Technical Report

A Systems Study of Fiber Optics for Broadband Communications

The Final Report

BNR Project TR 6259
March 1978

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A Systems Study of Fiber Optics for Broadband Communications

The Final Report

BNR Project TR6259
March 1978

for
Communications Research Centre
Department of Communications
Government of Canada

under DSS Contract
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TABLE OF CONTENTS

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PAGE

ACKNOWLEDGEMENTS

The study summarized in this report has been carried out by a project team, comprising the following individuals (some of whom participated on a part-time basis):

K.Y. Chang (Project Manager)
N. Toms
M. Larose
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B.L. Board
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J. Lougheed
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S. Rosenberg
J. Straus

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EXECUTIVE SUMMARY

Summary and Conclusions

The advent of fiber-optic technology in the late 1960's, and the rapid advances that followed, have provided a new transmission medium that has the potential of opening up a whole new dimension in the field of telecommunications. It has not only provided a new and potentially lower-cost alternative to the paired cable and coaxial cable media, but, also, it has offered the possibility of a melding of their characteristics such as to provide a distribution network capable of supporting CATV, telephony, and data services, as well as a wide range of new and more elaborate broadband/narrowband communication services. Due to the more easily attainable cost objectives, most efforts to date have been directed to such applications as long-haul and short-haul inter-office trunking of the telephone network.

Recognizing the profound impacts that fiber-optic technology will likely have on the future of broadband communications in general, and on the development of a fully integrated broadband/narrowband communications network in particular, Bell-Northern Research Ltd., with the support of the Department of Communications, Government of Canada, has carried out the present system study of fiber optics for broadband communications.

Briefly stated, the objectives of the study are to identify and develop the most suitable methods of using fiber optics for CATV, asymmetric switched visual services, and integrated distribution of video, voice and data services, and to examine the technical, economic and operational feasibilities of using fiber optics to provide these services. The emphasis of the study is placed on rural areas, as rural communications have been identified as a major concern within the Department of Communications.

The study was started in November 1976 and completed in March 1978. It has been carried out through ten separate study activities, each resulting in a stand-alone activity report. These ten activity reports, in conjunction with the present final report, represent, in its entirety, the outcome of the study.

The study began with a state-of-the-art review of the fiber-optic technology. Based on the capabilities/limitations and other characteristics of the technology, the study then examined in detail the methods and design aspects of using fiber optics for distribution of CATV, asymmetric switched visual services, and integrated video, voice and data services, in rural, urban and suburban areas. This was followed by an investigation of the cost effectiveness of optical fiber based systems as compared to conventional systems. Finally, the compatibility, maintenance, implementation and operational aspects were then examined.

The CATV service considered provides all subscribers with access to a number of TV channels (e.g. 5, 12, 21, and 35). This is the CATV service as it commonly exists today. The asymmetric switched visual services were defined as video broadband and narrowband services involving interaction with the subscriber. The systems that were studied had the capability to provide, in addition to the basic CATV as defined above, services such as Pay TV, visual library, and still pictures requested by the subscriber. They could also accommodate a limited amount of subscriber originated video information with or without responses from the other subscriber(s). This response could be either a narrowband signal (e.g. in educational TV) or a broadband signal (e.g. in teleconferencing). For the integrated distribution of video, voice, and data services, the presently available CATV, telephony, and data services were considered as well as the new services described above with the extension to full two-way video capability.

Various system configurations were examined for providing the different services. These configurations were classified as switched and non-switched approaches depending basically on the method used for handling the video channels. The non-switched approach is practically synonymous with tree-structured networks as currently used for coaxial cable CATV systems. In the switched approaches, the subscriber's request for a video channel is transmitted to a remote distribution point where the channel selection physically takes place, as opposed to non-switched approaches where this selection is performed at either the TV set tuner or the frequency converter which are both located at the subscriber's premises.

Based on the results obtained, the following major conclusions can be drawn:

a) Of various system configurations considered, the switched, star-structured configuration consisting of a center node and a number of satellite remote switching units is found to be the most technically attractive, particularly for the asymmetric switched visual services and the integrated distribution of video, voice and data services. This configuration overcomes the technical limitations imposed by the present and forecasted near-term fiber-optic technology, such as the non-linearity of light sources and the lack of efficient and well-developed optical directional couplers. It offers flexibility in the alteration or expansion of service options. It is more reliable because of the minimization and concentration of field electronics. Further, it follows the current evolution trend of the telecommunication networks.

b) For CATV service only, a switched, star-structured system configuration is also considered to be attractive for the same reasons as described above. Such a configuration is particularly suited for near-term implementation and for areas where a large number (e.g. 12 or more) of TV channels are required.

However, for long-term implementation, particularly (1) when the technology of wavelength division multiplexing or frequency division mutliplexing has developed to the stage that multiplexing of a large number of TV channels on a single fiber becomes feasible and economical, and (2) when the techniques for directional coupling have advanced to the point where optical tapping can be efficient and practical, the use of a non-switched, tree-structured system configuration for CATV could become attractive for more sparsely populated rural areas. The feasibility of a non-switched approach is highly speculative, whereas a switched system is more readily achievable. Futhermore, by the time the non-switched system approach becomes feasible, the basic services to be provided may have expanded to include Pay TV and other interactive services. Should it be the case, the switched approach would again be preferred.

c) In comparison with conventional tree-structured coaxial cable based CATV systems, optical fiber based CATV systems with a switched, star configuration for the rural model are found to be cost effective should the low price projections materialize. Note that low, medium and high price projections are used in this study to reflect an optimistic, conservative or pessimistic view of the future developments in the fiber optic field.

For the urban and suburban model areas, fiber optic CATV systems could not compete cost-effectively with coaxial cable based CATV systems under the projected prices.

d) Integration of video, voice and data services on a single, optical fiber based network is found to be technically feasible and cost effective, particularly in rural areas. For the rural distribution models with aerial construction, the fiber-based integrated network, at the medium price projections, would cost 20-30% less than the segregated distribution approach of telephony on pairs and CATV on coaxial cables. The cost savings are greater with buried installation or with lower price projections.

e) For urban and suburban areas, the per subscriber cost of an integrated fiber-optic distribution network can be competitive with the cost of conventional segregated facilities, particularly at the low or even medium fiber optic price projections. In this case, the major cost element of the integrated network is found to be the per-subscriber terminal units, both at the subscriber end and at the remote switching unit end. Any cost reduction in the subscriber terminal unit would therefore enhance the economic attractiveness of the service integrated network.

It should be noted also that the cost figures derived in this study are based on initial first costs only. It is expected that with an integrated distribution network, significant cost savings will also result from the reductions in maintenance, operational and administrative efforts and expenses.

f) A multi-node star network for the integrated distribution of video, voice, and data is compatible with the evolving telephony network, but deviates significantly from the tree-structured CATV network that exists today. Moreover, remote powering, optical cross-connecting, and cable fault locating, definitively requires more work before actual system can be implemented.

In summing up, this study has shown that an optical fiber based distribution network for the provision of broadband services or the integrated distribution of broadband and narrowband services is technically and operationally feasible and, especially for the integrated case, has attractive costs. Its application to areas where improvement of existing communication services and/or introduction of new broadband communication services are desired, such as the rural areas of Canada, therefore warrants serious consideration.

Recommendations

a) As a logical follow-up step of this study, and with a view towards stimulating an early realization of a fiber based broadband or service-integrated distribution network, it is recommended that the field trial of a fiber optic distribution system, such as the one presently being defined for implementation in a typical rural area*, be carried out at an earliest possible date. It is expected that such a trial would (1) permit a more complete and precise assessment of the technical, economic, and operational advantages and limitations of fiber based distribution systems, (2) enable practical problem areas to be uncovered and thus provide guidance to future research and development efforts, and (3) stimulate the interests of operating companies and equipment suppliers and thus lead to the realization of operational type fiber-based distribution systems.

b) To better quantify the economic advantages of integrating various telecommunication services into a single fiber-based network, it is also recommended that a more in-depth study of the costs of integrated fiber optic systems in comparison with conventional separate facilities to be carried out. The study should take into account the costs associated with the maintenance, operation and administration of the integrated and separate systems. As well, possible problems in evolution from present structures and the costs of meeting future growth and new service requirements should be considered. The study should preferably be conducted based on the provisioning of the facilities in one or more actual geographical areas.

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*A program definition study of a proposed field trial of fiber optic communication technology in Elie, Manitoba, is currently being conducted by Northern Telecom/Bell Northern Research. The study is scheduled for completion in May 1978. The study is being carried out under the joint sponsorship of the Department of Communications (DOC) and the Canadian Telecommunications Carriers Association (CTCA).

LIST OF TABLES

LIST OF FIGURES

1. GENERAL

1.1 INTRODUCTION

The past few years have witnessed one of the potentially more dramatic developments in the history of telecommunications. That is, the emergence and advance of a new technology - fiber optics. This began with a prediction in theory in 1966 that the purity of glass fibers can be improved to reduce their attenuations to less than 20 decibels per kilometer. This prediction was made at a time when the attenuations of available glass fibers were in the order of several hundred decibels per kilometer or higher. Intensive efforts in various telecommunications research laboratories around the world followed immediately in an attempt to reduce the theory to practice. These efforts have been very successful and, only a few years later, fibers of less than one half of one decibel per kilometer have been fabricated. Today, a wide variety of low-loss optical fibers, at price levels comparable to those of some of commonly used copper based transmission media, such as coaxial cables, are available on the market. As well, practical applications of optical fibers in the telecommunications network are fast becoming a reality, as demonstrated by the numerous field trials that have been, or are being, successfully conducted around the world.

The broad bandwidth, low attenuation and many other unique and advantageous features this new medium possesses, in conjunction with its very low cost potential, render it technically and economically attractive for applications to almost all areas of the telecommunications network. In particular, as the fiber-optic technology is becoming mature, and as the cost differentials between optical fibers and coaxial and paired cables decrease, the use of optical fibers in areas where coaxial cables are used, such as CATV and other broadband video transmission systems, will become attractive, and their use as an alternative to paired cables may become feasible. Further, this opens the possibility for the implementation of more versatile broadband or integrated broadband/narrowband communication systems.

While the potential of fiber optics for broadband or integrated broadband/narrowband communications has been widely advocated, many questions still need to be answered and problems analyzed and solved before practical implementation can be seriously considered. These questions and problems include:

1) To use fibers for providing CATV-type of service, what system approach should be taken? What network structure is more efficient? Should tree structured, multi-channel per transmission line network, as commonly used in present-day coaxial cable systems, be also used for fiber systems, or should an alternative network structure be employed?

