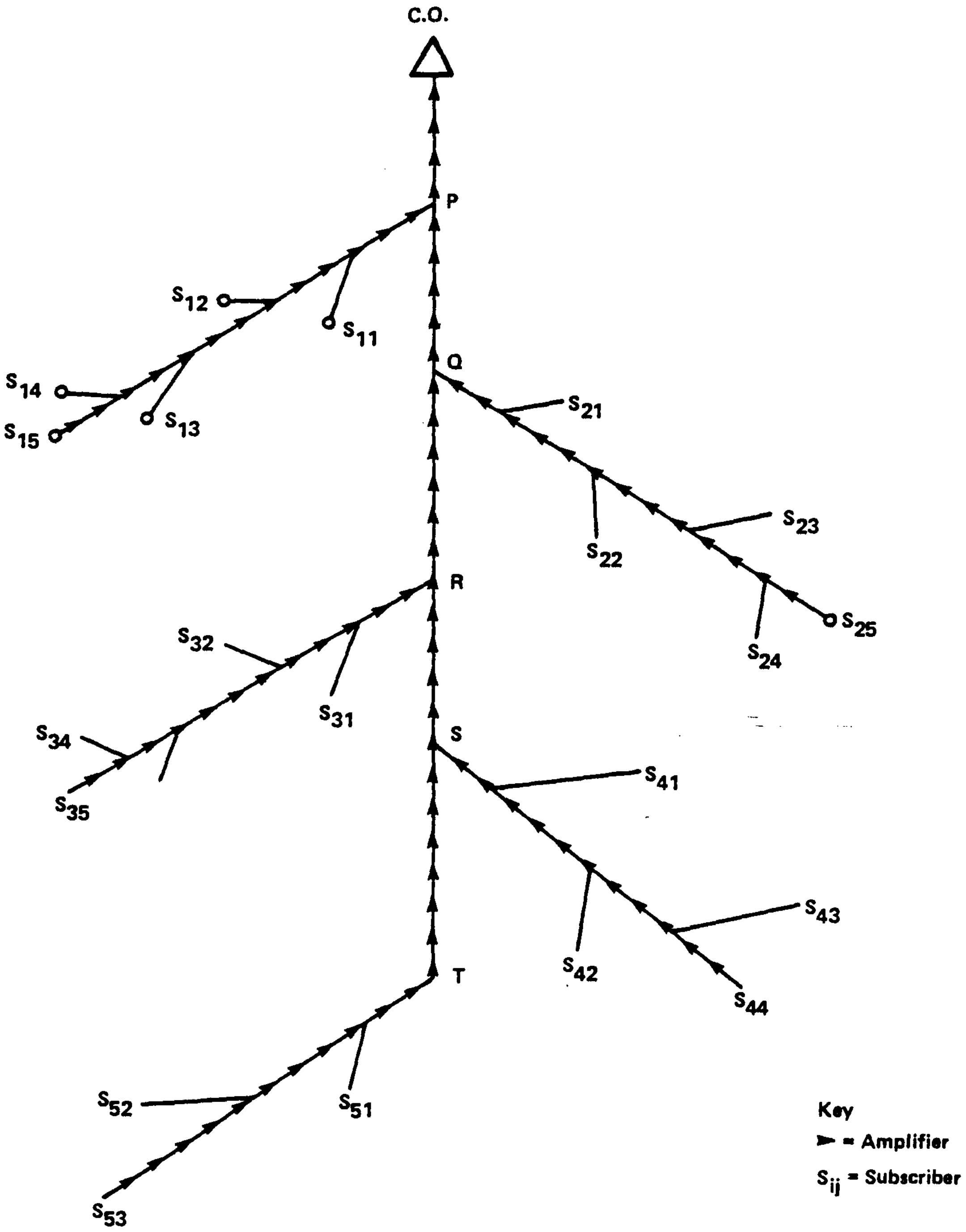


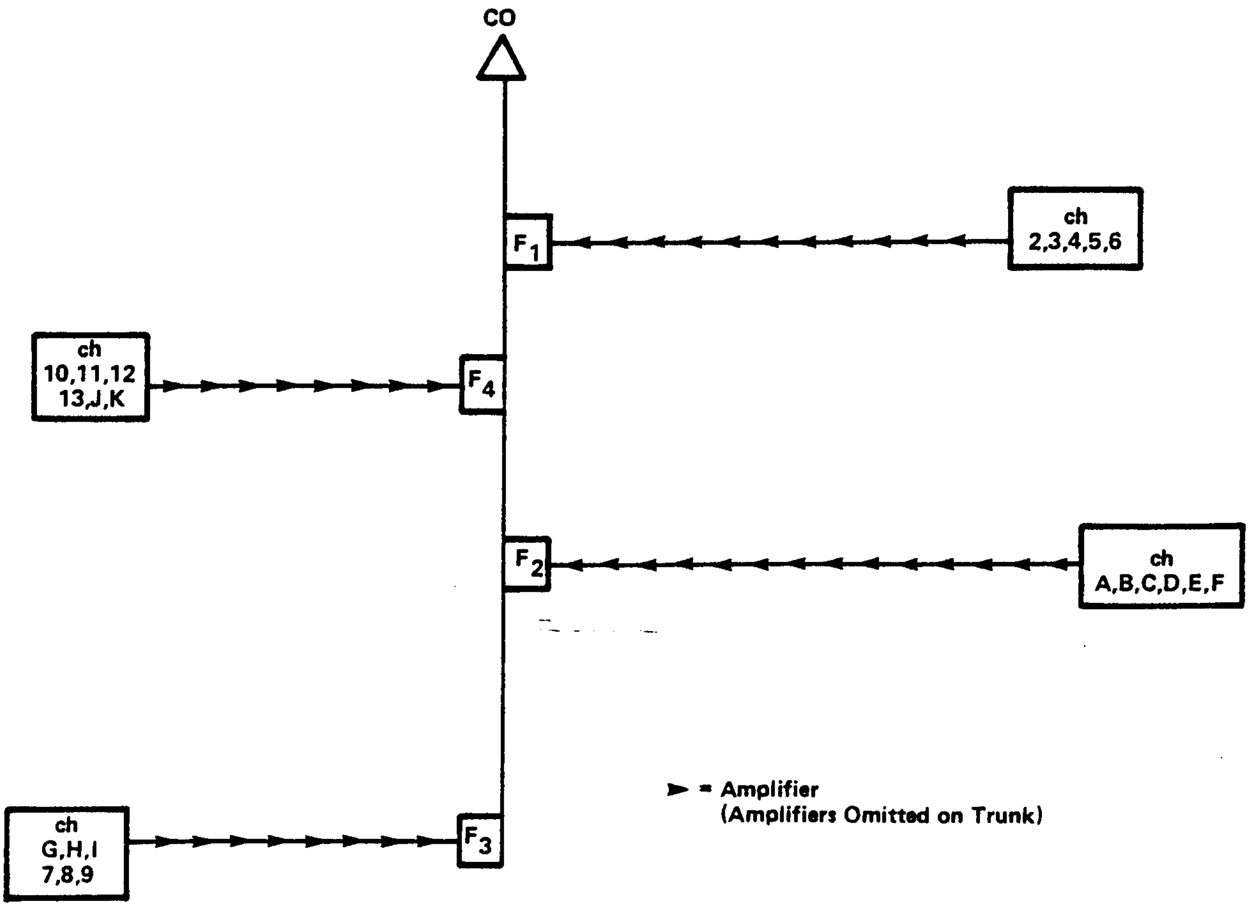
Figure 5.3 – An Illustration of Noise Gathering

entering the system along the direct path from C.O. to a given subscriber affects that subscriber. Thus, taking the purely hypothetical network of figure 5.3, all 86 amplifiers shown contribute thermal noise at C.O. and this noise is "white", therefore it affects all channels equally. In the downstream direction the worst case arises at subscriber S_{53}, where 38 amplifiers between C.O. and S_{53} contribute - a difference of about 3 dB. In addition to the easily quantifiable effects due to thermal noise one has noise contributions due to radio frequency ingress (RFI) at open splices in the copper cable and in the comparatively poorly shielded drops to subscribers' premises, as well as spurious signals from faulty subscribers' equipment. All these noise sources have the same funnelling effect amplifying them in the upstream direction.

It will be noted that the central cause of noise gathering is that noise sources are all considered white. Thus, no matter where the noise enters the network it affects all channels.

In allocating signal to noise objectives to the network of figure 5.3, therefore, one can specify high SNRs to each arm. If the objective for SNR degradation between any subscriber and C.O. is 40 dB, for example, one could allocate $40 + 10 \log 6 \approx 48$ dB to each of the arms and to the trunk PQRST. Should this standard be impossible to meet, noise gathering can be restricted by using filters, as in figure 5.4. Here, F1 is a bandpass filter passing only channels two through six, and thereby rejecting noise falling in any other bands which entered the network on the arm passing through F1. Subscribers served by this arm must, of course, transmit on channels two through six only. The function of filters F2, F3 and F4 is identical to that of F1, with appropriate constraints on the channels used by subscribers whose signals pass through these filters. The only word of caution here is that currently available filters are not sufficiently flat to permit more than three of them to be cascaded in a total system (fewer if a channel converter occurs in the system). Surface Acoustic Wave (SAW) technology will hopefully remedy this limitation.

With specific reference to fibre optic systems, it is apparent that the funnelling effect central to upstream noise gathering only arises with FDM tree type structures. (It is assumed that noise sources are not sufficiently broadband as to affect a WDM system - i.e. the separation in optical frequency between two light sources is greater than the noise bandwidth. There will be some noise gathering in a WDM system due to imperfect isolation between channels, but this is a very insignificant effect. Non-linear optical effects could also contribute, but these effects should be negligible in multimode fibres at normal power levels.) Highly multiplexed FDM networks are unlikely in the near future, if ever, due to the linearity constraints already mentioned together with the difficulty of coupling. If, however, they are ever implemented calculations of noise gathering and allocation of degradations to sections of the network have proved to be quite straightforward in the case of coaxial cable networks.



F_1 = Band–Pass Filter for Channels 2 Through 6

F_2 = Band–Pass Filter for Channels A Through F

F_3 = Band–Pass Filter for Channels G Through I and 7, 8 and 9

F_4 = Band Pass Filter for Channels 10 Through 13, J and K

Figure 5.4 – The Use of Filters to Control Noise Gathering

Noise sources other than thermal noise need to be considered for fibre systems as for coaxial cable systems, even when funnelling does not occur. Direct inductive ingress into the fibre cable does not occur, but even with coaxial cable systems this is rarely a major problem. Repeaters used in fiber systems will need the same shielding as in coaxial cable systems. In fact, since noise from electrical machinery, car ignition and, recently, CB radios is mainly located below 50 MHz, and this is the frequency range where fibre systems will operate initially, screening will have to be good. On the other hand an attraction of fibre systems is that far fewer repeaters will be needed than the one every 500 metres typical of CATV installations. In fact, the separation between repeaters will probably be an order of magnitude greater. Ingress at any point in a fibre system with open metallic wiring (such as at the subscriber's premises or at remote switches) will need to be avoided in exactly the same way as in CATV systems. At the risk of repetition, though, it is pointed out that the funnelling or noise gathering effect which magnifies ingress on an upstream FDM coaxial cable system will not arise with practical (low multiplex) fibre systems.

In summary, then, problems of noise gathering are minimal for fibre optics systems in a star or hybrid star/tree configuration. Even in FDM trees the problems are significantly less than in coaxial cable systems. In all video systems (coaxial cable, fibre or microwave) care must be taken to adequately screen amplifiers, switches and any other sources of radio frequency ingress.

5.6 FLEXIBILITY

A property of a system which is hard to quantify is its flexibility - how easy is it to accommodate some new requirement with that system? From the point of view of serving a new subscriber, tree structures are the most flexible, since all that is needed is to run a drop from the new subscriber to a coupling point on the feeder. This is true with electrical tapping, as defined in Activity 2, but is not the case when optical tapping is used.

From the point of view of providing extra channel capacity, star systems are the most flexible, since no modifications are needed to the outside plant, only a change in the switching machinery. A tree/star hybrid needs upgrading of all remote switches together with extra fibres connecting the program centre to each remote switch. Tree networks need extra fibres to be installed throughout the whole network, along with extra repeaters and couplers.

6. VIDEO SWITCHING

6.1 INTRODUCTION

The remaining major component which needs to be considered before constructing realistic system models is the video switch. We have already mentioned that switches fall into two classes: spatial and frequency. Both will be needed in systems which use any frequency multiplexing. Frequency switches are channel converters - a signal occupying one position in frequency space has to be transferred to another region in frequency space. Spatial switches are collections of cross points - N inputs for connection to M outputs need NM crosspoints on a matrix. What those crosspoints are, physically, makes no difference to the block schematic of the total switch, although it obviously greatly affects the cost of the switch and such factors as its size and power requirements.

The main parameter which we use to define both kinds of switch is the ratio of the desired to undesired signal passing through a many-input switching assembly to any output. The most stringent requirement is for the elimination of single frequency interference falling near the video carrier or colour sub-carrier of the desired signal. Where such single frequency interference is completely uncorrelated with the carrier (or sub-carrier) near which it falls, its effect is severe, and BP23 specifies that it must be 57 dB down with respect to the carrier (or sub-carrier) at the subscribers' premises. However, when the single frequency interference is at exactly the same frequency as the carrier or sub-carrier with a constant phase relationship, its effect is much less severe. In harmonically related carrier (HRC) FDM systems all video carriers are harmonically related, and single frequency interference due to intermodulation falling near a video carrier can be as little as 40 dB down with respect to the carrier (ref. 12). Colour sub-carriers, being typically 15 dB down on the video carrier give negligible intermodulation products.

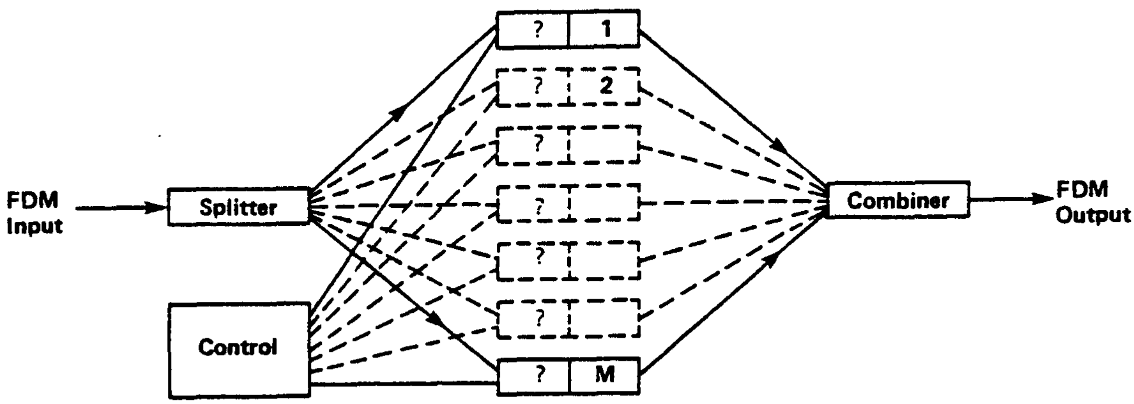
With spatial switching, Rediffusion experience with their Dial-A-Program system has been mainly derived from systems where they control the video carrier, which is the same for each signal, and hence 40 dB isolation at the carrier is ample. In this case, however, interference between colour subcarriers cannot be ignored. In intermodulation systems one is concerned with interference between a relatively weak colour sub carrier, and the product of three other such carriers, which are negligible. With spatial systems, interference is simply between one weak sub carrier and another equally weak sub carrier. Some operators report adequate phase stability between colour sub-carriers from various live programme sources to tolerate 40 dB isolation, such stability arising since the colour sub-carrier is derived from the 60 Hz of the public utilities' electricity supply. However, when distant signals are imported or, worse, when recorded programmes are encountered then the full 57 dB isolation will be required. On this basis, we specify that received signals must meet BP23 with respect to single frequency interference. (note that, due to colour sub-carriers this applies to baseband signals as well as RF signals).