2) To provide bi-directional interactive broadband services, with a limited or full switching capability, what system approach should be taken? Should it be developed in a manner similar to the telephone network, or the CATV network?

3) Can all the services, including visual, voice and data, be economically integrated into a single optical fiber based facility? And how?

4) At present, a coaxial system that provides 12 video channels using commonly-used low-loss coaxial cables (e.g. 3/4" coax) can be stretched up to 15 miles or so without degrading the signal quality. When more channels are required or a longer distance is to be served, it is difficult to meet the signal-to-noise ratio, intermodulation, cross-modulation or other technical standards as specified in BP-23. Can a fiber system alleviate these problems? If so, how?

5) Would fiber cables present problems in handling, splicing, connecting, testing, fault-locating, etc. as compared to copper-based media? If so, what are the solutions?

6) An optical fiber cannot carry electrical power. What should be the method used to power intermediate repeaters, if and when required?

7) Can a fiber system provide the same or better reliability as compared with conventional system? What methods and procedures should be used for the maintenance of a fiber system?

8) When will broadband fiber-optic systems become cost competitive with conventional systems?

With a view to answering these and many other relevant questions, Bell-Northern Research has conducted, under the sponsorship of the Department of Communications, Government of Canada, the present systems engineering study of fiber optics for switched and non-switched broadband communications. In accordance with the objectives of the Department of Communications, emphasis of the study is placed on the applicability and feasibility of fiber systems in rural areas, where it is desired to improve telecommunication services. The study was started in November 1976 and carried out over a period of 1 1/2 years.

1.2 STUDY METHOD

In conducting this study, all items relevant to the use of fiber optics for broadband communications were first examined, including the problem areas mentioned above. These were then grouped into ten specific areas and individually investigated through ten study activities. Each of the ten activities was performed separately, but in a systematic manner to ensure consistency and coherence.

In essence, the study began with an examination of the methodology and other system aspects of the existing coaxial cable technology for providing broadband services and made a thorough review of the present status of fiber-optic technology. Based on this knowledge, system concepts and network configurations suitable for fiber-optic systems to provide various broadband services were then derived and studied.

Following this work on system concepts and network configurations, details of system design principles were developed and the cost-effectiveness of the systems investigated. Finally, outside plant methods, maintenance procedures, and operational aspects were studied.

It is noted that in the original study plan, a system model suitable for field trial implementation in a particular area was to be selected, studied and proposed. During the course of the study, however, DOC decided to expand the scope of this activity and have a "Program Definition Study of a Fiber Optic Field Trial in a Rural Area" conducted under a separate contract. This contract is carried out under the joint sponsorship of the Department of Communications and the Canadian Telecommunications Carriers Association. The original activity has therefore been replaced by a study on wavelength division multiplexing (Activity No. 10).

1.3 OUTPUT OF THE STUDY

The results of each of the ten study activities have been documented separately in the form of a technical report, also referred to as an activity report. These ten activity reports, in conjunction with the present final report summarizing the major results of these activities, constitute, in their entirety, the total output of this study.

The titles and authors of these activity reports are given in the following:

Activity Report No. 1, State-of-the-Art Review of Fiber Optic Technology, by K. Abe et al.

Activity Report No. 2, Methodology of Fiber Optics for CATV, by M. Larose

Activity Report No. 3, Integrated Distribution of Video, Voice and Data, by N. Toms

Activity Report No. 4, Methodology of Fiber Optics for Asymmetric Interactive Switched Visual Services, by N. Toms

Activity Report No. 5, System Design Rules and Guidelines, by M. Larose

Activity Report No. 6, Cost Effectiveness, by M. Larose

Activity Report No. 7, Operational Considerations, by M. Desautels

Activity Report No. 8, Outside Plant Considerations, by B.L. Board et al.

Activity Report No. 9, Compatibility with Existing Systems, by N. Toms

Activity Report No. 10, Wavelength Division Multiplexing, by J. Straus et al.

1.4 STRUCTURE OF THE FINAL REPORT

This final report is divided into three main sections. Section 2 deals with the system design and network configuration for different type of systems, which are classified in terms of the services provided, namely, CATV, Asymmetric Interactive Switched Visual services, and Integrated Distribution of Video, Voice, and Data. These systems are considered for application to three model areas: rural, suburban, and urban, with the emphasis on rural applications. Section 2 covers primarily the material contained in Activity Reports No. 2, 3 and 4, although materials contained in Activity Reports No.1 and 5 are used as supporting data.

Section 3 deals with the cost considerations associated with the use of fiber optic broadband communication networks. Cost projections of individual fiber optic components are made and an assessment of the cost effectiveness of fiber optics on a system basis is presented. The system configurations that are identified in Section 2 to be the most attractive from the point-of-view of technical feasibility are used for detailed cost evaluation and comparison with conventional systems. This section covers essentially the work that has been done in Activity Report No. 6.

The conditions that must be met by fiber optics in order to be cost-effective being identified in Section 3, Section 4 addresses the problems associated with the implementation and operation of a fiber optic network, particularly as it relates to the outside plant, maintenance and compatibility aspects. The findings of Activity Reports No. 7, 8 and 9 are presented in this section. New material on this subject is also added in this final report in order to present a more comprehensive view on the problems associated with the introduction of fiber optic networks in a real environment.

This report format is used with the objective of presenting a comprehensive summary of the findings of the overall study. Activity Report No. 1 - State-of-the-Art Review and Activity Report No. 5 - System Design Rules and Guidelines are not specifically covered in this final report, because they constitute supporting material for the other activities and thus do not lend themselves to summarization in that context. Also, Activity Report No. 10 which studies in detail the technical aspects of wavelength division multiplexing, a promising technique for future applications, has not been summarized here.

2. METHODOLOGIES AND DESIGN CONSIDERATIONS

2.1 DESCRIPTION OF THE MODEL AREAS

At an early stage of the study, the need for models representing the rural, suburban, and urban areas was identified. As a geographic or demographic study to characterize these areas was beyond the scope of this study, simple models based on typical population densities were used. The models had to be simple enough to permit rapid evaluation of the quantity of material required by various network configurations. This quantity of material constituted a basis of comparison for the evaluation of the relative merits of the different approaches considered.

Due to the wide variation of population densities from one region to another, it is difficult to say that the models employed in this study are typical of rural, suburban and urban areas in all regions. However, the approach taken and the results obtained in this study are such that they can be easily extended to other population densities. In particular, it is believed that the conclusions reached will still hold even if the actual distribution does deviate somewhat from the model used.

2.1.1 Rural Models

For rural areas, both uniform and non-uniform subscribers density models are considered. In both cases the aerial distance from the central distribution point (e.g. Central Office) to any subscriber was set at 40 km maximum.

For the uniform subscriber density model, a density of 10 subscribers per km squared is used. Each subscriber is assumed to be located at the center of a 320 meter square lot. In rural areas it is unlikely that two subscribers living on opposite sides of the road will face each other. For this reason rows of subscribers are offset by 160 meters. The resulting grid model is illustrated in Figure 2.1. With this model, there are 50,000 subscribers in a 40 km radius distribution area.

In some rural areas the subscribers are located only along the roads and the roads are widely spaced. For this non-uniform subscriber density, a linear distribution model is assumed which places subscribers at 160 meter intervals along the roads and 160 meters from the roads. This strip model is illustrated in Figure 2.2.

2.1.2 Suburban model

For suburban areas, an uniform subscriber density of 300 subscribers per km squared is assumed. Each subscriber is placed at the center of a 58 meter square lot. This model is illustrated in Figure 2.3.

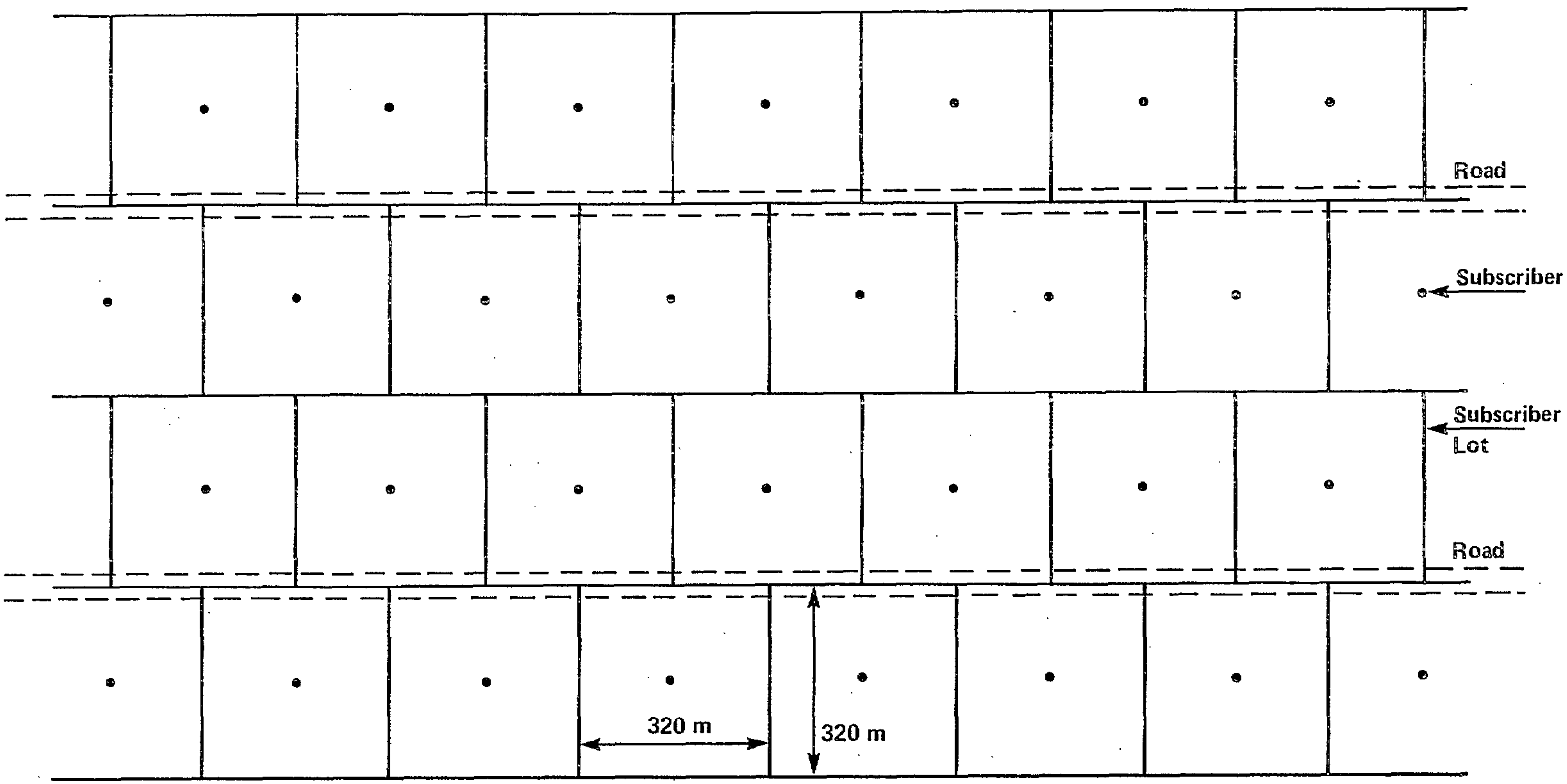

Figure 2.1 Rural Area — Grid Model

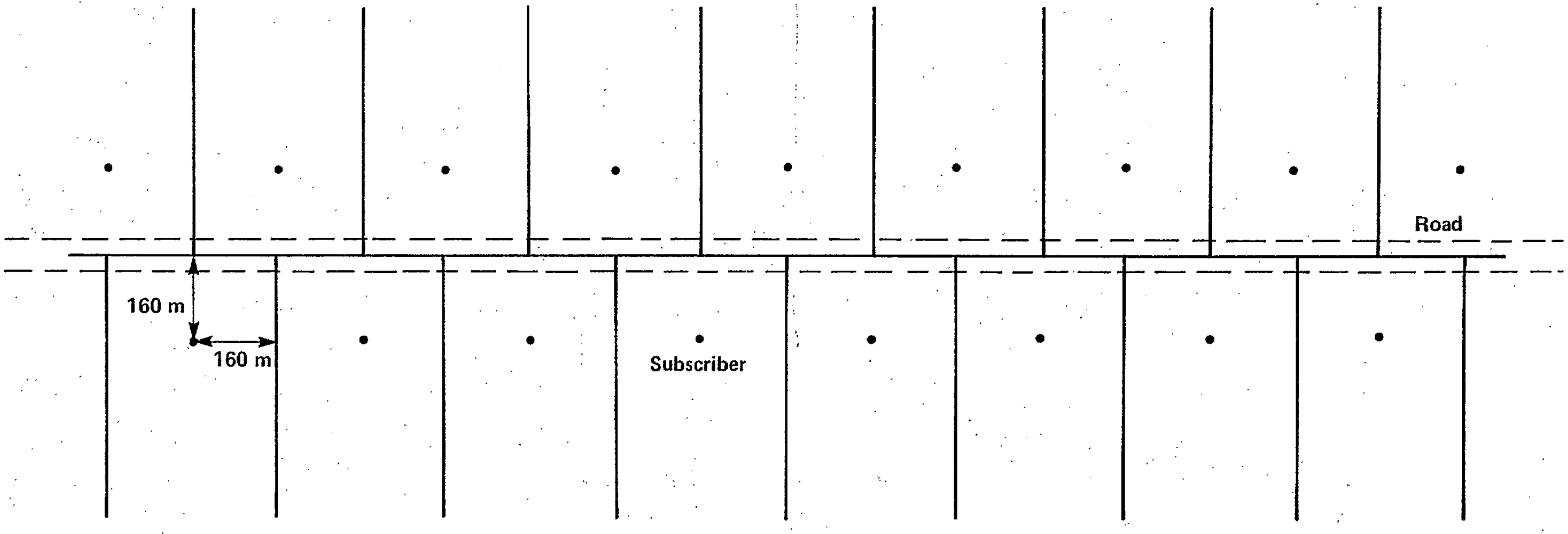

Figure 2.2 Rural Area — Strip Model

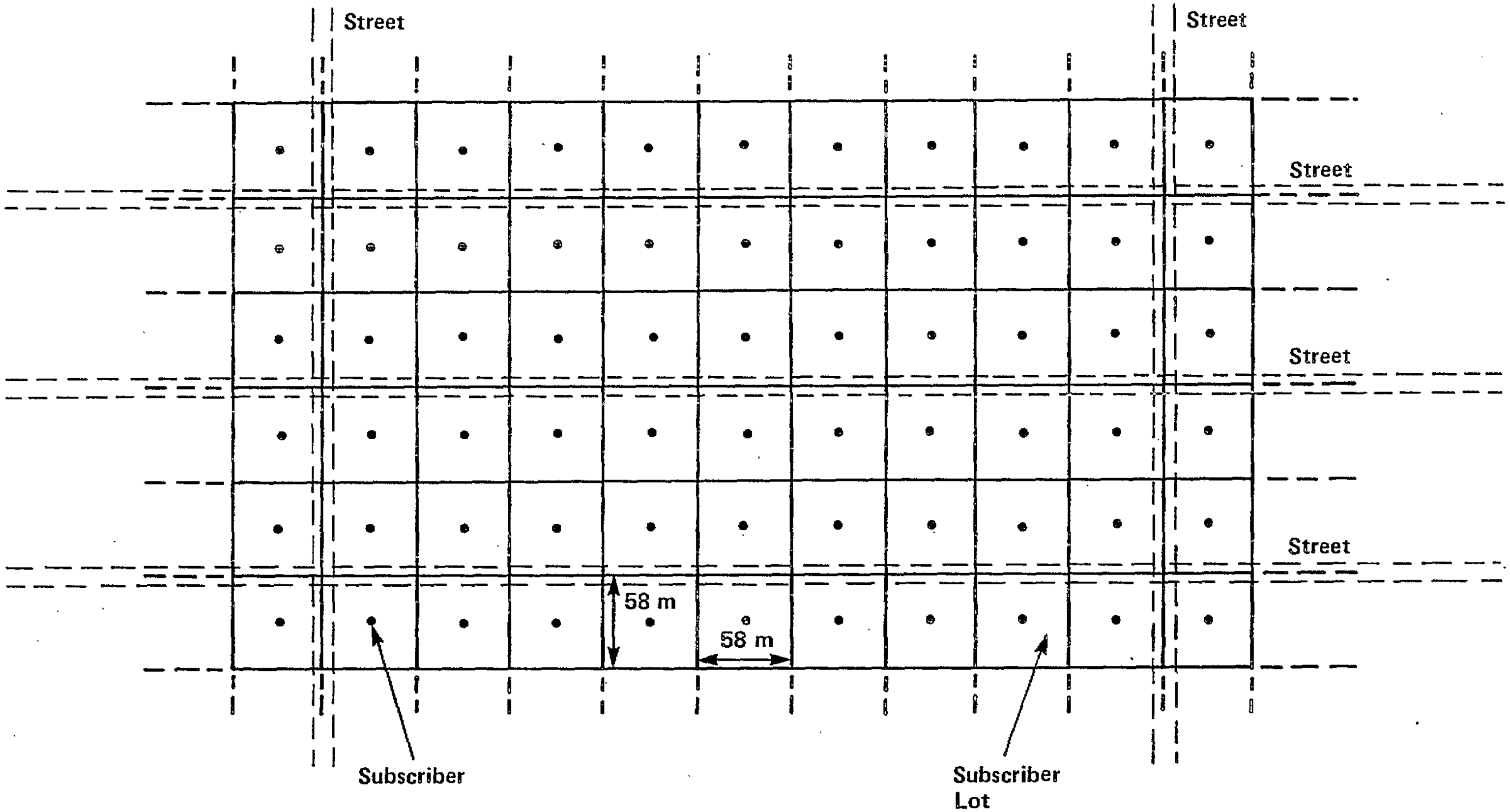

Figure 2.3 Suburban Area Model

2.1.3 Urban Model

For urban areas, an uniform subscriber density of 5000 subscribers per km squared is used. In this case, four subscribers are assumed to share a 28 m square lot and they are all located at the center of the lot. This lot model simulates a typical urban apartment building of four dwellings.

2.2 FIBER OPTICS FOR CATV

CATV, considered as a basic broadband communication service, was treated first in this study. The methodology of using fiber optics for CATV and its application to the three model areas were studied, with the results presented in Activity Report No. 2, and summarized in the following.

2.2.1 Service and Performance Requirements

The service and performance requirements of a CATV system are defined in this section as they are experienced by the subscriber. The subscriber perception of the service can be expressed in terms of the number of video channels accessed and the quality of the signal received. The number of channels to be provided by the system depends on the area to be served. For urban and suburban areas, systems capable of providing 12, 21 and 35 channels are considered. However, since a smaller capacity may be adequate in certain rural areas, 5-channel systems are included in rural area applications. The CATV signal considered in this study is of the standard NTSC format. The performance requirements are in accordance with BP-23, or its equivalent when it does not apply directly.

2.2.2 Fiber Optics for CATV Transportation Trunking

A CATV system can normally be separated into two distinct parts, namely the transportation trunk and the distribution system. Signals are brought in from a remote antenna site via the transportation trunk to the program center (also called distribution center), where disribution to the subscribers is made through the distribution system. Transportation trunks are usually characterized by high performance requirements and relatively long lengths. In this study, a signal quality characterized by a signal-to-noise ratio (SNR) of 56 dB is used.

For certain system configurations, as shown in Figure 2.4, there exists secondary distribution centers or remote units. In this case, transportation trunks would also be required to bring the signals from the program center to the remote units. A lower performance level, e.g. 46 or 43 dB SNR, may be considered for these trunks, provided that the distribution system can be designed at such a level that the BP-23 requirements issued by the Department of Communications are met by the overall system.