The problem now remaining is allocation of single frequency interference between the switch and the transmission line. This allocation will depend on the multiplexing used in the transmission system. With FDM and WDM single frequency interference will accumulate in the transmission network through intermodulation and cross talk (inadequate optical wavelength selectivity) respectively. Without multiplexing, or with low levels of FDM using frequencies which cannot produce beats falling on or near carriers, negligible single frequency interference should accrue in the transmission path. For systems with intermodulation (cable transmission) CBC specifies -66 dB for single frequency interference other than in the transmission medium, leaving -57.5 dB for the transmission medium to meet BP23 at the subscriber's terminal. Allowing for a signal to pass through two switches in our system (one at the P.C., one at the remote switch) we therefore tentatively require switches to have 69 dB isolation at both carrier and colour subcarrier frequencies in a system contributing single frequency interference on the distribution network. In systems without such degradation on the transmission medium, 60.5 dB isolation is tentatively specified, requiring a contribution no greater than -66 dB from the transmission medium.

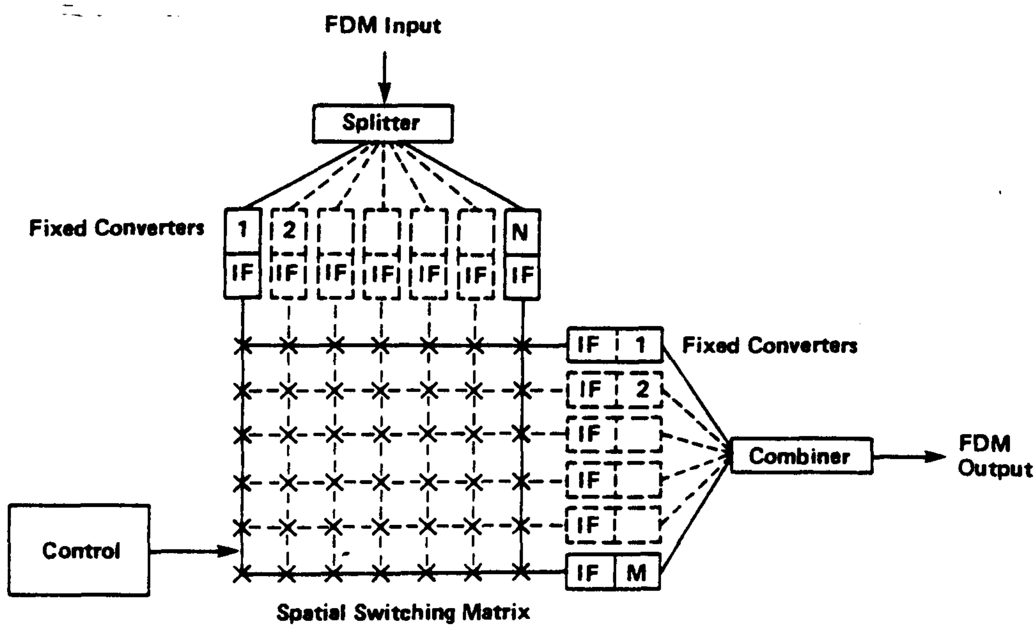
In summary, colour sub-carrier crosstalk dominates the requirements for baseband and controlled carrier systems. Such a requirement derives from specifications designed for systems where such an effect does not occur in practice, therefore some experimental work to investigate the subjective effect of colour sub-carrier crosstalk is needed. If a switch with the isolation specified above is provided, though, it is no longer necessary to synchronise video carriers (if used), allowing more flexibility.

6.2 FREQUENCY SWITCHING

In a purely FDM system (i.e. only one fibre with all the required channels multiplexed on it) the system of figure 6.1 (a) acts as a switch. A tunable oscillator at each location marked "?" converts the desired signal to IF for re-conversion to the desired output channel. For example, if it is desired to switch the signal entering the switch on channel 9 to leave on channel 2 the control signal would select the appropriate oscillator frequency at the converter whose output is channel 2. Note that it is preferable to have a variable input oscillator rather than vary the output, since in this way a fixed high quality filter at the output of each converter can minimise spurious frequency outputs. Development work would be needed for such a switch. Some problems may arise due to the fact that the filter normally used at the input to a fixed channel converter cannot be used.



a) Frequency Switching Using Tunable Converters



b) Frequency Switching Using Fixed Converters and a Spatial Switch

Fig. 6.1 — Frequency Switching

Figure 6.1 (b) shows another switching arrangement which could be used for a pure FDM system and which would be necessary for a system with several fibres each operating in an FDM mode. Here all channels are converted to IF and a spatial switch is used. In general this system is preferable to that of figure 6.1 (a), especially since a pure FDM system is improbable with fibre optics. We will assume throughout the rest of this discussion that, if FDM were used, a scheme like that of figure 6.1a would be available, thereby making the switching problem a purely spatial one. A similar approach can be taken with W.D.M.

6.3 STATE-OF-THE-ART

6.3.1 TECHNICAL COMPARISON

For frequency switching the fixed channel converters of figure 6.1(b) come from several suppliers (such as Scientifica Atlanta, RCA). The tunable converters need development.

For spatial switching the cross-points can take many forms, and the lay-out can resemble a matrix or a step by step configuration. The literature reports the use of reed relays, crossbar and solid state crosspoints, with reed relays the most widely used.

Practical experience with operating systems is almost entirely restricted to the Rediffusion "Dial-A-Program" system. An array of six of the switches used by Rediffusion is shown in figure 6.2. The cross-points activated by the step-by-step action switch are all reed relays, and the switch units are commercially available as two pole 36 input units. Isolation against crosstalk from one channel for the switch alone is specified as 63 dB at 9 MHz (inputs in quadrature). (The more widely quoted figure of -45 dB includes a length of copper wire in the Rediffusion "Quist" arrangement). Other commercially available reed relays are available from Trompeter and Matrix Systems Corporation, with isolation up to 100 dB at 100 MHz. It should be noted immediately that these are considerably more expensive than Rediffusion's crosspoints (prices below). Other workers also report the use of reed relay crosspoints for video switches (ref. 13, 14) with best isolation figures of 60 dB at 4 MHz.

Work on cross-bar switches for video has also been published (refs. 15-17). Isolation on these switches is typically 50 dB at 4 MHz. Solid state cross points offer the most compact switching units. Although several articles have been published (refs. 18-20) the best performance seems to be that of the switch designed by the BBC for studio mixers, using FET's (refs. 21, 22). By careful attention to circuitry, isolation of over 70 dB with baseband colour video signals is reported, with higher isolation available using better FET's. In passing, it is noted that this circuitry introduces sufficiently small differential delays in different paths to allow output signals to be combined in split screen type effects, thus the standards are more than adequate for our

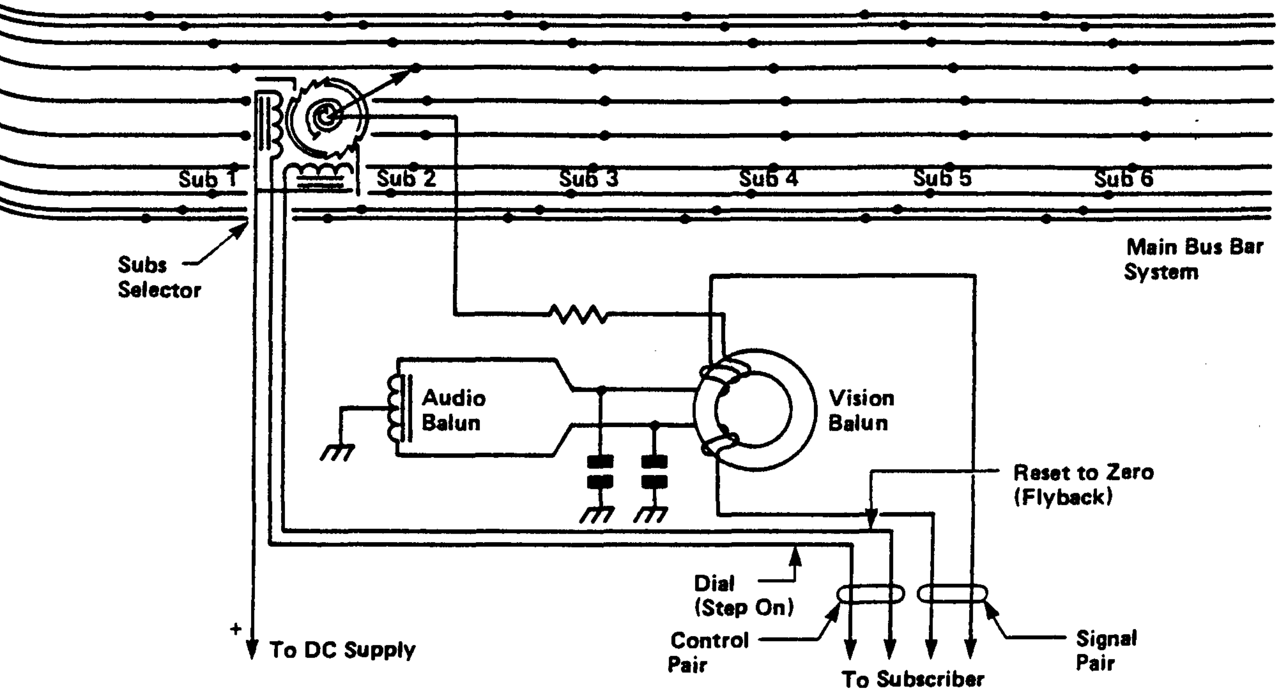


Figure 6.2 — Rediffusion Dial-A-Program Switches

purposes. Rediffusion, in a private communication, comment that they have studied the application of solid state switches to their system, and project costs about 80% greater than those of their reed relay switches. Several manufacturers have been approached concerning their solid state video switches. The only commercial solid state video switch encountered by the authors is from the Matrix Corporation, with isolation of 60 dB at 10 MHz (FET) or 60 dB at 30 MHz (diode).

6.3.2 BALL-PARK PRICE COMPARISON

Prices are based on somewhat limited information available since many of the switches are not commercially available and other prices were salesmen's over-the-phone prices, which could be reduced with large orders. The Rediffusion Dial - A - Program switch sells for about $1 per cross-point. (42 pounds sterling for a 2 x 36 switch). Their projected cost for a solid state switch was about $1.80 (48 pounds sterling for a 4 x 12 switch in quantities of 100,000). (Both 1976 prices). The Trompeter and Matrix reed relay switches reflect their excellent isolation properties in the very high price of approximately $25 per cross point.

In view of the potential economics of hybrid circuitry, it is believed that, given an adequate demand, solid state circuits could be produced at prices competitive with relays, and such switches would offer considerable savings in bulk, which will be of special importance for remote switches. Estimates are awaited from some manufacturers.

6.4 DESIGN AND OPERATION OF A REMOTE SWITCH

6.4.1 DESIGN

Figure 6.3 shows a design for a remote switch. Following the discussion of section 5.1 it is assumed that fibres, both in the trunk and in the subscriber's feeders, are multiplexed with two channels, "high" and "low". (The multiplexing on the trunk, in fact, does not greatly affect the switch design). The actual frequencies do not affect the switch, except that isolation is harder to provide at higher frequencies. Since the nature of the switches is not specified yet, there is no need to unnecessarily specify the frequencies at this stage. The remote switch uses the ideas of section 5.1 to save on cross points by restricting each subscriber to a maximum of one private access channel at any time. Thus the private access channels on the trunk from the program centre are demultiplexed by simple filtering of the low channel and down conversion of the high channel, as shown, for input to the low band switching matrix only. Common access channels are duplicated at high and low frequencies, and input to the low and high band switching matrices.

Control signals from the subscriber together with "upstream audio" signals are coupled off the subscriber's fibres as described in

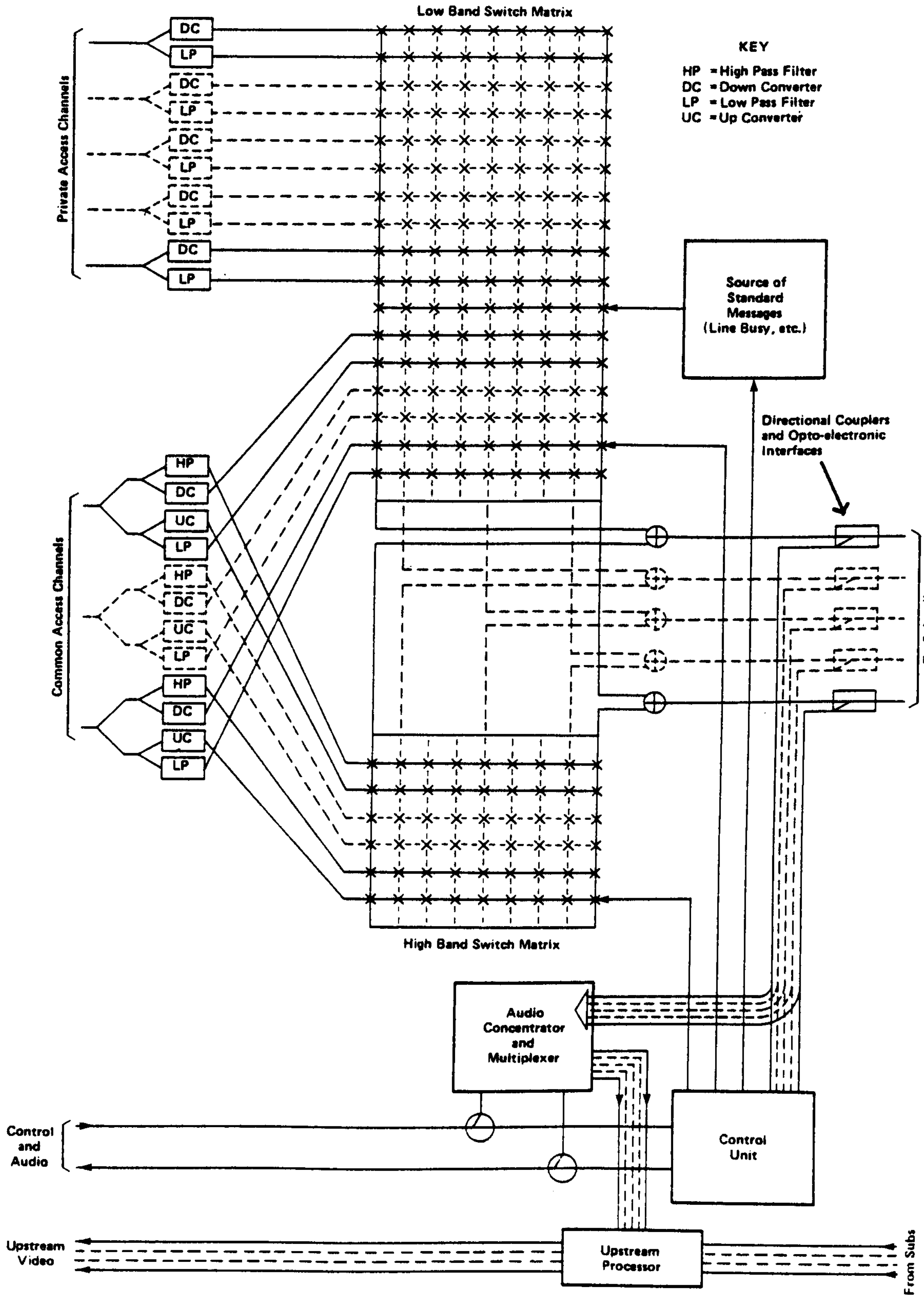


Figure 6.3 – Design of a Remote Switch

section 5.4. The control signals, on frequency f_c, are filtered off for input to the control unit, while audio signals enter a concentrator, acting under the control of the control unit, as described below.

Upstream video signals undergo no switching at the remote switch, but are amplified if necessary and transmitted directly to the program centre.

6.4.2 OPERATION

Figure 6.4 shows a flow chart for the operation of the remote switch, in response to requests for video service. One thing to notice is that the use of the local video display for messages is inefficient - if all subscribers have frame grabbers their use for signalling would be superior.

Figure 6.5 shows the flow chart for handling upstream audio to a video originating subscriber - the only permissible use for upstream audio in this activity.

6.5 DESIGN AND OPERATION OF A PROGRAM CENTRE

Figure 6.6 shows a block diagram of a program centre.

In order to minimise switching, program origination for each remote switch is handled separately in dedicated patch areas. If this is not done, an enormous patch board is needed, with several thousand inputs for patching to any of several thousand outputs. Separate patch areas need slightly more program sources in total, but significantly reduce the patching complexity.

Figure 6.7 shows the lay-out of a patch area.

As seen from the flow diagram of figure 6.4 the P.C. is not involved in CATV or Pay TV operations, other than for accountancy and the original provision of these services. For visual library requests, the P.C. operator has to load the tape requested, if the tape is available and a line is free, and inform the remote switch which channel is being used for transmission. Normally, each video player will be associated with a given line, so continuous re-patching is not needed.

If a request for a subscriber originated video (S.O.V.) channel is received, the operator in the patch area serving the subscriber making the request will determine if the subscriber is authorized to view that program, and whether a channel is available, and will then patch the free channel using the bus carrying all subscriber originated video channels. (If the signal is already being transmitted to the subscriber's remote switch, the channel number being used will be relayed to the remote switch, so that two channels from the P.C. to the remote switch are not tied up with the same transmission.)

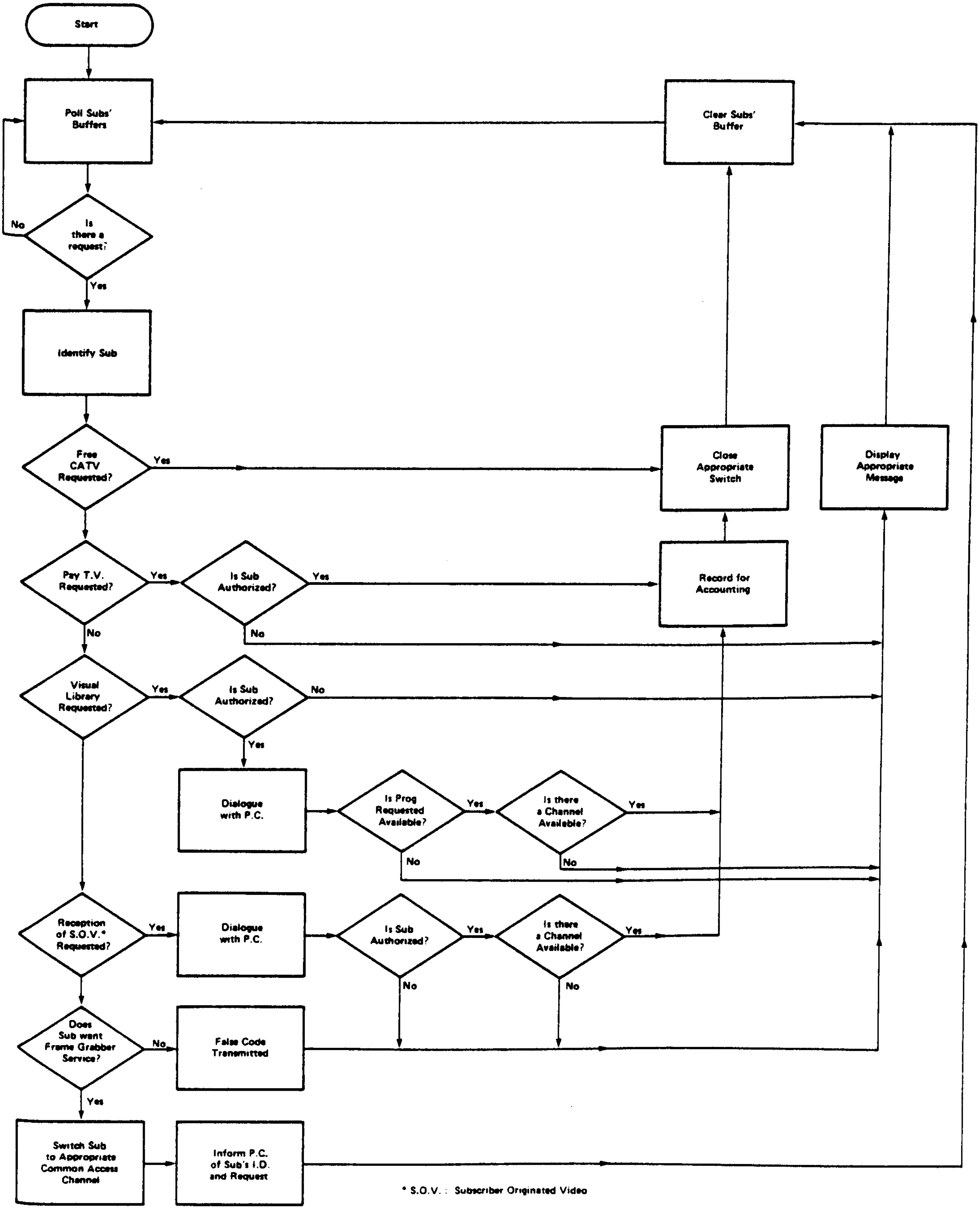


Fig. 6.4 – Video Switching Flowchart

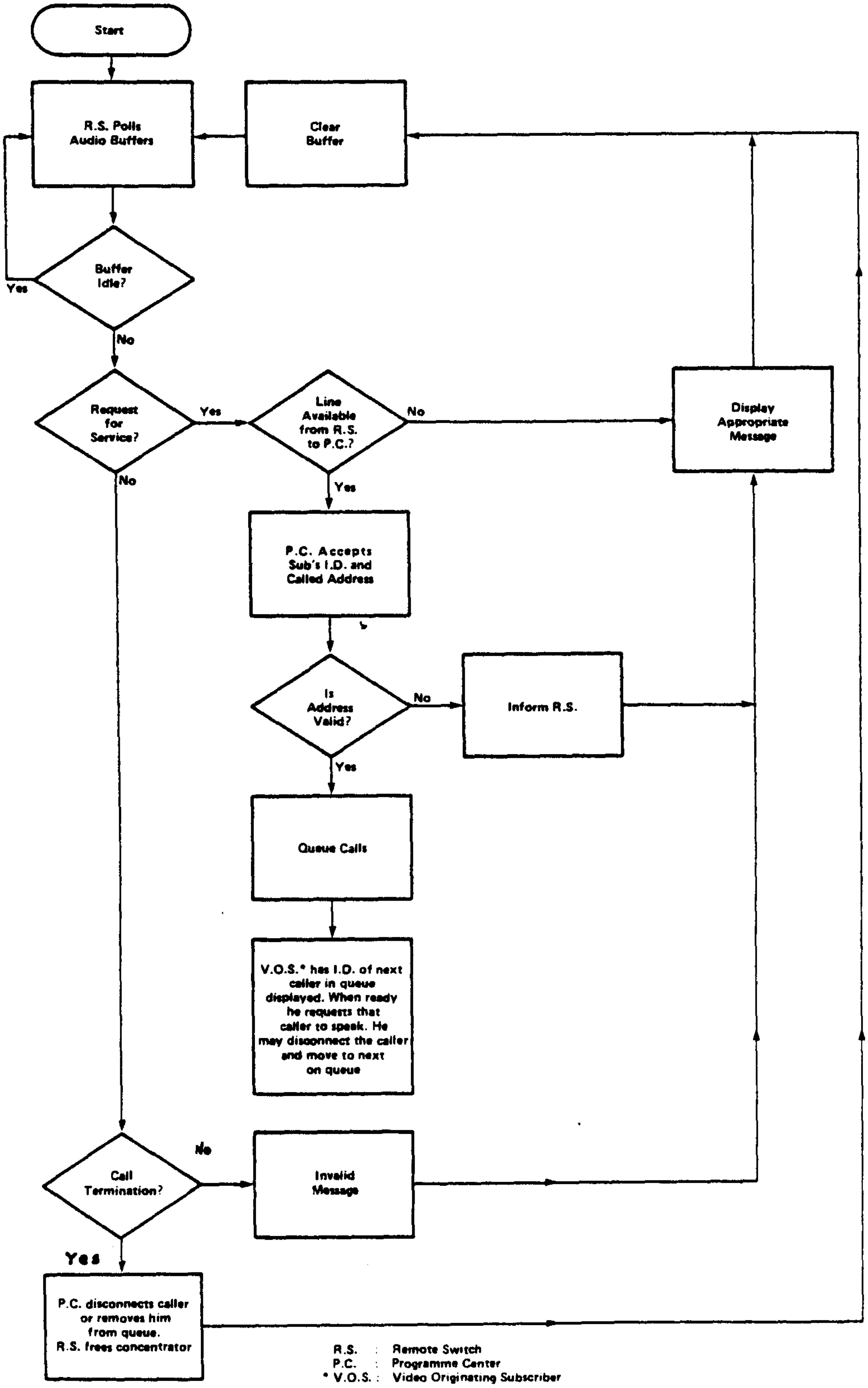


Fig. 6.5 – Upstream Audio Switching Flowchart

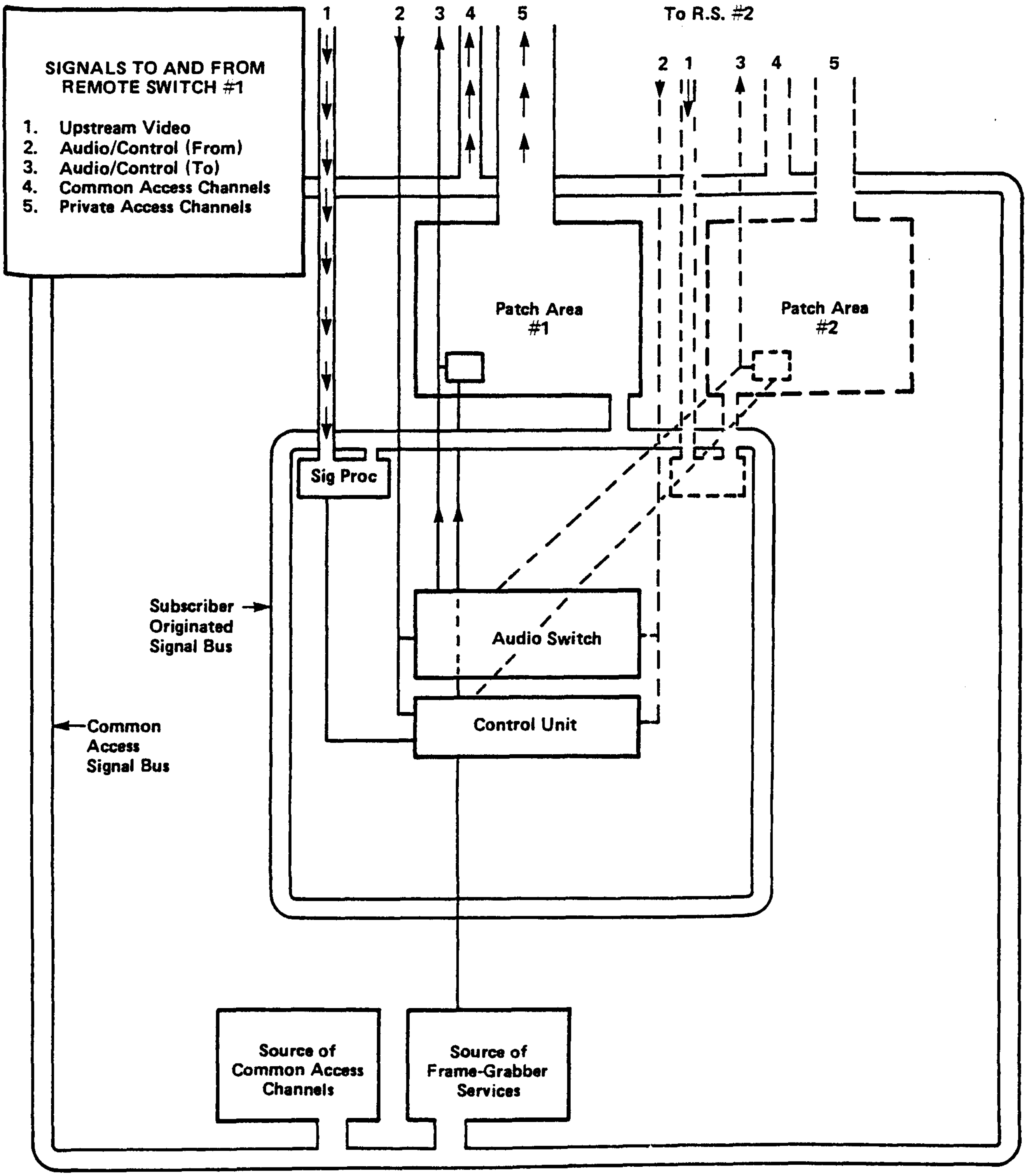


Figure 6.6 – Design of a Program Centre

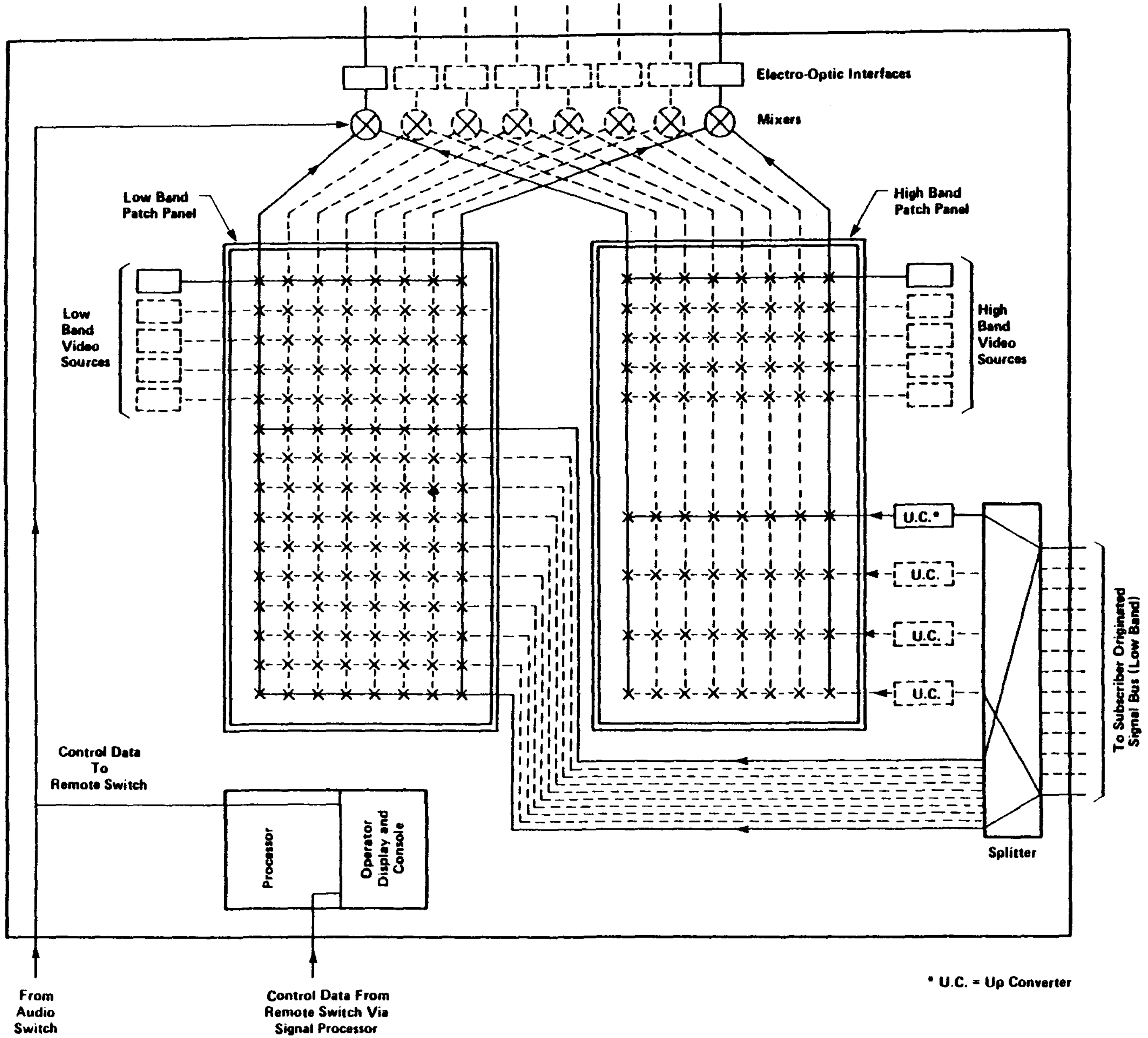


Fig. 6.7 — Details of a Program Centre Patch Area

Requests for frame grabber services are not referred to the patch area, but rather to a "source of frame grabber services". Depending on traffic this source area may have one common access channel per group of remote switches, or one or more common access channels per remote switch. The message requested is put on the channel serving the subscriber, with his individual address encoded on it.