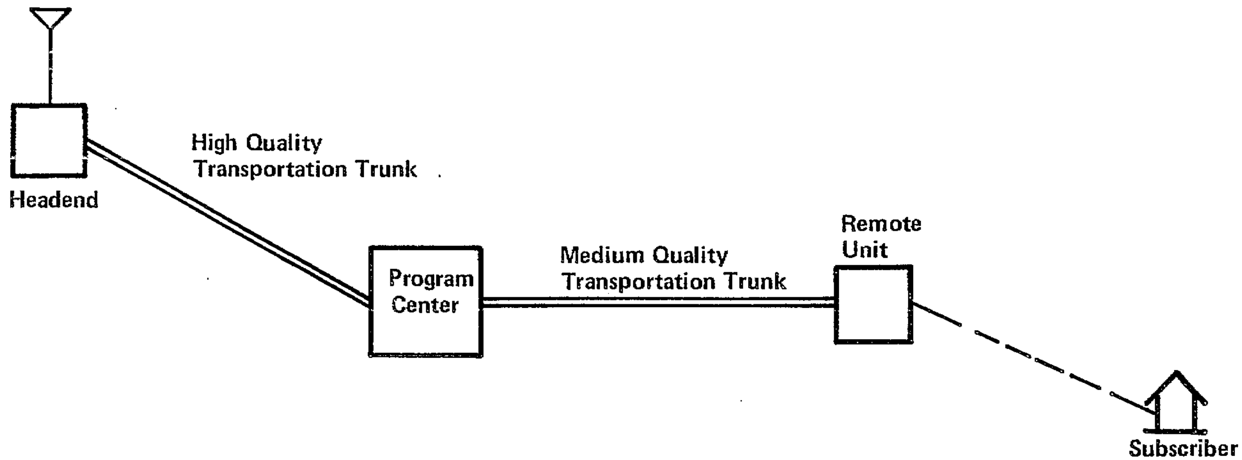

Figure 2.4 CATV System Configuration

For high quality transportation trunks (56dB SNR), it is shown that transmission of 1 channel per fiber is the preferred approach. Both baseband transmission and transmission on a modulated low frequency carrier can be used.

With 5 dB/km installed fiber cable, it is shown that a high quality CATV trunk can be established over a 60 km distance with repeater spacing of more than 3 km. For medium quality trunks (46 or 43 dB SNR), it is possible to use frequency division multiplexing (FDM) to transmit a small number of channels (e.g. 3) over a single fiber. However, single channel per fiber transmission is again a preferred approach, particularly when the distance is long.

2.2.3 Fiber Optics for CATV Distribution

There are two basic approaches to the distribution of CATV service, namely switched and non-switched. With the non-switched approach, which has been used in conventional coaxial-based CATV systems, all video channels are multiplexed for transmission onto the system and are available to all subscribers. With the switched approach, a video switch is employed at the distribution center to provide only the specific video channels requested by the subscriber.

a) Non-Switched CATV Distribution

Optical fibers can be used to implement a non-switched, tree-structured CATV systems, in much the same way as present-day coaxial cable based CATV systems, although not necessarily on a frequency division multiplexing basis. However, such systems lack the flexibility in accommodating future growth, both in terms of increases in number of channels and in system length. Nevertheless, because of the high common usage of the transmission medium permitted with this tree-structure approach, the quantity of the fiber required can be minimized.

With this configuration, tapping of the signals from a fiber optic trunk or feeder cable is required. This can be performed either optically or electrically. The latter is simpler, but it can only be made from a repeater point where electro-optical conversion has taken place. Also, an extra light source is required for every subscriber. Optical tapping is functionally similar to the tapping employed in coaxial systems. As indicated in the Activity Report No. 1, optical directional couplers for use as taps are still in the laboratory development stage.

Four multiplexing schemes have been considered for implementing non-switched CATV systems, namely, frequency division multiplexing (FDM), space division multiplexing (SDM), hybrid SDM/FDM, and wavelength division multiplexing (WDM). Due to the nonlinearity and limited power output of the light sources, the number of channels that can be multiplexed in one fiber with FDM for transmission over a significant distance is rather limited (refer to Activity Report No. 5). SDM provides only one channel per fiber and therefore requires a large quantity of components, particularly fiber. Hybrid FDM/SDM offers a good compromise to the above. The most attractive solution, however, appears to be WDM, which has the advantages offered by FDM but does not have the linearity limitations.

Availability of the devices needed for WDM, however, can be a problem unless an extensive effort is expended to its research and development in the coming years.

b) Switched CATV Distribution

Switched distribution is another attractive alternative to the FDM-based, tree-structured fiber optic CATV distribution system which is subject to severe channel capacity limitations. With a switched star configuration, the number of video channels available to a subscriber is limited virtually only by what the system operator can offer. As well, a switched CATV system can be readily upgraded to provide other types of broadband services.

A more detailed description of the switched and non-switched CATV systems that are subsequently used in Section 3 for cost estimation are given in Section 2.2.5.

2.2.4 Application to the Model Areas

Based on the above basic system approaches, possible network configurations for the three typical population densities, representing the rural, urban and suburban areas, were studied and the amount of components required for each configuration estimated and compared.

a) Rural areas

The results of the application study and components counts for the rural models indicate that the switched approach to CATV distribution is the most attractive and presently feasible approach in rural areas with a uniform subscriber density. In areas where the linear density model applies, the non-switched SDM/FDM approach with electrical tapping may be preferred to the switched approach, especially for systems providing 5 or 12 TV channels and if the video switch is too costly. For systems providing 21 or 35 channels, the switched distribution approach is clearly the preferred approach.

For long-term implementation, particularly when the technology for WDM or FDM will have matured to the stage that multiplexing of 20 to 35 TV channels on one fiber becomes feasible and when the techniques for directional coupling will have advanced to the point where optical tapping becomes practical and economical, the use of non-switched tree-structured distribution for CATV in rural areas should be seriously considered.

b) Suburban Areas

The results of the evaluation of various possible configurations and the associated components required for the suburban model have led to the conclusion that the switched distribution is most attractive technically and economically although the non-switched approach should not be ruled out should multiplexing of many channels with FDM or WDM and the techniques for directional couplers become practical in the future.

c) Urban Areas

Because of high shared usage of the video switch permissible in this case, as well as the short subscriber lines involved, it is found that the switched approach has a definite advantage over non-switched approaches.

2.2.5 Description of the CATV Systems used for cost evaluation

a) Switched CATV system

In the switched CATV system considered for the cost estimates, video channels from the program center are transmitted to remote video switching units. The subscriber then selects his desired channel through a dedicated subscriber fiber line connected to the remote switching unit. Each remote switching unit covers a distribution cell (diamond shaped area in the model), whose size is limited by the maximum length that can be achieved by the subscriber line without repeaters. The system is schematically shown in Figure 2.5. It is applicable to rural, suburban, and urban grid models. Details of a distribution cell for the rural grid model are illustrated in Figure 2.6. The distribution cells for suburban and urban models are similar, except that more than one drop originate at a feeder connection point.

For the rural strip model, the distribution cell consists of only one feeder cable parallel to the trunk cable, as illustrated in Figure 2.7.

The functional diagram of the remote switching unit is shown in Figure 2.8. Video switching is assumed to be done at a low RF channel (e.g. T7) of the sub-low VHF band. The trunking would also be at the same frequency, with one channel being transmitted per fiber. The video switch supplies each subscriber interface unit with three selected video channels. The interface unit converts two of these channels into different sub-low band channels (e.g. T9 and T10) then converts the multiplexed electrical signal into an optical signal that is coupled into the fiber of the subscriber line. This interface unit also receives the subscriber's request for the channel selection. The configuration of the unit is illustrated in Figure 2.9. Bidirectional operation of the subscriber fiber line is assumed, which necessitates the use of directional couplers in the interface units.

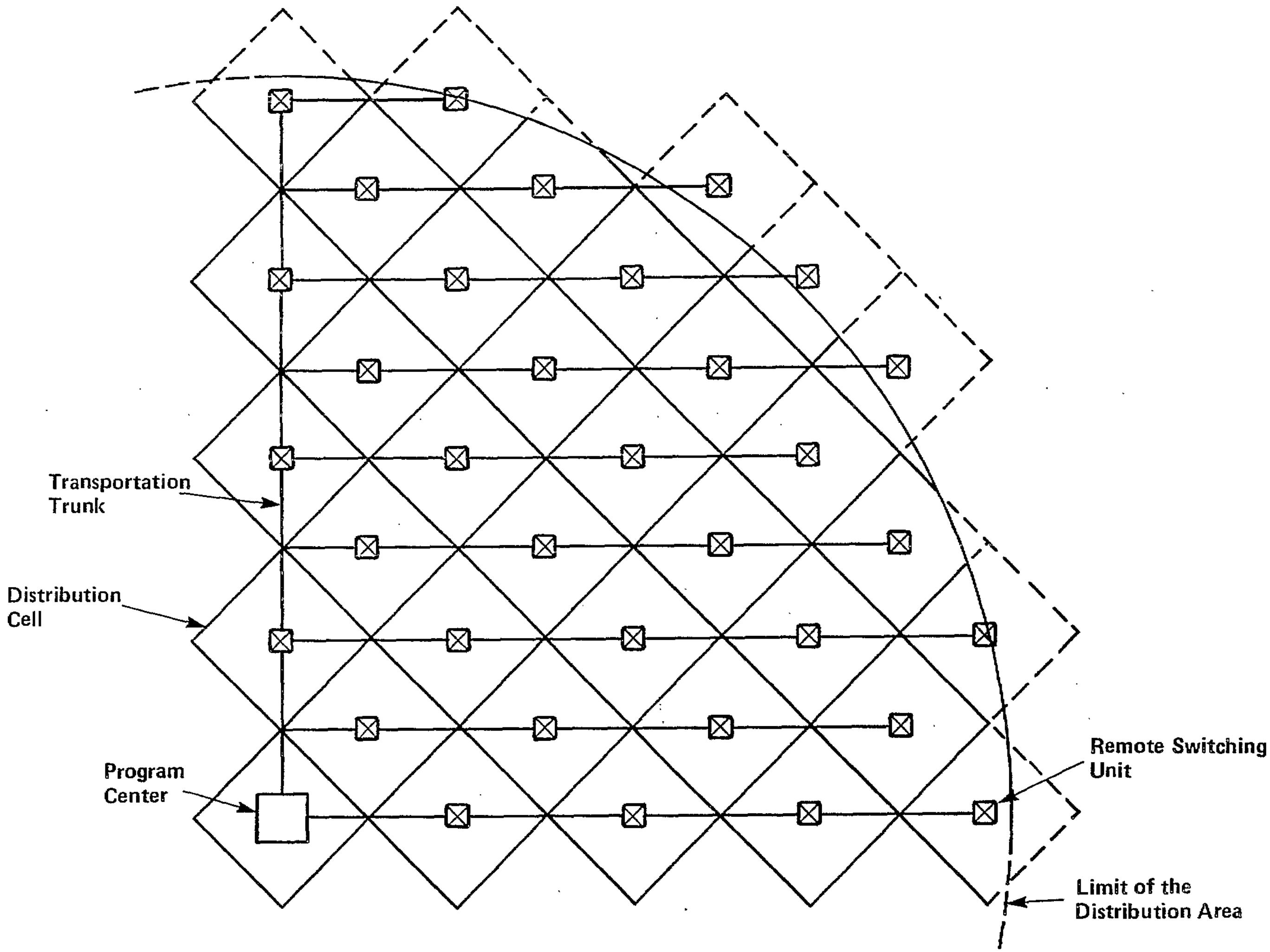

Figure 2.5 Switched CATV System for Grid Models
One Quarter of the Distribution Area Shown Only

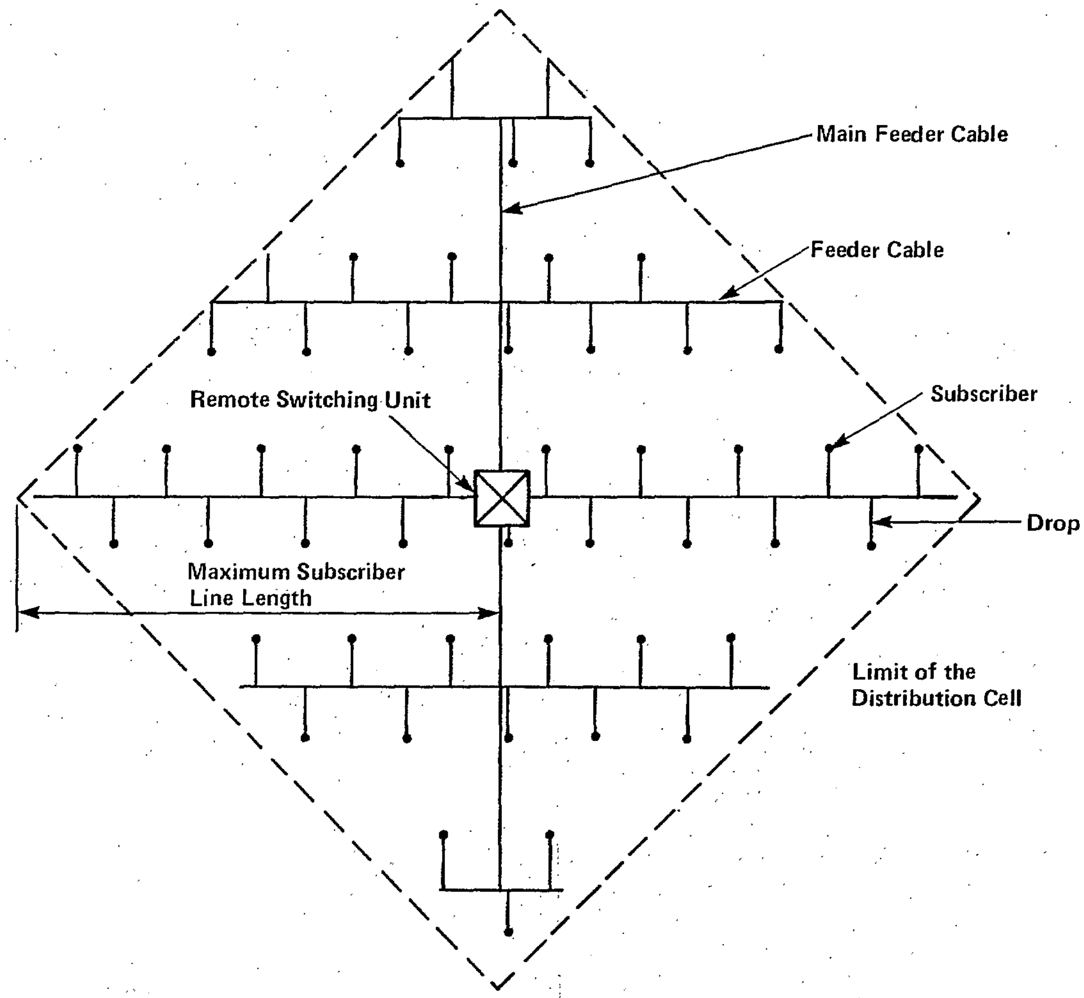

Figure 2.6 Detailed Distribution Cell for the Rural Grid Model

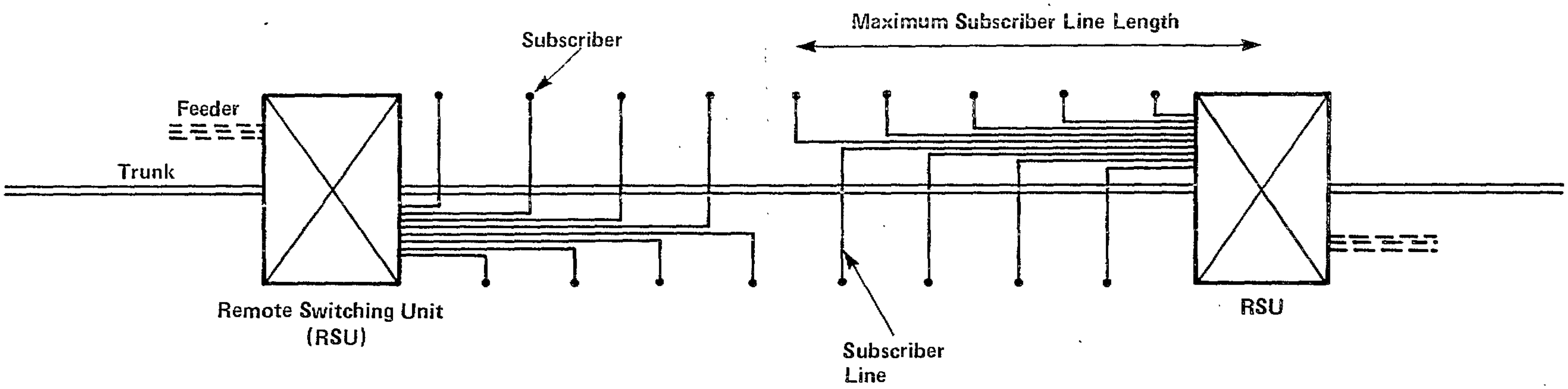

Figure 2.7 Switched CATV System for the Rural Strip Model

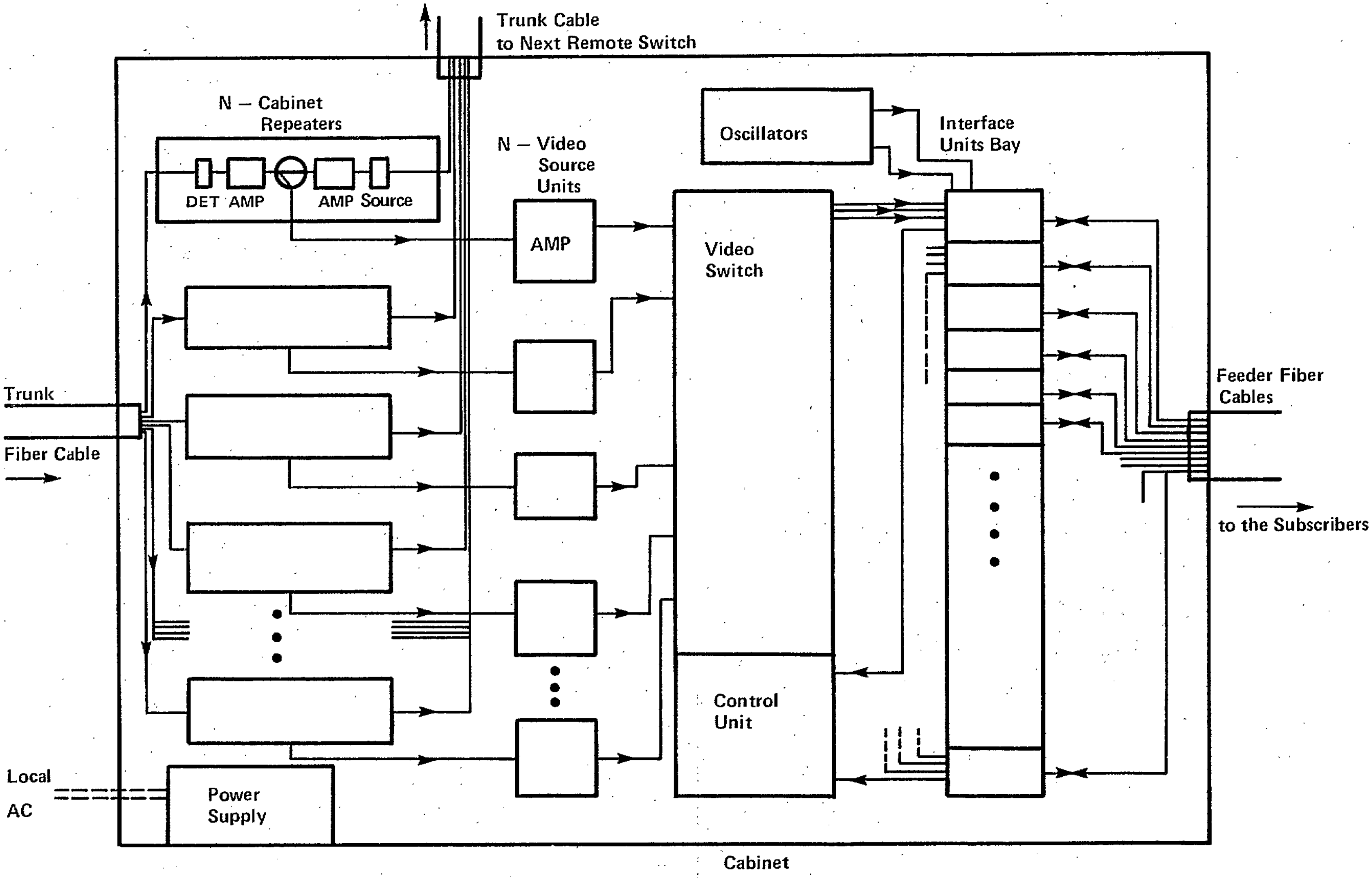

Figure 2.8 CATV Remote Switching Unit

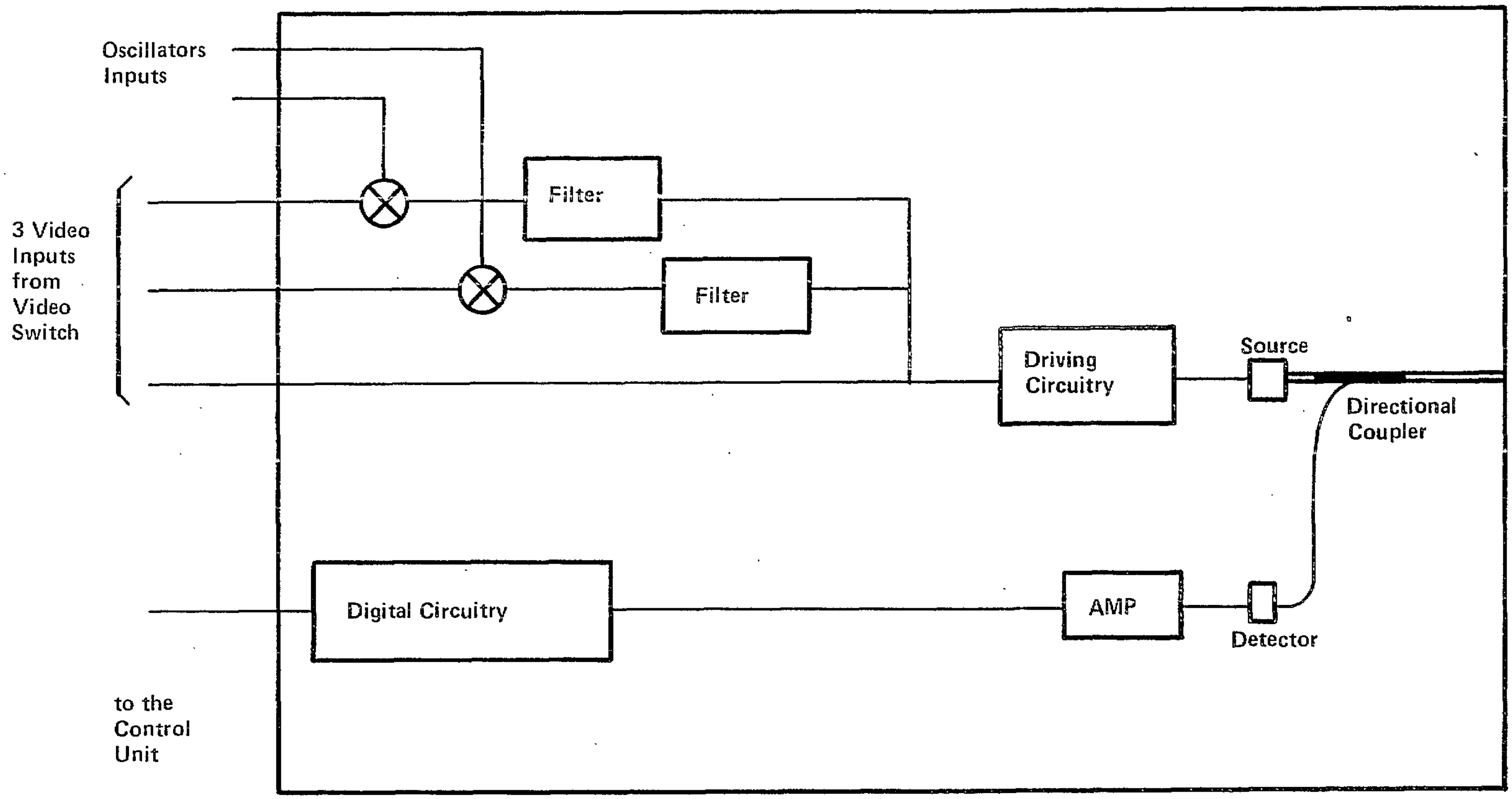

Figure 2.9 CATV Subscriber Interface Unit at the Remote Switching Unit

At the other end of the line, a subscriber terminal as shown in Figure 2.10 interfaces with the subscriber's TV set(s). Also, it transmits the channel selection signal to the subscriber interface unit located in the remote switching unit.

b) Non-Switched CATV System

The non-switched CATV system used for the cost estimation in Section 3 uses a tree structured network configuration similar to the one presently used for coaxial cable based CATV systems. Specifically, it consists of a repeatered trunk line with feeders that originate at the repeater point and from which the signals are optically tapped in the subscriber's drop.

In the model, each trunk repeater covers a diamond shaped area, the diagonal of which equals the trunk repeater spacing in rural areas or twice of the maximum achievable feeder line length in suburban and urban areas. The resulting distribution cell is illustrated in Figure 2.11 for the rural grid model. Again, suburban and urban distribution cells are similar except that more than one drop originate from an optical tap. For the rural strip model there is only a feeder cable parallel to the trunk cable.

Since a tree configuration is used to supply all the available CATV channels to every subscriber, these channels must be multiplexed and supplied to every part of the network. A hybrid FDM and SDM multiplexing scheme is employed for this purpose.

The technical assumptions used for the design of the non-switched systems that are different from the ones used for the switched approach, or that have a major effect on the performance of the non-switched system, are listed below:

1. A laser transmitter with a differential quantum efficiency of 0.34 mW/mA and with relative second and third harmonics of -70 dB for a fundamental of 20 mA peak-to-peak, is available, and has an adequate lifetime.

2. Intermodulation beats accumulate from one repeater to another on a power basis (10 log N law, where N is the number of repeaters).

3. Amplifiers have an input capacitance of 0.12 picofarad and a noise figure of 3 dB. This is difficult to achieve, especially for systems having 12 or more channels because of the higher frequencies involved.

4. Only the minimum power required to meet BP-23 is coupled into the subscriber drop. Consequently, optical taps are assumed to be available with any desired coupling ratio.