The Audio Switch at the P.C. performs the tasks assigned to it in the flow chart of figure 6.5.

One problem which has not been treated is signalling to a subscriber that someone wishes to transmit a S.O.V. channel to him. In practice this is done most easily by using the telephone. If, however, it is wished to do this within the network, the remote switch control unit could multiplex a low capacity control channel on the mixers serving each subscriber, and any message on this control channel could activate an alarm. This channel could also be used by the control to poll meters at the subscriber. In the absence of such a channel, meters would simply transmit at certain preselected frequencies on the upstream control channel. However, this problem is more properly delegated to activity 3.

7. MODEL NETWORKS SUITABLE FOR NEAR TERM IMPLEMENTATION

7.1 GUIDELINES

From the discussions above we impose the following restrictions on a network for near term implementation:

i) Multiplexing will be by FDM and will transmit no more than two channels per fibre.

ii) Couplers will be kept to a minimum. No couplers will be permitted outside the switching units and subscribers' residences.

Several implications follow from these restrictions. The first restriction would make a tree distribution very expensive on fibre for large channel loadings. The second restriction makes the use of a tree structure even less attractive, since subscribers' drops would have to be taken from repeaters, thereby considerably increasing fibre requirements. (See the discussion on "electrical tapping" in activity 2). Of the two remaining networks discussed in section 4, the star network was shown to be expensive on fibre. Thus, one is left with the star/tree hybrid as the optimum from the point of view of fibre requirement.

7.2 THE GRID TYPE RURAL DISTRIBUTION

We now construct a more realistic model than that of section 4 for a hybrid tree/star network serving a rural population distributed on a grid. The serving area of each remote switch is chosen to have a maximum feeder length of 4.16 km to any subscriber*. This is considered to be a fairly conservative estimate for a repeaterless fibre carrying two channels. Increasing this length would decrease the total number of remote switches needed to serve a given area at the expense of increasing the total amount of fibre needed. The model of figure 7.1 shows how 364 subscribers on a 320 metre grid would be served in such a system. Feeders are assumed to follow a rectilinear path, following roads. Using the graph of figure 4.1, Table 7.1 shows the number of private access channels needed to serve 364 subscribers.

A practical problem, for discussion in later activities on outside plant considerations, is the nature of the cabling. Every fibre must eventually be packaged adequately to run on its own to a subscriber. However, a cable leaving the remote switch with 100 fibres so packaged would be bulky. A suggestion is that the cable should consist of sub-assemblies of, say, 12 fibres, which could be spliced to 12 individually cabled fibres when needed.

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*The precise figure of 4.16 is dictated by the 320m. separation of subs.

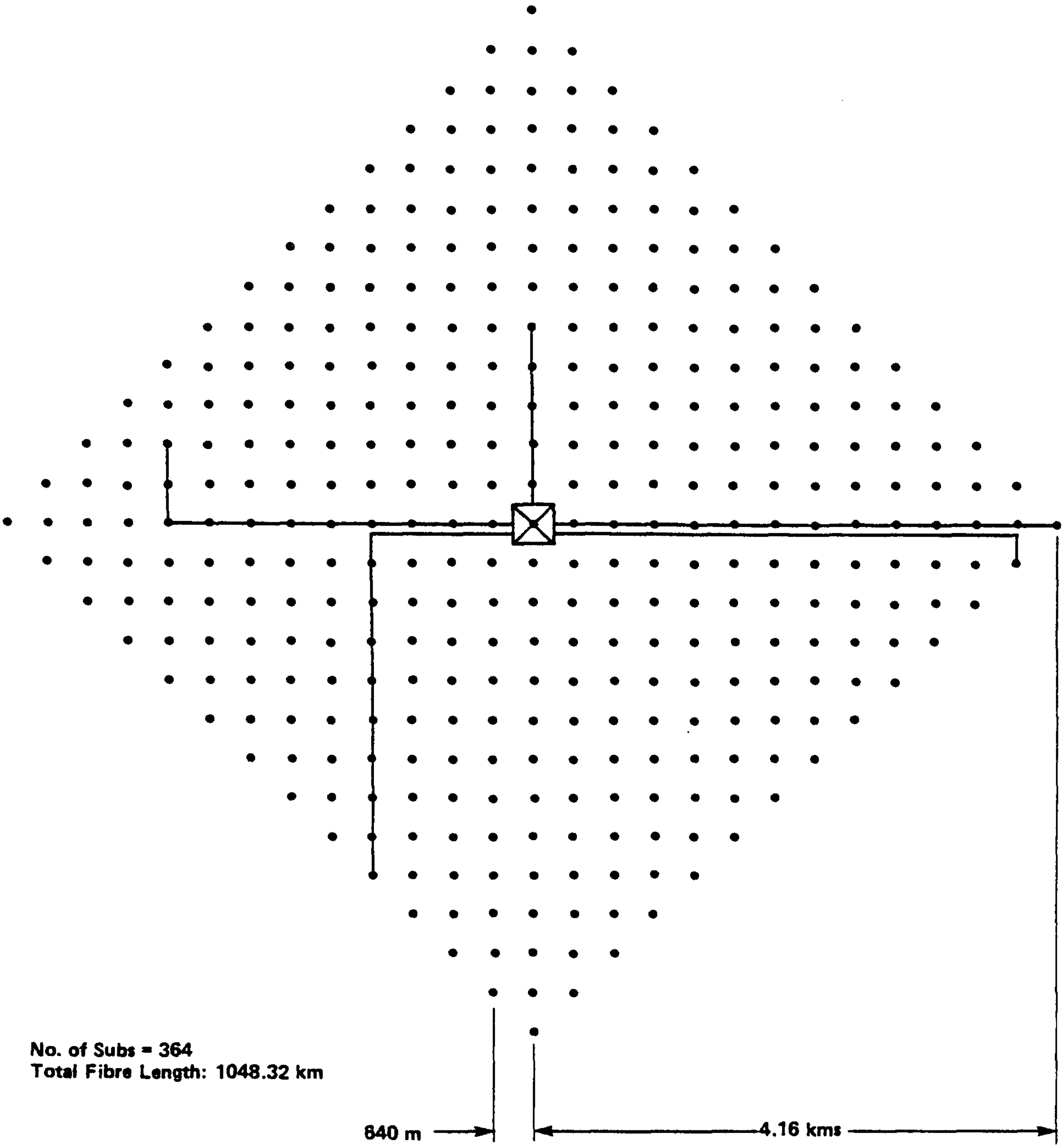


Figure 7.1 — Remote Switch Serving Area, with Some Feeders illustrated
(Rural Grid Population Distribution Model)

PERCENTAGE USAGE	5%	10%	15%	20%	25%
NO. OF CHANNELS	32	54	74	96	116

Table 7.1 Number of private access channels needed to serve 364 subscribers at various percentage usage rates.

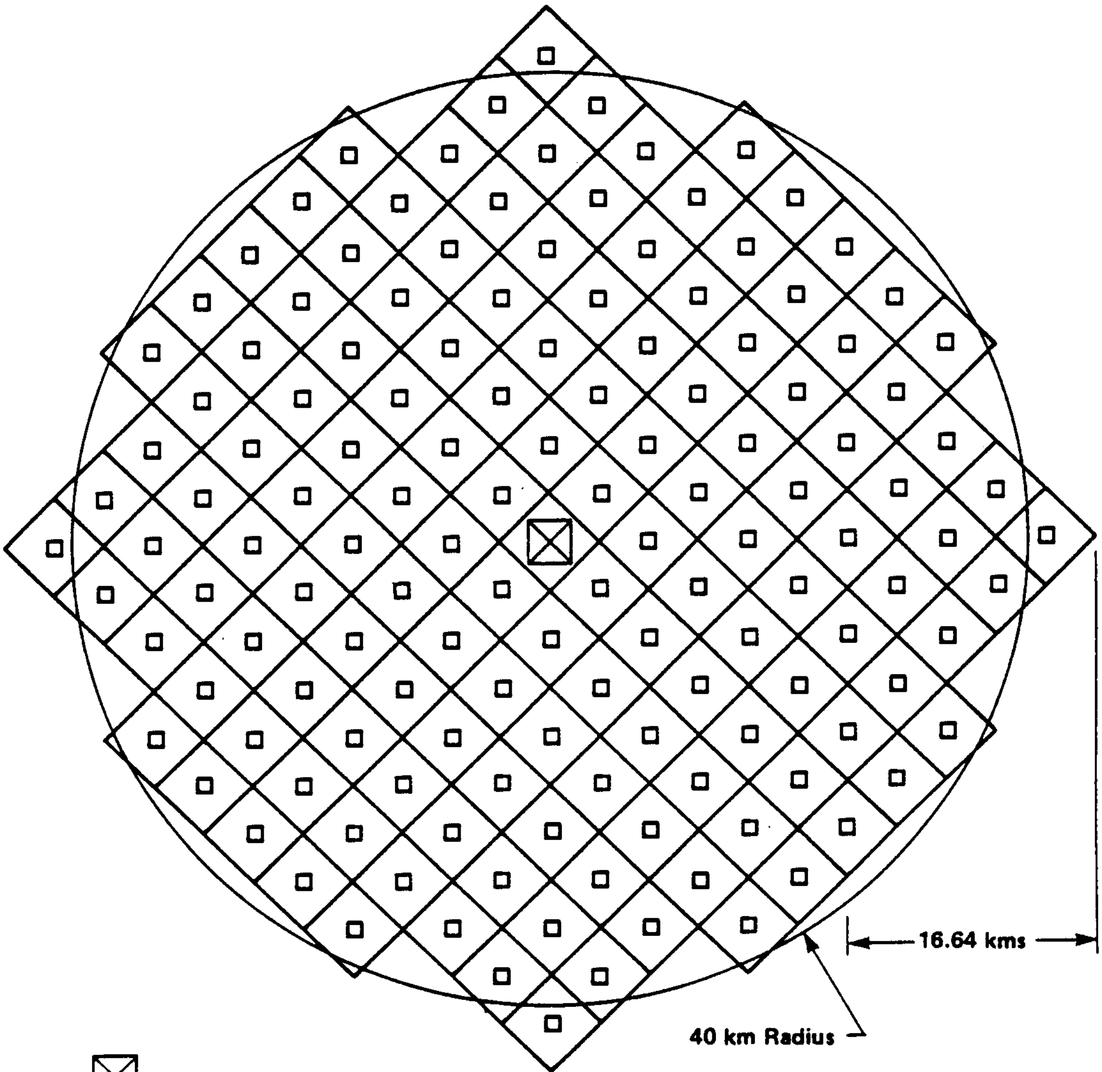
Figure 7.2 shows how the remote switches would be deployed to cover the area of 40 km radius around a program centre. 141 remote switches are used to cover the area, serving 48245 subscribers. A total trunk route length of 4660 km is involved, defining this length as the sum of the distances between each remote switch and the P.C., and following a rectilinear route. (The calculation is tedious and was done manually).

The approach which will be taken now will be to establish the quantity of the principal components needed to implement the network. Since the evaluation of the network will rely on its downstream video section, only this will be considered. The small amount of fibre needed for upstream signalling along the trunk route will also be ignored in this section.

To calculate the amount of fibre needed per subscriber one notes that this is in two sections - the traffic invariant distribution of figure 7.1, and the traffic dependent trunks whose total length of 4660 km per fibre was mentioned above. A manual evaluation of the total length of fibre needed to run one fibre from a remote switch to each subscriber served by that switch along a rectilinear path yields a total of 1048 km for 364 subscribers, or 2.88 km/subscriber. In fact adjacent areas overlap slightly, so most remote switches serve slightly less than 364 subscribers. The difference in fibre used per subscriber is insignificant. Table 7.2 applies the channel capacities of Table 7.1 to give the fibre needed to serve the 48245 subscribers of figure 7.2, with the results expressed both in terms of total fibre used and in fibre length per subscriber.

Continuing the "component count", Table 7.3 shows the number of repeaters needed to span certain point-to-point distances with a SNR of 43 dB, assuming 5 dB/km fibre. The assumptions behind these calculations were discussed in Activity 2, and the calculations will be presented in detail in Activity 5. Table 7.3A is for the case where the low channel is baseband and the upper channel is T7 (video carrier at 7 MHz). Table 7.3B is for the case where the two channels are T7 and T8 (video carrier at 13 MHz). Since the figures are not greatly different we shall use the slightly more pessimistic figures of the T7/T8 case for the calculations. Table 7.4 shows the number of repeaters needed. The top table shows how the trunks from the P.C. to the remote switches are grouped (by inspection of figure 7.2) - 20 @ 49.92 kms, 40 @ 41.6 kms, etc. The number of repeaters to span these lengths are derived from Table 7.3, and hence the total number of repeaters per fibre per trunk are calculated and shown in column five. The two tables which complete Table 7.4 show the total number of repeaters and number of repeaters per subscriber needed to supply the 48245 subscribers, using the channel requirements of Table 7.1. Note that one half repeater per fibre is at a remote switch, and one half at the P.C., acting as electro-optic interface units.

Having dealt with the outside plant components (repeaters and



KEY: P.C.

Remote Switch

No. of Subscribers: 48245
Length of Trunk Route: 4592.6 kms
No. of Remote Switches: 141

Figure 7.2 – Area Served by Program Centre with Remote Switches
(Rural Grid Population Distribution Model)

Total fibre in system (distribution and trunk). Figures rounded to nearest 50

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	161 800	236 350	287 600	334 200	385 450	432 000
12	175 750	250 300	301 550	348 150	399 400	446 000
22	199 050	273 600	324 850	371 450	422 700	469 300
36	231 700	306 250	357 500	404 050	455 300	501 900

Total fibre in system per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	3.35	4.90	5.96	4.93	7.99	8.95
12	3.64	5.19	6.25	7.22	8.28	9.24
22	4.13	5.67	6.73	7.70	8.76	9.73
36	4.80	6.35	7.41	8.38	9.44	10.40

Table 7.2 Amount of fibre (in km) required for the rural model of figs. 7.1 and 7.2.