5. Taps through loss equals 1.5 dB. This figure does not include power loss resulting from coupling into the fiber drop.

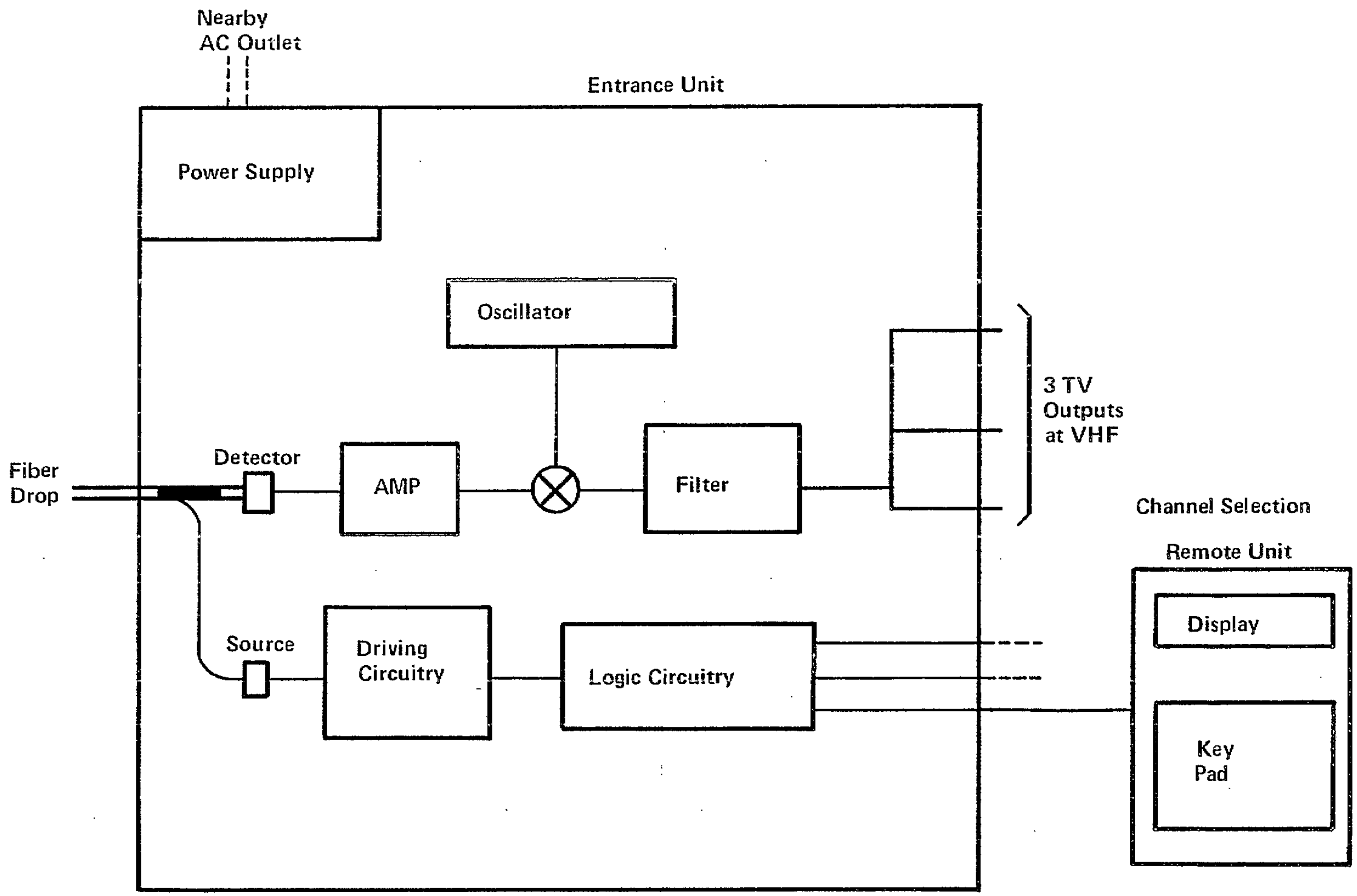

Figure 2.10 CATV Subscriber Terminal

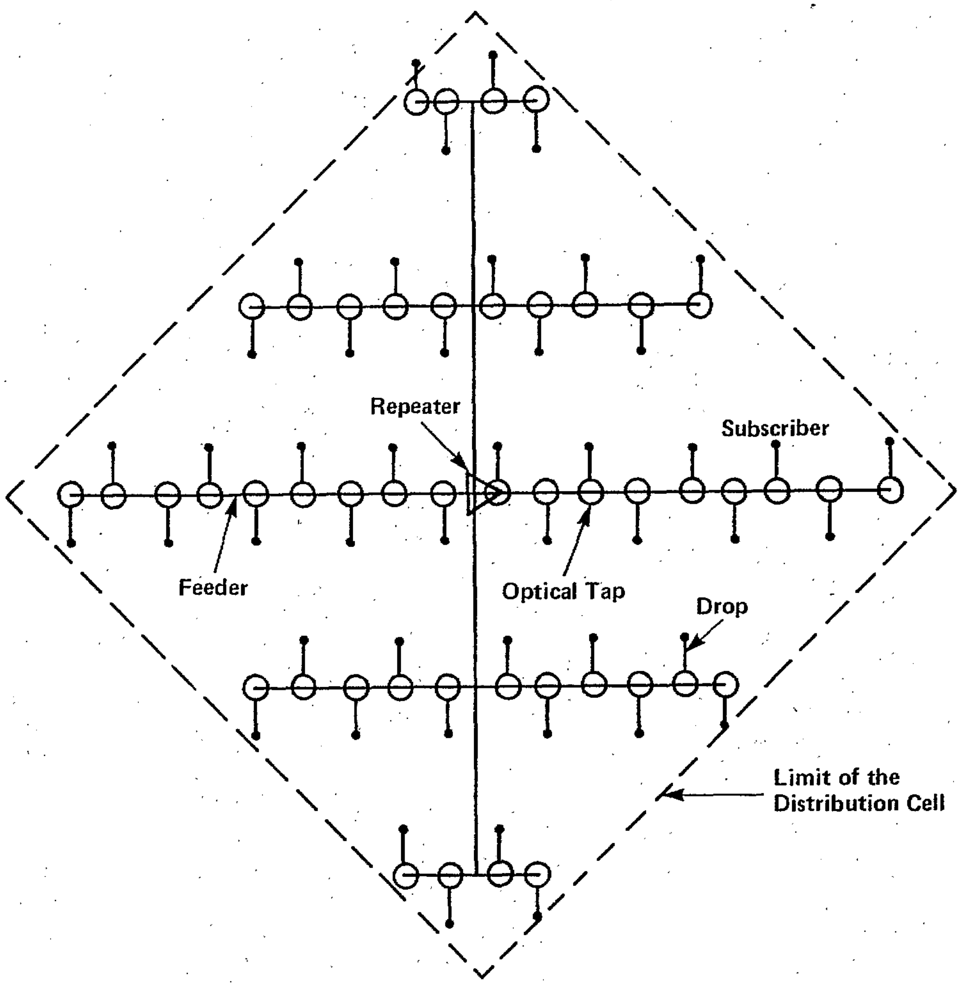

Figure 2.11 Distribution Cell for Non-Switched CATV Systems

6. Feeder cables contain up to 3 fibers in FDM systems. In most cases one fiber is not sufficient to accommodate the subscribers served by the feeder cable. For SDM-FDM systems, a maximum of 3xK fibers are used where K is the number of fibers required to transmit the total number of channels of the system.

7. 12 channel systems use harmonically related carriers (HRC) with "phase phiddling".

Based on these assumptions and the analysis of Activity Report No. 5, it is found, for rural areas, that 5 channel transmission is possible with a repeater spacing of 3.2 km, with a 5 dB/km installed fiber attenuation. Similarly transmission of 12 channels would be possible with a repeater spacing of 2.9 km when harmonically related carriers are used in conjunction with "phase phiddling". Otherwise, transmission of 12 channels is not possible. Phase phiddling is used to minimize the peak-to-peak video signal amplitude. However it is not a proven technique. The phase relationship between the carriers is difficult to maintain due to thermal drifts in the equipment. FDM transmission of 21 or 35 channels is not possible with or without HRC.

Similarly, for the suburban model a maximum of 12 channels can be transmitted on a single fiber when FDM is used. For the urban model, the amount of power that must be coupled in each subscriber drop for 21 or 35 channel systems makes optical tapping unattractive.

Effects of modifying some of the preceding assumptions

- Assuming that the intermodulation beats build up on a voltage basis with the number of repeaters (20 log N law), five channel transmission is not possible in rural areas.

- When the power required by each subscriber is increased by 2 dB in a 12 channel system, optical tapping is no longer possible in rural areas for distribution cells farther from the headend. This increase of 2 dB could be the result of an increase in amplifier noise or due to the fact that taps would be available only in discrete values of coupling ratios, as it is the case with coaxial cable taps today.

These points are raised to indicate that, although non-switched CATV systems are not strictly impossible, their practical feasibility is very uncertain especially for application in rural areas.

2.3 FIBER OPTICS FOR ASYMMETRIC INTERACTIVE SWITCHED VISUAL SERVICES

The provision of asymmetric interactive switched visual services is a first major step towards the realization of the so-called wired city concept. It also represents a significant step beyond the broadcast-type CATV services discussed in the previous section. Activity Report No. 4, "Methodology of Fiber Optics for Asymmetric Interactive Switched Visual Services", examines the concepts, methods and problems of using fiber optics to provide such services. Given in the following is a brief summary of this report.

2.3.1 Definition of Asymmetric Interactive Switched Visual Services

The asymmetric visual services considered in this study include, in addition to CATV, services of the following categories:

a) Pay TV: Except for billing and control, the Pay TV service is basically no different from CATV. The subscriber's interaction is limited to requesting delivery of a channel whose content is scheduled in advance by the system operator.

b) Visual Library: This is a natural extension to Pay TV. The subscriber can, in this case, select from a catalogue of recordings any one he wishes to view and request the visual library operator to transmit it to him.

c) Subscriber Originated Video: Certain subscribers may wish to originate their own visual information to be transmitted to the program center for distribution to all subscribers or to a selected group of subscribers. Examples include local council meetings and religious services.

d) Subscriber Originated Video with Responses from Other Subscribers: A video program originated at one point in the network is distributed to all or a group of subscribers, who may react to the transmitted material by transmitting a non-visual (vocal or numerical) response to the program originator. Examples under this category include educational TV and telemedicine.

e) Still Picture Services: In many instances, subscribers only need a stationary visual display, such as time tables, weather forecasts, and stock exchange informations. The subscriber would transmit a request for the desired information and view the display on his screen.

f) Symmetric Video Services: Although primarily concerned with asymmetric services, a small amount of two-way symmetric video traffic, for such services as teleconferencing, have also been accommodated by the asymmetric network considered.

2.3.2 Performance Requirements

All categories of service discussed above require downstream video channels from the program center 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.

The transmission to a subscriber of a minimum of two video channels is considered. This would allow simultaneous and independent use of two television sets. As for the video signal quality required, the standards of BP-23 are adequate for most purposes, but a SNR of 42 dB, instead of 40 dB, is proposed to be used as a design objective. This latter objective would permit 95% of the viewers at the worst locations to consider that they have received a fine picture. With regard to the video signal format, the standard NTSC format commonly used in North America is a logical choice.

Only two services may call for exception to the above, namely telemedicine and still pictures. In the case of telemedicine, the standard 525 line resolution of the NTSC format may not be adequate. Should higher resolution be required, it may be worthwhile considering an overlay network for this and other similar high quality service. In the case of still pictures, the use of a continuous 4.5 MHz NTSC signal for each still-picture service would be extremely wasteful. However, frame grabbers could be employed to significantly improve the efficiency, with 30 or 60 frames, or still pictures, transmitted over a standard video channel.

2.3.3 Optimum Network Configuration Based on Fiber Requirements

Based on the above service and performance requirements, the problem of designing a network which will accommodate them is then considered. For the purpose of comparing various possible network configurations, "channel-kms", derived by multiplying the length of each section of the network by the number of channels it is carrying, are used. Although having certain shortcomings, this parameter reflects, to a large degree, the quantity of fiber required.

Three principal network configurations are considered, namely a tree, a multi-node star (also referred to as hybrid tree/star), and a star network. By applying the three configurations to a simple model of a rural population distribution, and taking into account the effect of varying video usage patterns, the total channel-km capacities required were obtained. The results indicate that a multi-node star configuration requires a much smaller channel-km capacity, and hence the least amount of fiber. This configuration is therefore considered to be optimum, in terms of the quantity of fiber required.

2.3.4 Other Considerations

In addition to the amount of fiber required, there are also other parameters to be considered in the selection of a suitable network configuration for asymmetric switched visual services. These parameters are unique or more critical for a basically switched two-way system, as compared with CATV.

a) Multiplexing Approaches. As discussed in Section 2.2, to transmit more than one analog video channels over a fiber, one may use either frequency division multiplexing (FDM), or wavelength division multiplexing (WDM). Up to five video channels per fiber using FDM could be considered as being practical at present as it can be deduced from the results of the Activity Report No. 5. Higher level multiplexing, however, would need a major breakthrough in light source linearity or development of wavelength division multiplexing. This multiplexing consideration, therefore, tends to favor the star or multi-node star network configuration.

b) Switching Approaches. For all network configurations, a video switch is required at the remote unit. A simple and effective scheme to supply any two out of a number of video channels from the remote unit to a subscriber is proposed, whereby all channels coming into the switch are duplicated at the two frequencies used on the subscribers' feeders. Two spatial switches are provided at the remote unit, allowing the subscriber to independently select his high and low channel signals.

c) Optical Couplers and Taps. A tree-structured distribution network could be realized by multiplexing a number of channels on one fiber with each subscriber allocated his own wavelengths or frequencies (or both), thus reducing the amount of fiber cables required. However, optical couplers would have to be used extensively in the system in this case. As indicated in the State-of-the-Art Review report (Activity Report No. 1), optical couplers are still in an early stage of development and further work would be needed before their use for practical applications can be considered.

d) Upstream Transmission. Transmission of control or channel request signals from the subscriber to the remote unit or program center via existing telephone pairs is considered rather impractical. Moreover, transmission of video signals via existing telephone pairs is technically impossible . Therefore upstream transmission using bi-directional operation of a single fiber is proposed. The approach would work well with the star and multi-node star configurations. With the multiplexed tree configuration, upstream, transmission involves coupling FDM or WDM signals onto a fiber, which would result in performance degradation due to noise gathering.

e) Noise Gathering. Noise gathering is a common phenomenon and a serious design constraint for bi-directional coaxial cable based broadband communication systems. For optical fiber sytems using star or multi-node star configuration, however, the problems of noise gathering are minimal. With an FDM tree configuration, similar problems as those in bi-directional coaxial systems exist and, therefore, it suffers a severe limitation.

2.3.5 The Proposed Configuration for Asymmetric Switched Visual Services and the Design of the System

Based on the above considerations, it is concluded that the multi-node star configuration is the best choice for the provision of asymmetric interactive switched visual services. A conceptual design of the system based on this configuration has therefore been developed and discussed in detail in the Activity Report No. 4, particularly as it relates to the designs of the program center and the remote switching unit. Block diagrams of these sub-systems, together with flow charts illustrating the signalling between subscribers and these units, have been presented. The components needed to implement the system are listed in detail. These component counts are based on certain assumed video traffic estimates and are presented for the two models of rural population distribution and for suburban and urban populations, as described in Section 2.1.

Implementation of the proposed network, for the near term as well as for the long term, has also been considered. The network model for near term implementation assumes multiplexing by FDM of two video channels per fiber with the use of couplers kept to a minimum. For long-term implementation, multiplexing of 20 video channels on one fiber is considered.

For a network to be implemented in the near term, a compact and inexpensive video switching matrix and optical couplers for use in subscribers' premises and in remote switching units are required. For the long term network using high-level multiplexing, components for WDM and robust optical couplers for outside plant use would be necessary.