A/ Baseband and T7

No. of repeaters	Max range (km)	No. of repeaters	Max range (km)
1	5.52	11	44.44
2	10.28	12	47.76
3	14.70	13	50.96
4	18.88	14	54.04
5	22.90	15	57.00
6	26.76	16	60.16
7	30.52	17	62.90
8	34.08	18	65.88
9	37.62	19	68.78
10	41.00	20	71.60

B/ T7 and T8

No. of repeaters	Max range (km)	No. of repeaters	Max range (km)
1	5.22	11	42.68
2	9.72	12	45.84
3	13.92	13	48.88
4	17.92	14	52.08
5	21.80	15	54.90
6	25.56	16	57.92
7	29.12	17	60.86
8	32.64	18	63.72
9	36.00	19	66.50
10	39.40	20	69.20

Table 7.3 Maximum distance capable of being covered by different numbers of repeaters for 43 dB SNR, 5 dB/km fibre.

Calculation of number of repeaters.

No. of Trunks of length "X" km.	"X" (km)	Total length of trunks, each "X" km long.	No. of repeaters per trunk of length "X" km.	Total No. of repeaters on trunks of length "X" km.
20	49.92	998.40	14	280
40	41.60	1664.00	11	440
32	33.28	1064.96	9	288
24	24.96	599.04	6	144
16	16.64	266.24	4	64
8	8.32	66.56	2	16

Total trunk route length: 4659.2 km.
Total no. of repeaters (per fibre): 1232.

Total No. of Repeaters:

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	3 696	23 408	36 960	49 280	62 832	75 152
12	7 392	27 104	40 656	52 976	66 528	78 848
22	13 552	33 264	46 816	59 136	72 688	85 008
36	22 176	41 888	55 440	67 760	81 314	93 632

Repeaters per Subscriber.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.08	0.49	0.77	1.02	1.30	1.56
12	0.15	0.56	0.84	1.10	1.38	1.63
22	0.28	0.69	0.97	1.23	1.51	1.76
36	0.46	0.87	1.15	1.40	1.69	1.94

Table 7.4 Repeater requirements to serve a Rural Grid Development Model.

fibre) we now turn to the remote switch of figure 6.3. The components fall into two categories for the purposes of a component count: those which are dependent on traffic and subscriber numbers, and those which are not. In the invariant category one has the following components:

i) The structure itself.

ii) A power supply unit.

iii) A microprocessor based control unit.

iv) An upstream audio concentrator.

v) A source of video messages (assuming this is not done by a frame-grabber).

In addition, each subscriber needs the following components at the remote switch or at his home:

i) 2 light sources (one of low quality) with circuitry.

ii) 2 photodetectors with circuitry.

iii) 2 optical couplers.

iv) 1 electrical mixer.

v) 1 sub-VHF converter (including, possibly, a baseband to VHF capacity).

All of these components remain the same for the urban, suburban and the two rural models in this section - all that changes is the number of subscribers sharing a remote switch.

The number of the following components needed on a per subscriber basis are determined by the number of common access channels and private access channels:

i) Crosspoints

ii) Up converters.

iii) High pass filters.

iv) Down converters.

v) No of low pass filters

If N_c are the number of common access channels, N_p the number of private access channels, inspection of figure 6.3 shows that, on a per subscriber basis:

No. of crosspoints = $2N_c$ (Common access only)
In the presence of private access channels, this becomes:
No. of crosspoints = $2N_c + N_p + 1$ (The "one" being for video messages, which are not needed with common access only)

No. of Up Converters = No. of H.P. filters = $N_c/2$

No. of Down Converters = No. of L.P. filters = $(N_p + N_c)/2$

The numbers for all these components are tabulated in Table 7.5.

Turning now to the program centre of figure 6.6, the traffic invariant components are:

i) The building.

ii) Power supply.

iii) Source of common access channels.

iv) Source of frame grabber services*.

v) Control signal processor and central intelligence.

vi) Audio switching machine (whose size is traffic dependent).

Also, each patch area, regardless of size, needs:

i) An operator console.

ii) One splitter and up converter per subscriber originated video program.

The light source drivers at the P.C., taken with the detectors and circuitry at the remote switch together form one repeater in the component count of Table 7.3.

The strongly traffic dependent components in the program centre, then, are principally:

i) The patch board crosspoints

ii) The video sources.

If N_s are the number of subscriber originated video channels in the whole P.C. serving area, and, as before, N_p the number of private access channels needed to serve a remote switch at a given level of

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* Frame grabber services are weakly traffic dependent.

A/ Number of Cross-points per subscriber.

COMMON CHANNELS	PERCENTAGE	USE	OF	PRIVATE	ACCESS	CHANNELS
	0%	5%	10%	15%	20%	25%
6	12	45	67	87	109	129
12	24	57	79	99	121	141
22	44	77	99	119	141	161
36	72	105	127	147	169	189

B/ Number of Up-Converters per subscriber.

COMMON CHANNELS	6	12	22	36
UP-CONVERTERS	.008	.016	.030	.049

No. of High Pass filters = No. of Up-Converters.

C/ Number of Down-Converters per subscriber.

COMMON CHANNELS	PERCENTAGE	USE	OF	PRIVATE	ACCESS	CHANNELS
	0%	5%	10%	15%	20%	25%
6	0.008	0.052	0.082	0.109	0.140	0.167
12	0.016	0.060	0.090	0.118	0.148	0.175
22	0.030	0.074	0.104	0.132	0.162	0.189
36	0.049	0.093	0.123	0.151	0.181	0.208

No. of Low Pass filters = No. of Down-Converters.

Table 7.5 Remote Switch Components for a Rural Grid Development Model.

usage, it follows by inspection of figure 6.7 that:

No. of patch board cross points = $N_p \times (N_s + N_p/2)$

No. of video sources = N_p.

Table 7.6 tabulates these two parameters for the rural grid serving area.

One set of components remaining are the mixers of figure 6.7 - one is needed for every two private access channels.

This concludes the component count for the rural grid distribution serving area of figure 7.2.

7.3 THE STRIP TYPE RURAL DISTRIBUTION

Although some rural areas are modelled quite accurately by a grid type distribution of population, many others have their population distributed along one or more roads radiating from the village centre, giving a strip type rural distribution. Figure 7.3 shows a 52 km strip stretching from the P.C. Subscribers are assumed to lie every 320 metres on both sides of the strip, and at a distance of 160 metres from the strip. The two rows of subscribers are staggered - i.e. there is one subscriber every 160 metres alternating between the left and right side of the road.

To supply every one of the subscribers in figure 7.3 with his own fibre direct from the P.C. would need 26 km of fibre per subscriber. To avoid this heavy use of fibre, the region is again divided into areas served by remote switches. Allowing a maximum distance of 4.16 km from a switch to its furthest subscriber, as in section 7.2, one uses six remote switches serving 49 subscribers each, with the P.C. serving 25 subscribers directly. Table 7.7 shows the number of private access channels needed to serve 49 subscribers at various levels of usage. Since the remote switches are in line, the common access channels are run along a trunk feeding each switch in turn. The total amount of fibre in the distribution network is 2.2 km per subscriber (a figure easily calculable from inspection of figure 7.3). Table 7.8A shows the total amount of fibre per subscriber needed to implement the network. These figures are derived by noting from figure 7.3 that 168 km of fibre are needed to run one fibre from the P.C. to each remote switch separately, and that the common access trunk is 48 km long. Applying the channel capacities of Table 7.7 to this, with the usual assumption of two channels multiplexed per fibre, and adding the 2.2 km for distribution, gives the results of Table 7.8A.

The calculation of the number of repeaters is the next stage in the component count. For the common access trunk, two repeaters per fibre per remote switch will be assumed adequate, although this requires a slight improvement in the parameters used to derive Table 7.3. Applying Table 7.3 to each private access fibre, one finds that 44

A/ Patch Area Cross-points per subscriber.

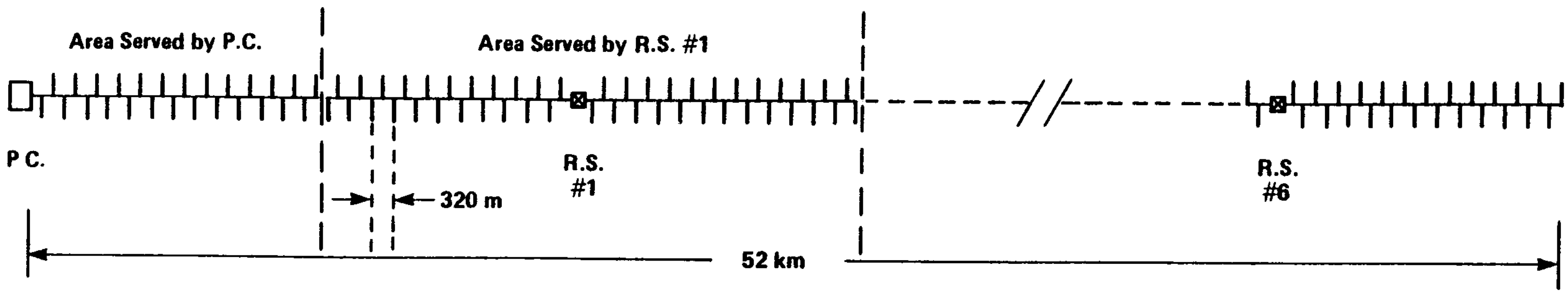
S.O.V.* CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
	5%	10%	15%	20%	25%
0	1.41	4.01	7.52	12.66	18.48
10	2.29	5.49	9.55	15.30	21.67
20	3.17	6.97	11.59	17.93	24.86
30	4.04	8.46	13.62	20.57	28.04
40	4.92	9.94	15.65	23.21	31.23
50	5.80	11.42	17.69	25.85	34.42

*S.O.V. = Subscriber Originated Video.

B/ Number of Video sources per subscriber.

PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
5%	10%	15%	20%	25%
0.09	0.15	0.20	0.26	0.32

Table 7.6 Program Centre Components for a Rural Grid Development Model.



Note: Subscribers' drops not to scale.

Figure 7.3 – The Rural Strip Development Population Distribution Model

PERCENTAGE USAGE	5%	10%	15%	20%	25%
NO. OF CHANNELS	8	12	16	19	23

Table 7.7 Number of private access channels needed to serve 49 subscribers at various percentage usage rates.

A/ Total fibre in system (distribution and trunk) Unit: km./Subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	2.65	4.76	5.81	6.86	7.92	8.97
12	3.10	5.21	6.26	7.31	8.37	9.42
22	3.86	5.97	7.02	8.07	9.13	10.18
36	4.91	7.02	8.07	9.12	10.18	11.23

B/ Number of repeaters per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.15	0.70	0.98	1.25	1.53	1.81
12	0.30	0.85	1.13	1.40	1.68	1.96
22	0.55	1.10	1.38	1.65	1.93	2.21
36	0.90	1.45	1.73	2.00	2.28	2.56

Table 7.8 Fibre and repeater requirements for a Rural Strip Development Model

repeaters per fibre are needed to connect all the remote switches to the P.C. Once again applying the channel requirements of Table 7.7 yields the number of repeaters per subscriber given in Table 7.8B.

Turning now to the remote switch, applying the relationships given in section 7.2 yields the figures of Table 7.9.

Finally, Table 7.10 shows the traffic dependent components in the program centre, concluding the component count for a rural strip development model.

7.4 SUBURBAN MODEL

For suburban areas subscribers are once again modelled as being distributed on a grid, this time with a spacing of 58 metres between subscribers, giving a population density of 300 per square kilometre. These subscribers could be served in exactly the same manner as the rural subscribers by simply scaling down the models of figures 7.1 and 7.2. It is not likely that this is optimum, since the number of remote switches is far greater than the minimum which could be used. This is the case since the serving area of a rural switch was limited by the repeaterless range of the feeders from each switch - in the suburban case such a range would encompass about 11,000 subscribers, or, in other words, four such switches could cover the same number of subscribers as the 141 switches of the rural area. To investigate this further, consider again the diamond shaped remote switch serving area of figure 7.1. Here the maximum distance of any subscriber from the switch is 13 grid units. In Table 7.11 the effect of extending this range to 25, 50, 75, 100, 125 and 150 units is considered. The table shows the total number of subscribers served by each such area, together with the length of feeders in each area, expressed as a total and as a per subscriber figure. The figures are given for a rural, suburban and urban grid. (the latter to be discussed later), by simply taking one grid unit to be 320 m, 58 m, and 14 m respectively.

If one were to use a remote switch serving area of range 75 units (4.35 km) in a suburban area one would be serving 11400 subscribers. From the traffic formulae of section 4.2 these subscribers would need 2589 channels to serve them at a 20% usage rate. Thus, at this usage rate, the remote switch of figure 6.3 would need some 2600 cross points per subscriber, the exact number depending on the number of common access channels. It is this growth in the number of cross points per subscriber with the number of subscribers which distinguishes our case from that of CATV distribution. To avoid this situation one can either go for a larger number of switches (scaled down rural) or subdivide each switch. This subdividion of switches is shown in figure 7.4 - subscribers are divided into sets of a few hundred, each served by their own private lines. Obviously this requires more channels in total, but as long as the sets are kept no smaller than a few hundred such an increase should be minimal.

A/ Number of Cross-points per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	12	21	25	29	32	36
12	24	33	37	41	44	48
22	44	53	57	61	64	68
36	72	81	85	89	92	96

B/ Number of Up-Converters per subscriber

COMMON CHANNELS	6	12	22	36
UP-CONVERTERS	0.06	0.12	0.22	0.37

No. of High Pass Filters = No. of Up-Converters

C/ Number of Down-Converters per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.06	0.14	0.18	0.22	0.26	0.30
12	0.12	0.20	0.24	0.28	0.32	0.36
22	0.22	0.30	0.34	0.38	0.42	0.46
36	0.37	0.45	0.49	0.53	0.57	0.61

No. of Low Pass Filters = No. of Down-Converters.

Table 7.9 Remote Switch Components for a Rural Strip Development Model.

A/ Patch Area Cross-points per subscriber

S.O.V.* CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
	5%	10%	15%	20%	25%
0	0.65	1.47	2.61	3.68	5.40
5	1.47	2.69	4.24	5.62	7.74
10	2.29	3.92	5.88	7.56	10.09
15	3.10	5.14	7.51	9.50	12.44
20	3.92	6.37	9.14	11.44	14.79
25	4.73	7.59	10.78	13.38	17.13

*S.O.V. = Subscriber Originated Video

B/ Number of Video sources per subscriber

PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
5%	10%	15%	20%	25%
0.16	0.24	0.33	0.39	0.47

Table 7.10 Program Centre Components for a Rural Strip Development Model.

MAX RANGE (No. of Subs)	NO. OF SUBS Served	TOTAL ROUTE LENGTH TO CONNECT EACH SUB TO CENTRE Rural (320m Grid)	Suburban (58m Grid)	Urban (14m Grid)
25	1 300	7 072 (5.44)	1 282 (0.99)	309 (0.24)
50	5 100	54 944 (10.77)	9 959 (1.95)	2 404 (0.47)
75	11 400	183 616 (16.11)	33 280 (2.92)	8 033 (0.71)
100	20 200	433 088 (21.44)	78 497 (3.89)	18 948 (0.94)
125	31 500	843 360 (26.77)	152 859 (4.85)	36 897 (1.17)
150	45 300	1 454 432 (32.11)	263 616 (5.82)	63 631 (1.41)

Unit: km

Figures in parentheses: Per Subscriber

Table 7.11 Amount of fibre to serve diamond shape distribution areas (like Fig. 7.1) for various ranges.

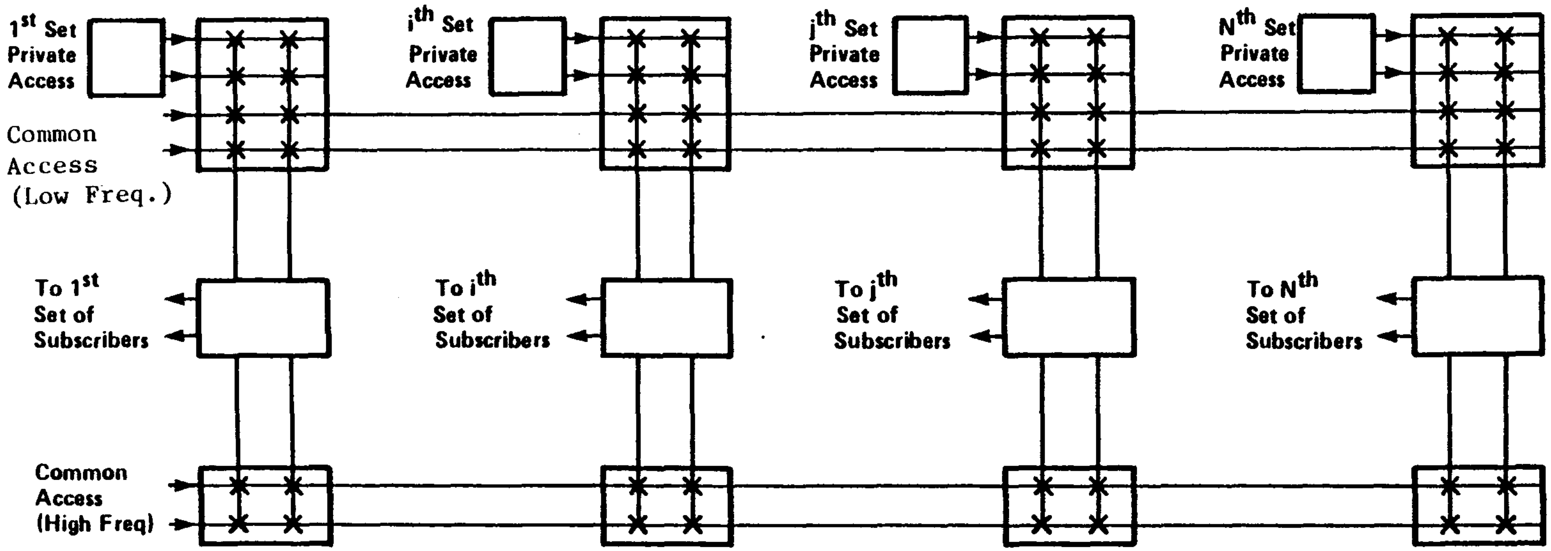


Figure 7.4 — Subdivision of a Remote Switch Serving Many Subscribers

The optimum arrangement of remote switches - many small switches or a few large ones - needs to be decided on economic grounds. Since the relevant financial parameters are not available and, in any case, vary from location to location, such an analysis is quite beyond the scope of this activity. For illustration, though, we consider the arrangement of figure 7.5 with eight remote switches and one switch at the program centre. This serves approximately 45300 subscribers (9 x 5100 less 600 on the boundaries between serving areas). Each remote switch serving area will be divided into ten sets of 510 subscribers each (ignoring the overlap of adjacent switching areas).

Table 7.12 shows the number of channels needed to serve 510 subscribers at various levels of usage, and hence the number of channels needed to serve 5100 subscribers in ten groups of 510.

From Table 7.11 one sees that 1.95 km of fibre is needed per subscriber in a diamond shaped distribution area serving 5100 subscribers. From figure 7.5 the trunk route length (length of fibre to run one fibre from each remote switch to the program centre along a rectilinear route) is 8 x 5.916 = 47.3 km. Using the channel capacities of Table 7.12, the total amount of fibre per subscriber is shown in Table 7.13A. Table 7.13B shows the number of repeaters per subscriber.

Tables 7.14 and 7.15 show the number of traffic dependent components in the remote switch and program centre respectively. Note that the subdivision of the remote switch into areas of 510 subscribers means that N_p of section 7.2 is based on the channels to supply 510 subscribers, not 5100. Further, the P.C. patch areas are similarly divided to serve 510 subscribers each.

7.5 URBAN AREA

An urban area will be modelled as consisting of subscribers distributed on a grid of 14 metres spacing (5000 subscribers per square kilometre). From Table 7.6 it follows that 45300 subscribers can be served from one switch, with 1.41 kilometres of fibre per subscriber independent of traffic. The savings in fibre which would accrue from using remote switches would not justify the problems of finding a location for the remote switches in a congested urban area. As discussed for suburban areas one wishes to avoid a switching matrix of thousands of crosspoints for each of the 45300 subscribers, and, again, this can be achieved by using the arrangement of figure 7.3 to divide the switch into smaller sections.

The outside plant component count in this case consists of 1.41 km of fibre per subscriber, and no repeaters.

The remote switch and program centre are now located in the same place, with the switch acting as a concentrator and the patch areas fulfilling their program originating function. Some savings on common

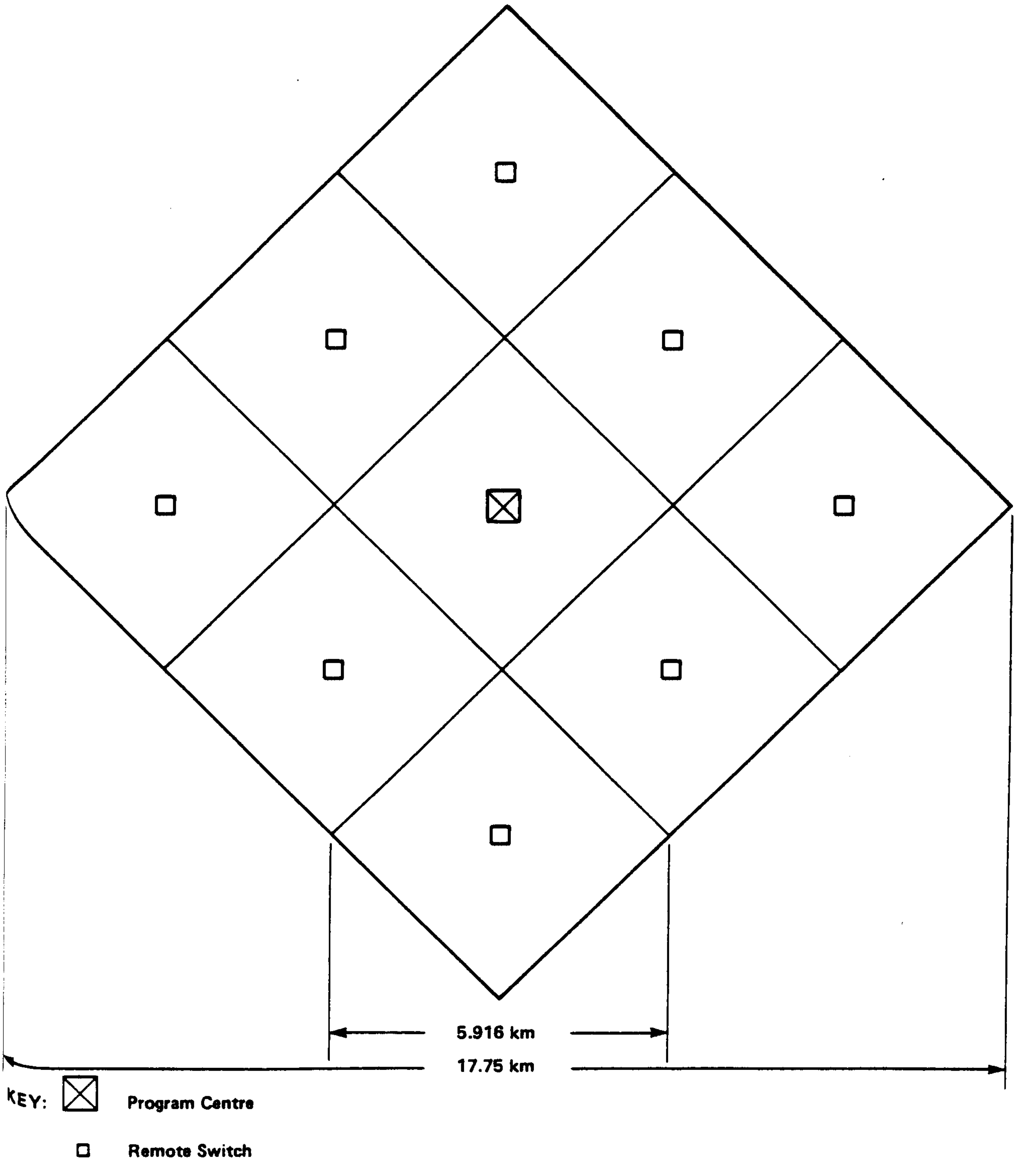


Figure 7.5 – Area Served by Program Centre with Remote Switches (Suburban Area)

PERCENTAGE USAGE	5%	10%	15%	20%	25%
NO. OF CHANNELS (510 Subs)	40	70	98	126	158
NO. OF CHANNELS (5100 Subs)	400	700	980	1260	1580

Table 7.12 Number of Private Access Channels needed to serve 510 and 5100 subscribers (in 10 groups of 510) at various percentage usage rates.

A/ Total fibre in system (trunk and distribution). Unit: km /Subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	1.96	2.16	2.32	2.46	2.61	2.77
12	1.96	2.17	2.32	2.46	2.61	2.77
22	1.96	2.17	2.32	2.47	2.61	2.78
36	1.97	2.18	2.33	2.47	2.62	2.79

B/ Number of repeaters per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	≈ 0	0.07	0.12	0.17	0.19	0.28
12	≈ 0	0.07	0.12	0.17	0.19	0.28
22	≈ 0	0.07	0.13	0.17	0.19	0.28
36	≈ 0	0.08	0.13	0.18	0.19	0.28

Table 7.13 Fibre and repeater requirements for a Suburban Area.

A/ Number of Cross-points per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	12	53	83	111	139	171
12	24	65	95	123	151	183
22	44	85	115	143	171	203
36	72	113	143	171	199	231

B/ Number of Up-Converters per subscriber

COMMON CHANNELS	6	12	22	36
UP-CONVERTERS	0.0006	0.0012	0.0022	0.0035

No. of High Pass Filters = No. of Up-Converters

C/ Number of Down-Converters per subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.0006	0.040	0.069	0.097	0.124	0.155
12	0.0012	0.040	0.070	0.097	0.125	0.156
22	0.0022	0.041	0.071	0.098	0.126	0.157
36	0.0035	0.043	0.072	0.100	0.127	0.158

No. of Low Pass Filters = No. of Down-Converters

Table 7.14 Remote Switch Components for a Suburban Model.

A/ Patch Area Cross-points per subscriber (Sub-Patch Area).

S.O.V.* CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
	5%	10%	15%	20%	25%
0	1.57	4.80	9.42	15.56	24.47
10	2.35	6.18	11.34	18.04	27.57
20	3.14	7.55	13.26	20.51	30.67
30	3.92	8.92	15.18	22.98	33.77
40	4.71	10.29	17.10	25.45	36.87
50	5.49	11.67	19.02	27.92	39.96

*S.O.V. = Subscriber Originated Video

B/ Number of Video Sources per subscriber.

PERCENTAGE USE OF PRIVATE ACCESS CHANNELS				
5%	10%	15%	20%	25%
0.08	0.14	0.19	0.25	0.31

Table 7.15 Program Centre Components for a Suburban Model.

equipment are possible, but the traffic dependent components still obey the rules of section 7.2. The exact numbers of components in these areas depend on the size of the sub-divisions - for 364 subscribers per division the figures supplied for the rural grid model apply, while for 510 subscribers the figures for suburban areas apply. In general, increasing the size of the sub-unit increases the number of cross points in an almost linear manner, while simultaneously decreasing the number of private access channels and related components, such as video sources. Once the sub-division increases over about 300 the latter effect becomes insignificant, although the former increase continues. Comparison of Tables 7.6, 7.10 and 7.15 clearly illustrates the slow increase in video source requirements for groups of over 300, while comparison of Tables 7.5, 7.9 and 7.14 show the trend for cross points.

8. MODEL NETWORKS SUITABLE FOR LONG TERM IMPLEMENTATION

8.1 GUIDELINES

The amount of fibre used in the networks of section 7 is large, especially in rural areas. The obvious solution is to multiplex many signals on the same fibre by FDM or WDM. Since digital transmission is still not anticipated to be economical for distribution even in the long term future of ten to fifteen years, TDM is not considered. Even if simple digital transmission were to enter the distribution market, without an expensive storage capability bit rates of at least 45 Mbit/s are needed, making high level multiplexing impossible without single mode fibres, which are again not anticipated to be viable within this time frame.

In order to consider the impact of multiplexing, one considers the remote switch serving area of figure 7.1. With a multiplexed system, instead of associating one fibre with each subscriber, one associates with each subscriber two frequencies (FDM) or two wavelengths (WDM), or even one wavelength carrying two FDM electrical signals. Throughout this section we shall study the impact of multiplexing 20 channels on one fibre on the component count.

Figure 8.1 shows how the remote switch serving area of figure 7.1 can be divided into 39 regions of 10 subscribers or less each. One fibre feeder serves each of these regions, with each subscriber having a drop optically tapped on to the feeder. Figure 8.2 shows the way in which a remote switch would need to be modified to accommodate WDM, assuming 2 channels in FDM per wavelength. Figure 8.3 shows the modifications needed for FDM.

8.2 THE GRID TYPE RURAL DISTRIBUTION

Multiplexing schemes are only justified when the saving in transmission medium is greater than the cost of performing the multiplexing. To see the saving in transmission medium for grid type areas, a count was made of the total fibre needed to serve each subscriber with the network of figure 8.1. A somewhat tedious manual count gave a figure of 0.57 km per subscriber - a saving of 2.31 km from the figure of 2.88 km given in section 7.2. The cost of multiplexing in such a network must, therefore, be less than the cost of 2.31 km of fibre, considering the distribution area only.

To evaluate the total network requirement for fibre we use the figures of section 7.2 for the channel capacity and trunk route length needed to serve 141 remote switches serving 364 subscribers each. The figure of 0.57 km per subscriber in the distribution network is used, and the 20 fold multiplexing in the trunk is used to produce the figures of table 8.1A for fibre requirement.

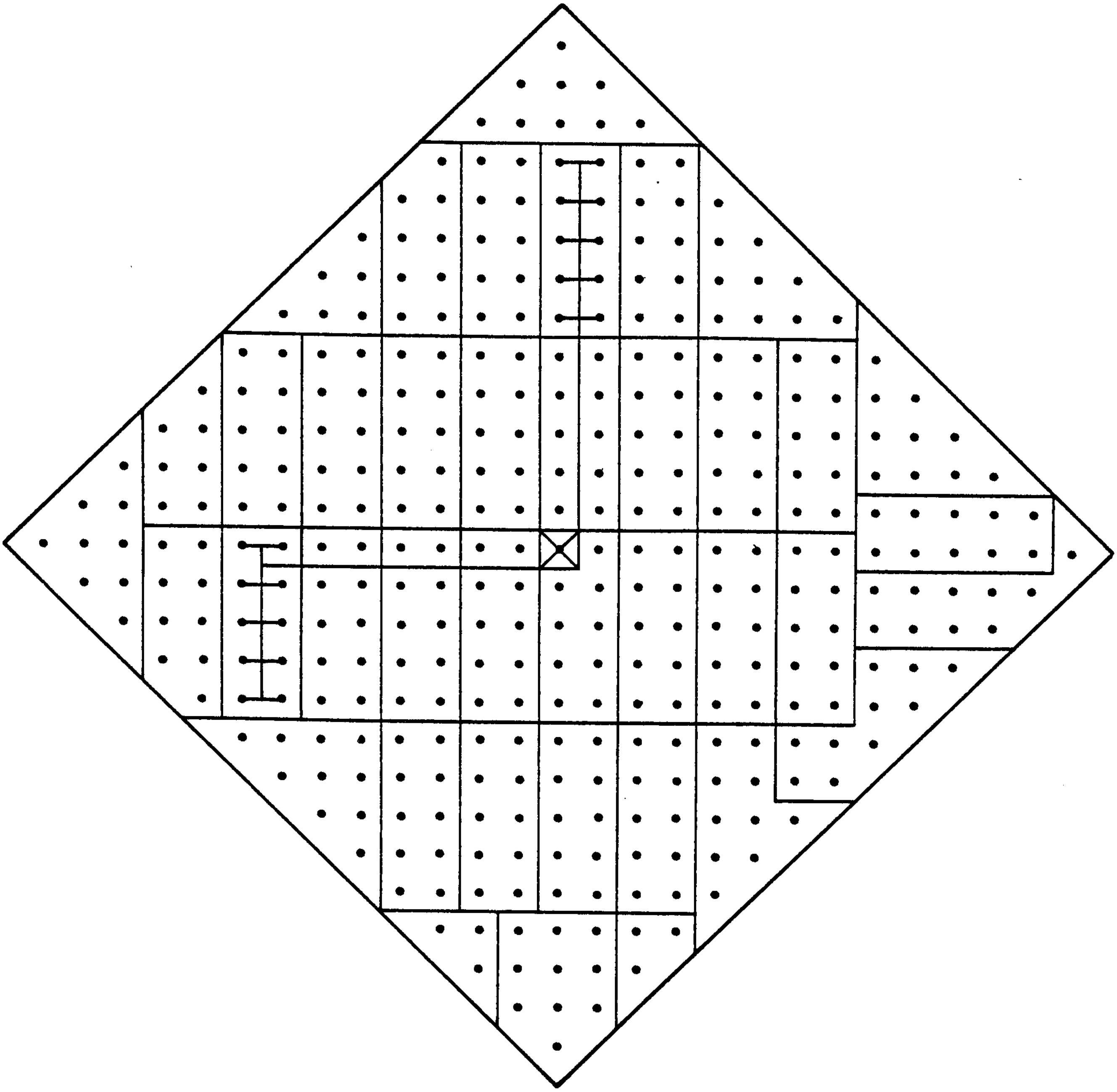


Figure 8.1 – Division of the Remote Switch Serving Area into 39 Regions (Rural Grid Development Distribution Model)

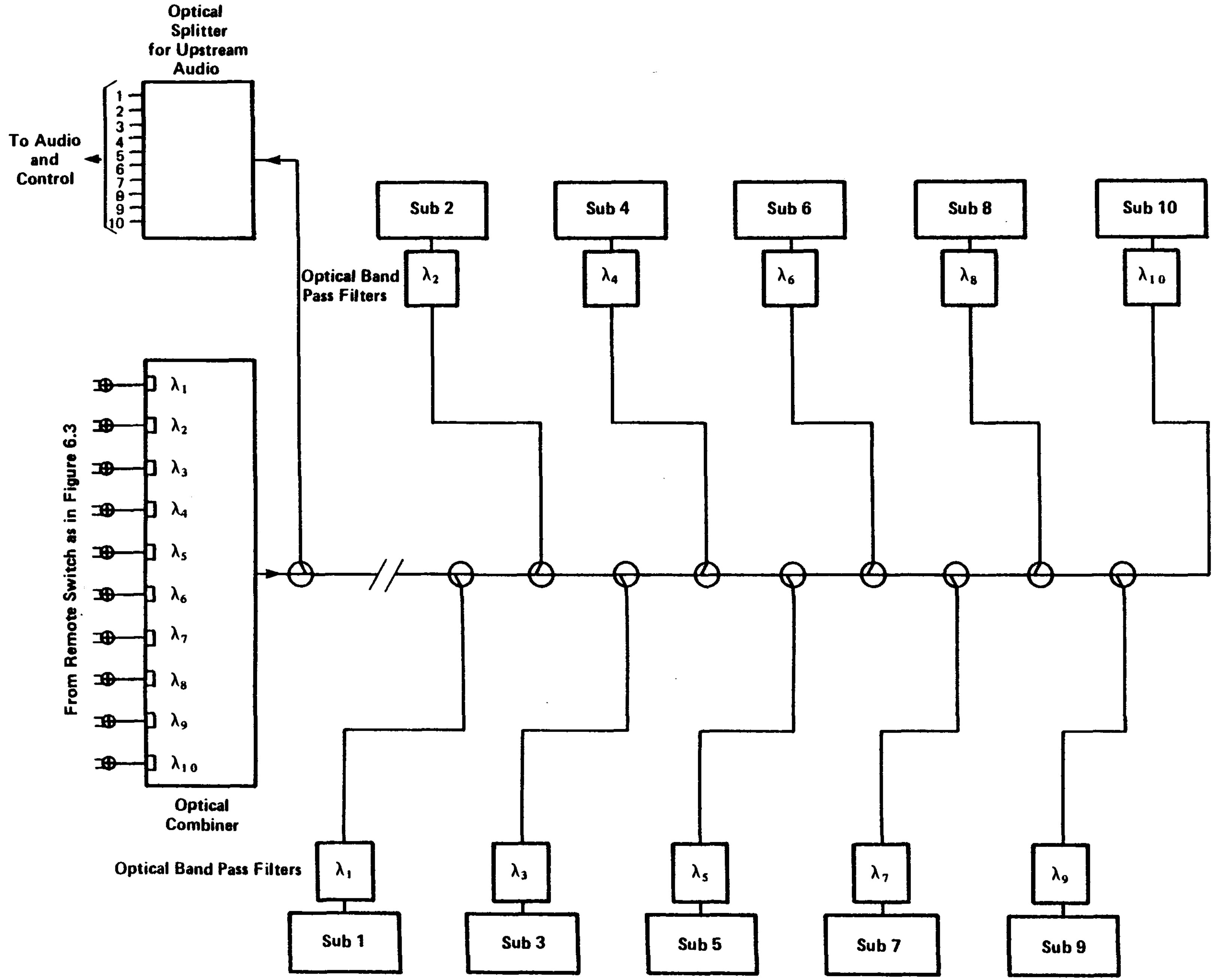


Figure 8.2 – Remote Switch Distribution with WDM

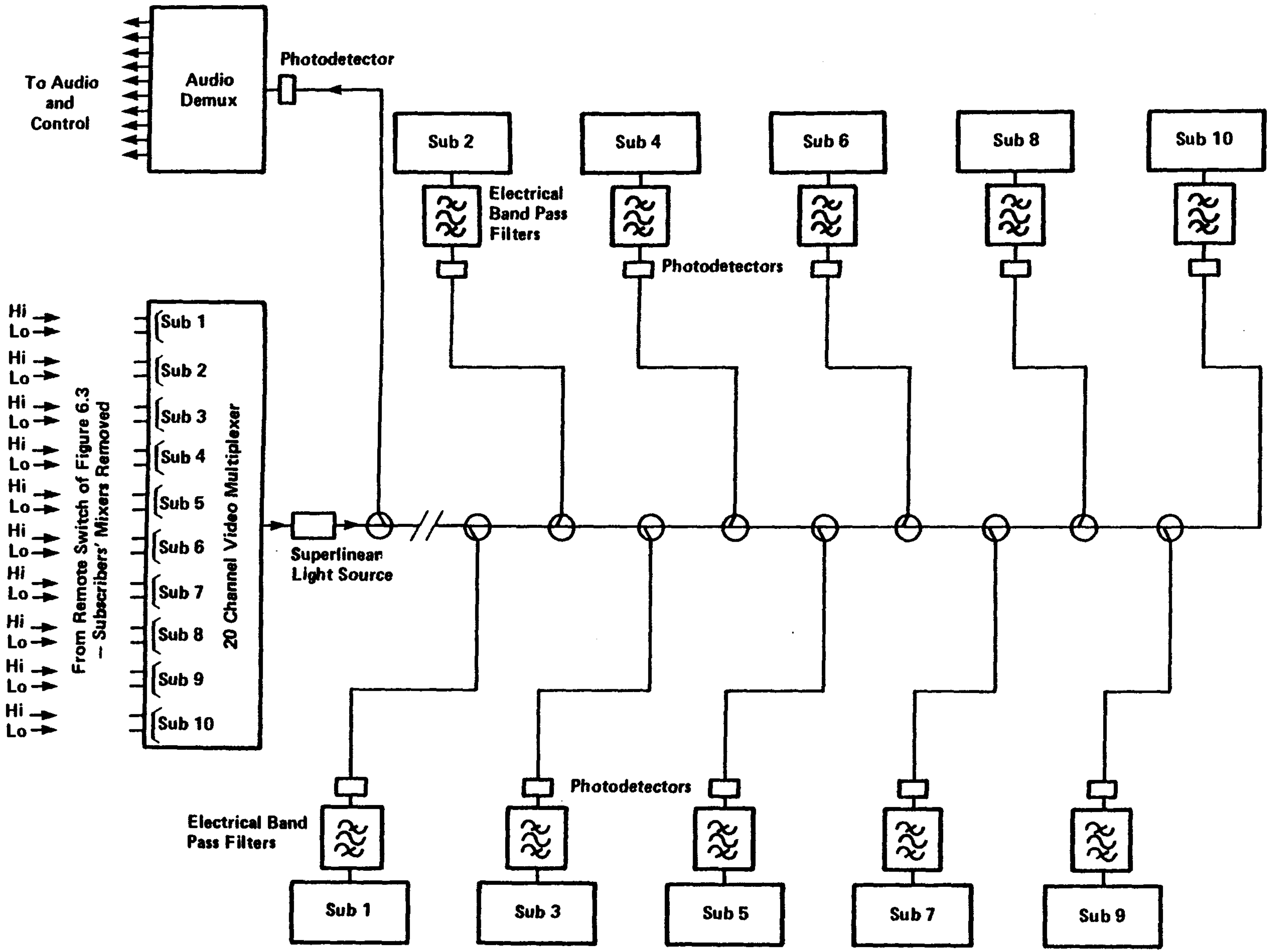


Figure 8.3 – Remote Switch Distribution with FDM

A/ Total fibre used (trunk and distribution): km per Subscriber

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.66	0.76	0.86	0.95	1.15	1.24
12	0.66	0.86	0.95	1.05	1.15	1.24
22	0.76	0.86	0.95	1.05	1.15	1.24
36	0.76	0.95	1.05	1.15	1.24	1.34

B/ Number of repeaters per subscriber (FDM)

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.026	0.051	0.077	0.102	0.153	0.179
12	0.026	0.077	0.102	0.128	0.153	0.179
22	0.051	0.077	0.102	0.128	0.153	0.179
36	0.051	0.102	0.128	0.153	0.179	0.204

Table 8.1 Fibre requirements for 20 channel multiplexing in a Rural Grid Development area, with repeater requirements for FDM.

The number of repeaters becomes more difficult to compare since WDM and FDM use different approaches. For WDM the 10 wavelengths are demultiplexed, amplified, and re-multiplexed at each repeater. The number of repeaters is thus the same as in section 7 (Table 7.4) assuming the same power from each source coupled into the fibre. For FDM such demultiplexing is not needed, but each repeater has to be considerably superior to those used for two channels only. The quality required, however, is well within the capability of current CATV amplifiers, if adequately linear light sources and driver circuits can be devised. This topic will be raised again in a later discussion. Table 8.1B shows the number of repeaters needed to implement FDM in a rural grid area, making the very arbitrary assumption that the same repeater spacing is preserved. The traffic dependent remote switch and program centre components remain the same as in section 7.2.

For WDM the number of light sources, detectors and other components remains exactly the same as in section 7 with the exception of one optical filter per subscriber and the optical combiners and splitters. Each group of subscribers served by one fibre will need one such combiner and splitter, from inspection of figure 8.2. (Such a group will normally comprise 10 subscribers, except where it is impossible to form such a group.) In the trunk, each group of ten repeaters will use a splitter/combiner. The figure includes the terminals at the P.C. and remote switches, which count as half a repeater each in the component count, and use a combiner and splitter respectively. Thus the number of such devices per subscriber is approximately $0.1\ I^{+}(N\ /10)$, where N is the number of repeaters, and I^{+} means the next highest integer value of the argument in parentheses. The number of optical couplers for WDM remains the same as for section 7, since nine have been saved on the upstream audio and nine have been introduced in the outside plant. The fact that the couplers are in the outside plant will probably add to their cost, and to the installation cost. The light sources, although the same in number as for section 7, may be more expensive, both because of their well defined wavelengths and because they will need to be more powerful to compensate for losses in the couplers and splitters.

With FDM, the number of light sources and detectors in the distribution network is 1.1 per subscriber, from figure 8.3, assuming that 10 subscribers can be grouped together. Each subscriber also needs one tenth of a 20-channel video multiplexer, which replaces ten mixers in the non-multiplexed switch, and one tenth of a 10-channel audio demultiplexer, as well as one electrical filter. (SAW technology is the most promising for these filters). In the trunk, the number of light sources and detectors is equal to the number of repeaters already tabulated in Table 8.1. It should be stressed that these light sources, and the tenth of a light source per subscriber in the distribution, must be highly linearised, involving extra expense in driving circuitry and possibly in device construction.

For FDM the remote switch of figure 6.3 can be slightly modified to give some savings. Both switching matrices can operate at a suitable IF (such as the low frequency of figure 6.3). This affects only the common access channels, which need no longer be duplicated in frequency. The high pass filters and down converters are, therefore, no longer needed.

Instead of using one light source for FDM it may be argued that twenty light sources operating at different frequencies could be combined in one fibre. Although a considerable saving in device linearity would be obtained, it can be shown on thermodynamic grounds (ref. 23) that coupling many sources of the same wavelength into a fibre is inherently inefficient. The same arguments do not apply when different wavelengths are used.

This discussion concludes the treatment of a 20 channel per fibre multiplexed system for application to a rural grid distribution.

8.3 THE STRIP TYPE RURAL DISTRIBUTION

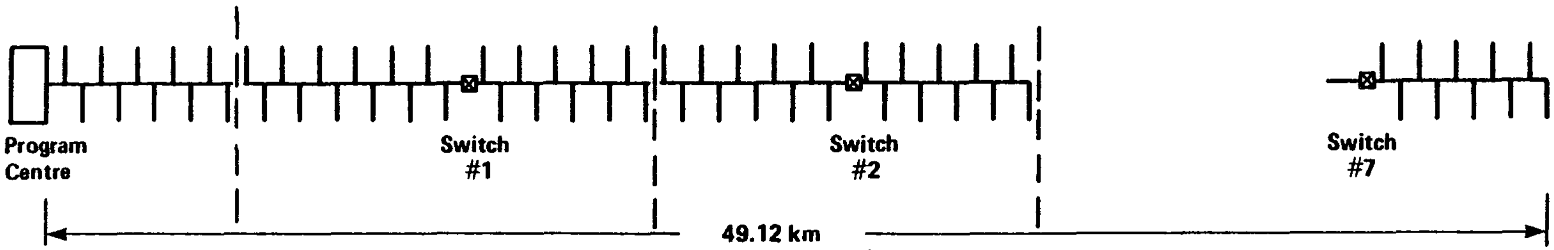
We consider again subscribers distributed as in figure 7.3. Because 20 channels are multiplexed per fibre, the remote switches will be spaced to serve 40 subscribers each, with 20 subscribers served from the P.C. Figure 8.4 shows how seven such switches would be deployed to serve 300 subscribers, each switch separated by 6.56 km. Also shown in figure 8.4 is the serving area for one remote switch.

Table 8.2 shows the channel capacity needed to supply 40 subscribers with private access channels. From inspection of figure 8.4 the total amount of fibre in each remote serving area is 16 km, or 0.4 km per subscriber (a saving of 1.8 km from section 7) with the same per subscriber usage among the 20 subscribers served directly from the P.C. The common access channels need 45.92 km per fibre to pass through all the remote switches, while the trunk route length to run one fibre from the P.C. to each remote switch is given by:

$$6.56 \times (1 + 2 + 3 + 4 + 5 + 6 + 7) = 183.68 \text{ km.}$$

Table 8.3A shows the resulting total fibre requirement per subscriber, while Tables 8.3B and 8.3C show the number of repeaters per subscriber when WDM and FDM are used respectively. This follows from the fact that, arbitrarily applying the spacings of Table 7.3 again, the trunk to the first remote switch needs 2 repeaters, that to the second, 3: that to the third, 5; that to the fourth, 7; that to the fifth, 8; to the sixth, 10, and to the seventh 12. These repeaters serve two channels each for WDM, up to twenty for FDM. Common access channels need two repeaters per remote switch with the same division of channels per repeater.

The traffic dependent components in the remote switch and P.C. are about the same as for the rural strip of section 7.3, and the same observations as already made in section 8.2 apply to the other components.



Note: Subscriber drops not to scale; trunks from P.C. to switches omitted.

Figure 8.4 – Deployment of Remote Switches for 20 Channel Multiplexed Systems
Along a Rural Strip Development Area

PERCENTAGE USAGE	5%	10%	15%	20%	25%
NO. OF CHANNELS	7	10	14	17	20

Table 8.2 Number of private access channels needed to serve 40 subscribers at various percentage usage rates.

A/ Total length of fibre (trunk and distribution) km per Subscriber.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.55	1.16	1.16	1.16	1.16	1.16
12	0.55	1.16	1.16	1.16	1.16	1.16
22	0.71	1.32	1.32	1.32	1.32	1.32
36	0.71	1.32	1.32	1.32	1.32	1.32

B/ Number of repeaters per subscriber (WDM)

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.14	0.77	0.92	1.24	1.55	1.71
12	0.28	0.91	1.06	1.38	1.69	1.85
22	0.51	1.14	1.29	1.61	1.92	2.08
36	0.84	1.47	1.62	1.94	2.25	2.41

C/ Number of repeaters per subscriber (FDM)

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.05	.21	.21	.21	.21	.21
12	0.05	.21	.21	.21	.21	.21
22	0.09	.25	.25	.25	.25	.25
36	0.09	.25	.25	.25	.25	.25

Table 8.3 Fibre requirements for 20 channel multiplexing in a Rural Strip Development area, with repeater requirements for FDM and WDM.

8.4 SUBURBAN MODEL

In order to calculate the amount of fibre needed to serve a diamond shaped serving area of the type encountered in suburban and urban areas, consider the subdivision of a quarter of one of these diamond shaped areas into groups of ten, as shown in figure 8.5. Triangular areas of 15 or 10 subscribers remain after the rectangles have been cut out, and these areas are reproduced in more detail on the figure. Referring to the spacing between two subscribers as one unit, the length of feeder to served the ten rectangular areas in the first column is:

$$\sum_{i=0}^{9}(2i + 5.5), \text{ by inspection.}$$

This gives 145 units of feeder, plus one half-unit long drop per subscriber. This calculation can be continued for each column. In calculating the fibre needed to serve the triangular subsections, it may be noted that the points marked with an "X" or by a square in the enlarged versions of these remnants correspond to the points so marked on the main diagram, which are all equidistant from the P.C. The fifteen subscribers need two fibres to run this length, the ten only one. Performing the calculations in this manner, it transpires that 831 units are needed to cover the 325 subscribers in this area, or 2.56 units per subscriber.

Extending the same calculations to a diamond serving a maximum range of 50 units it is found that 21350 units of fibre are needed to serve 5100 subscribers - or 4.19 units per subscriber.

For the suburban model of section 7.4, with a grid spacing of 58m, the fibre needed in the distribution is therefore 0.24 km per subscriber. This represents a saving of 1.71 km from the 1.95 km of section 7.4. Although this is a higher percentage saving than in the rural grid distribution model, it is a lesser absolute saving, and it is this which determines the practicality of multiplexing.

By combining the above figures with the channel requirements of Table 7.12 the fibre requirements of Table 8.4A are derived. It is seen that, due to the very short length of trunk (47.3 km from section 7.4) the amount of fibre used is very insensitive to usage. Table 8.4B shows the total number of repeaters (not per subscriber, due to the very small numbers) to serve 45300 subscribers.

The remote switch and program centre traffic dependent components are the same as in section 7.4, with the comments of section 8.2 above holding for other components.

8.5 URBAN MODEL

Treating the diamond shaped distribution area serving 45300

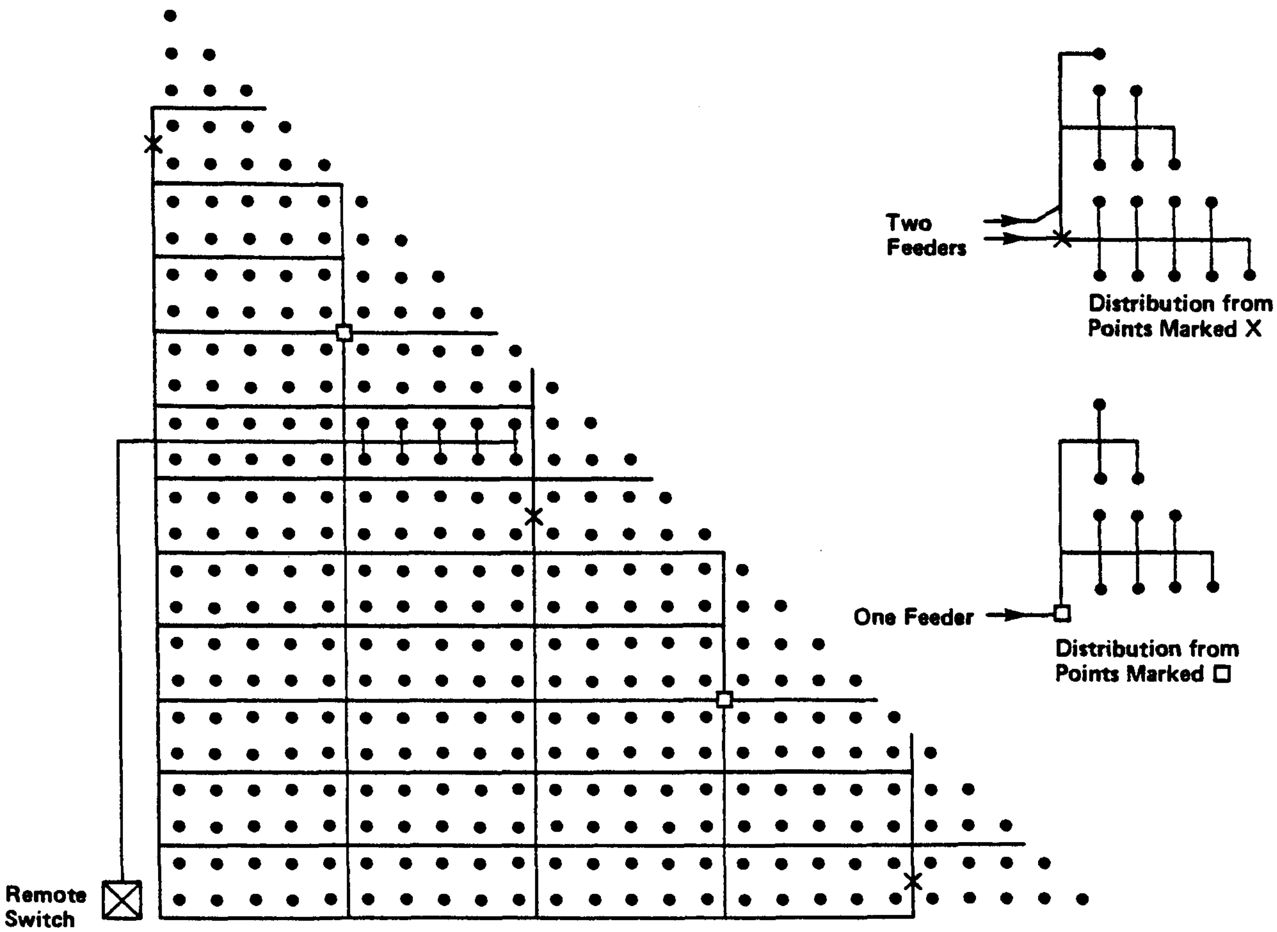


Figure 8.5 Division of a Grid Type Population Distribution Into Regions of Ten Subscribers Each

A/ Amount of fibre (trunk and distribution) km per Subscriber.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	0.24	0.26	0.28	0.29	0.31	0.33
12	0.24	0.26	0.28	0.29	0.31	0.33
22	0.24	0.27	0.28	0.30	0.31	0.33
36	0.24	0.27	0.28	0.30	0.31	0.33

B/ Total number of repeaters, serving 45300 subscribers by FDM.

COMMON CHANNELS	PERCENTAGE USE OF PRIVATE ACCESS CHANNELS					
	0%	5%	10%	15%	20%	25%
6	16	336	576	800	1024	1280
12	16	336	576	800	1024	1280
22	32	352	592	816	1040	1296
36	32	352	592	816	1040	1296

Table 8.4 Fibre requirements for 20 channel multiplexing in a suburban area, with repeater requirements for FDM.

subscribers, as in section 7.5, in the same way as described for the suburban area above, it is found that 0.159 km of fibre is needed per subscriber, independent of traffic, and no repeaters are involved.

The comments of sections 7.5 and 8.2 concerning the other components still apply.

8.6 F.D.M. v W.D.M.

Both FDM and WDM systems require components which have not yet been developed in the laboratory. For FDM the missing component is a sufficiently linear light source. In Activity 5 we shall specify the precise linearity required for various levels of multiplexing. However, to date development efforts over several years have failed to produce a source combining sufficient linearity and power to permit transmission of more than 3 or 4 TV channels over any useful distance. This is a problem of both solid state physics and circuit design. Although results on the relationship between device doping and linearity are available (ref 24), it is still far from clear whether or not there is a fundamental limitation to linearity imposed by the physics of the device.

The components other than light source and driving circuitry needed to implement FDM are all well developed and are mostly commercially available.

As for WDM, the availability of sources at well defined wavelengths appears to pose no fundamental problems, although development work would be needed to ensure that the power and linearity of the best currently available sources could be matched at all wavelengths. The combiners and splitters needed are, in principle, within the state of the art of optics, but again development would be needed, especially to determine how tight the component specifications must be made to meet system requirements (and hence how expensive the devices become). Activity 5 will set the system requirements for the combiners and splitters.

Thus, in summary, WDM components can, in principle, be developed, but their price is a complete unknown. With FDM systems the well developed electronic components will probably dominate the cost, but uncertainty exists about the realisability of the superlinear light source required. (Throughout the discussion it has been assumed that a directly modulated light source will be used, rather than an external modulator. This reflects the present state of the art regarding linearity of these components but should some unforeseen development produce a superlinear external modulator at a cheap enough price, this would be used.)

9. CONCLUSIONS

9.1 VISUAL LIBRARY

A study of the above component counts shows that the visual library service uses a very high proportion of the components in the network, even at comparatively low usage rates. For example, even at 5% usage in a rural grid distribution area, 0.09 video sources per subscriber implies some 4000 sources at the program centre. It is difficult to imagine an organisation capable of keeping enough films to usefully serve this number of sources. It would appear that an expanded Pay TV network could be configured to meet most of the demands made of the visual library, but in a much more economical manner. Although such a system could obviously not provide a specific program instantly on request, it should be possible to devise a system that would ensure that minority interests were represented. In this case, the only service remaining to be served by the private access channels are subscriber originated video. Some of these channels can be treated as common access channels (such as locally originated entertainment or debates), while the remaining services will require very few channels to accommodate them. One aspect of the remote switch design for private access channels could reasonably be maintained - that is the lack of duplication of such channels. It will be recalled that the effect of this is to prevent a subscriber from simultaneously viewing two such channels, which is believed to be an acceptable restriction, and gives rise to savings in switch components. If extremely cheap video cross points are developed, this will not be necessary.

One impact of the removal of the visual library on switch architecture will be to negate the argument for the division of large switches into sub-units, since the number of private access channels no longer grows with the number of subscribers served, but rather grows with the number of subscribers originating their own programming.

The effect on the component count of an increased number of common access channels, duplicated at the switches, can be calculated easily. To calculate the fibre requirements, the fibre in the distribution area should be subtracted from the value quoted in the column "0% use of private access channels". The remaining number is directly proportional to the number of common access channels, and can be scaled up to meet any demand requirement. (Note that, due to the multiplexing of two channels per fibre, an odd number of channels needs to be rounded to the next highest even number). To make this clear, Table 7.2 shows that 4.80 km of fibre is needed to provide 36 common access channels in a rural grid distribution area. Of this, 2.88 km is in the distribution (from the text), leaving 1.92 km in the trunk. To provide 71 common channels, then, would need twice the fibre in the trunk (rounding 71 to 72), plus, of course, the same amount of fibre in the distribution. The total required is thus: (2 x 1.92) + 2.88 = 5.72 km. (Should rounding off errors in the tables make the figures inaccurate, the exact trunk lengths are quoted in the text).

To calculate the effect of an increased number of common access channels on the number of repeaters, crosspoints, converters and filters, it is only necessary to directly scale the appropriate figures in the column "0% use of private access channels", or calculation can be made directly from the formulae in the text. (section 7.2). The rounding up of odd numbers to the next highest even number already discussed only applies to the calculation of repeaters, not to crosspoints, converters or filters.

Private access channels (i.e. channels not duplicated at a remote switch) have the same effect on fibre and repeater requirements as common access channels. However, they require no up converters or high pass filters, and only half the number of crosspoints, down-converters and low pass filters.

For the highly multiplexed systems of section 8 the above comments apply for all the components discussed except fibre and repeaters. Due to multiplexing, fibre calculations need the number of channels to be rounded up to the next highest multiple of 20. To make this clear, Table 8.1A shows that 6 channels need 0.66 km per subscriber to serve a rural grid area. Since the text states that 0.57 km of this is in the distribution, it follows that 0.09 km is in the trunk. Rounding "6" up it follows that one has actually got a 20 channel capacity here, while rounding "71" up shows that an 80 channel capacity is required - an increase in trunk length by a factor of 4. Thus, the

fibre requirement is:

$$(4 \times 0.09) + 0.57 = 0.93 \text{ km per subscriber}$$

Calculation of repeater requirements follows from the text.

Thus, the reader is left with the tools to calculate the components required to supply a wide range of alternative systems.

9.2 SUBSCRIBERS SET

It has been assumed throughout this report that the frequencies used in the system will be sub-VHF or baseband. These frequencies are needed due primarily to a decrease in efficiency of light sources with increasing frequency of operation, and also due to the increasing complexity of operating a video switch at high frequencies. Baseband offers a further gain, since no energy is wasted on a carrier. Such frequencies require a channel converter in order to interface with present day domestic receivers. However, if a real commitment were to be made to supply visual services by fibre optics, the full system economy could only be realised if domestic receivers were capable of tuning sub-VHF channels directly. Rediffusion experience in Great Britain has shown that such sets can be produced at a cheaper price than those incorporating VHF and UHF tuners. The decision on whether to use baseband or sub-VHF is deferred to activity 5, and will be made mainly on the basis of the difficulties encountered in cascading baseband repeaters due to DC clamping.

9.3 ITEMS REQUIRING ACTION

This activity has produced counts of the number of components needed to provide interactive switched video services in urban, suburban and rural areas, with a range of possible channel capacities. Although the absence of reliable dollar figures prevents an assessment of the economics of the system at this stage (an item to be studied in a later activity), it is possible to comment on the technical feasibility of the system.

For near-term applications, the major items needing development are:

a) Optical couplers suitable for use in subscribers' terminals and remote switches.

b) Compact and cheap video switching matrices.

Although these items are highlighted, the development of light sources needs a little more attention, and the circuitry for the other components in the remote switch and program centre would need development too, although this is a case of application of state of the art technology rather than development of a new technology.

For long term applications, in addition to the above, the major items for development are:

a) Optical couplers for outside plant applications

and b) Superlinear light sources

or c) Wavelength division multiplexing components and systems.

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