2.4 FIBER OPTICS FOR INTEGRATED DISTRIBUTION OF VIDEO, VOICE AND DATA

As indicated previously, the broad bandwidth, low attenuation, and many other features of optical fiber appear to lend itself well to the integrated provision of virtually all types of telecommunication services on a single network. Activity Report No. 3 addresses the methods, designs and problems associated with such a network.

2.4.1 Services Considered and Performance Requirements

The services considered for an integrated network in this study include, in addition to CATV and the asymmetric interactive visual services discussed in Activity Report No.4 (Section 2.3), telephony, data, and symmetric video services. Telephony is a basic and essential telecommunication service. The network can be rightfully considered as integrated only with its inclusion, along with such well penetrated service as CATV. Also, it is considered that the integrated network should allow low speed data to be transmitted, as well as providing higher speed lines compatible with the existing switched data networks and private networks.

The guidelines for setting transmission objectives for these services are that the performance levels of the fiber based network must at least match those achieve with conventional networks.

2.4.2 Possible Network Topologies

Basically, the network topologies as discussed in Activity Reports Nos. 2 and 4, namely, star, tree and multi-node star, can all be used for integrated distribution of the services discussed above. In addition, ring distribution, which has been proposed for telephony, especially digital telephony, in low density areas, has also been considered in this activity as a possibility for integrated distribution.

As with asymmetric interactive switched video services, Activity Report No. 3 concludes that an integrated network based on a multi-node star configuration is most attractive. This configuration is technically feasible in the near term and offers flexibilities when new services are required or when new subscribers must be added. The detailed conceptual design for an integrated network has therefore been made based on this configuration.

2.4.3 Recommended Topology for Service-Integrated Fiber Optic Distribution Network

Figure 2.12 illustrates the recommended topology for the integrated distribution of the various communication services with fiber optics. Subscribers are served by remote switching units, which in turn are served by a central office. The serving area of a remote switching unit may include as few as twenty or as many as several thousand subscribers, depending on the geography and demography of the area. The major components of the network are the central office, local trunks (also called feeders), remote switching unit and subscriber terminals.

a) Central Office (C.O.). Central office is traditionally associated with the telephone network. In this study, it can be generalized to mean a building containing the program center for CATV and other video services, as well as switching facilities for telephony and data.

b) Local Trunks. The local trunks carry the telephony, data and video separately from the C.O. to the remote switches. Telephony would be in digital form, most probably derived from a DS-1 rate signal (1.544 Mb/s for 24 voice channels). Video channels would be transmitted in analog form with one to three channels per fiber. The low bit rate data could be transmitted either by FDM or by TDM.

c) Remote Switching Unit. The remote switching unit is a key element of the network. Figure 2.13 shows a block diagram of the unit, consisting of a video switch, a telephony switch, a data switch, a control unit, subscriber's multiplexer and electro-optic terminals, and local trunk multiplexer and electro-optic terminals.

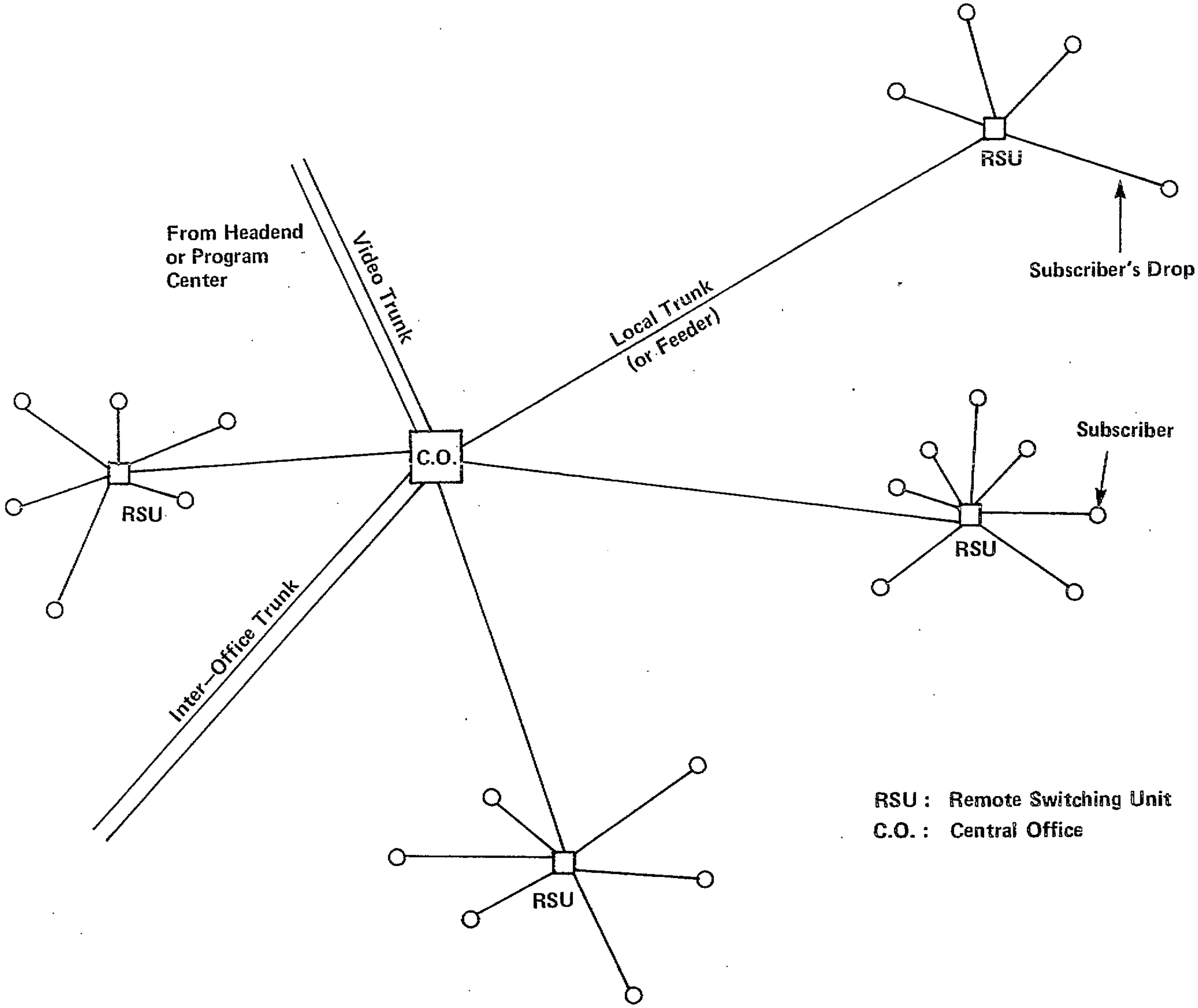

Figure 2.12 Recommended Topology for a Fiber Optic Integrated Distribution Network

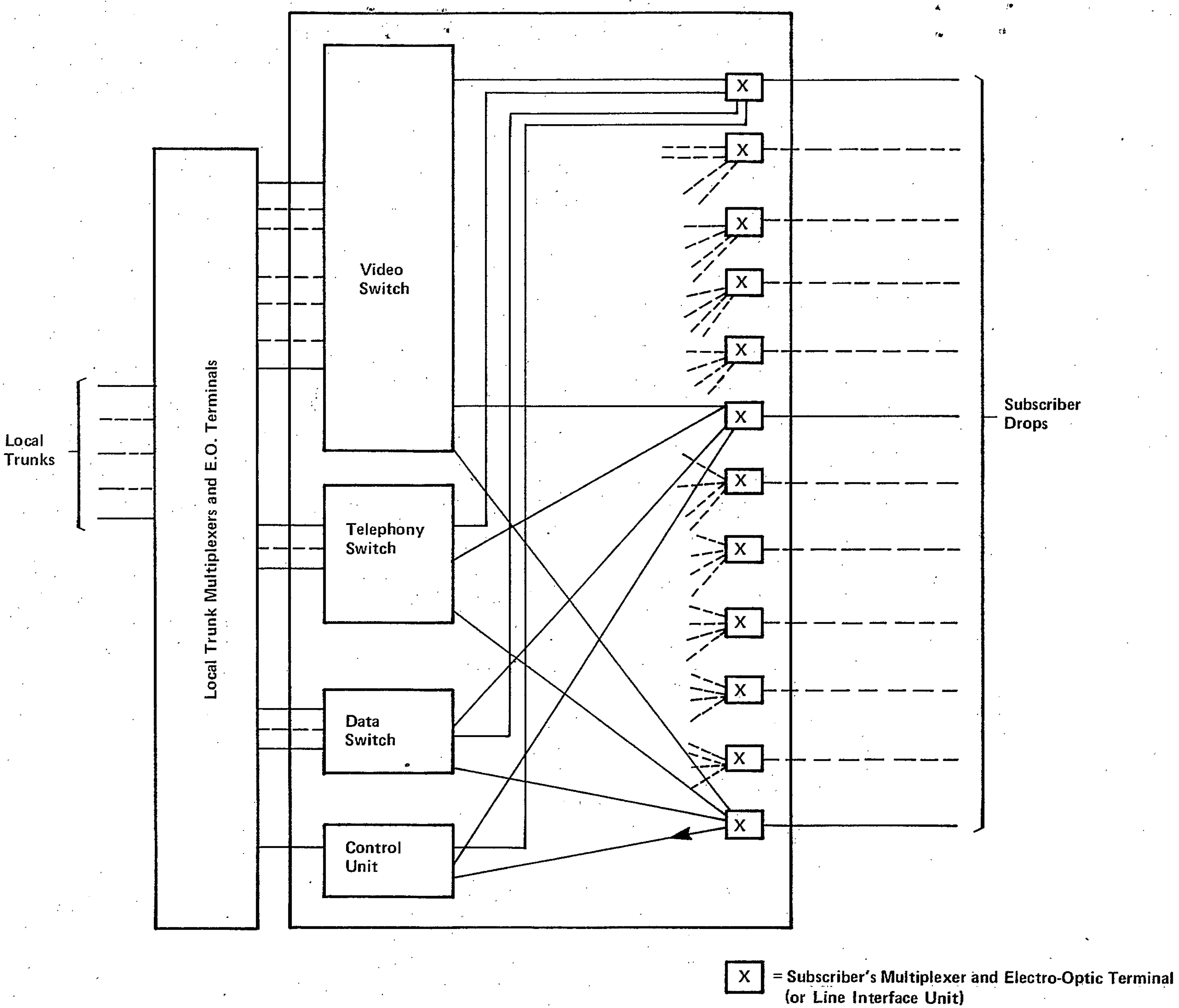

Figure 2.13 The Remote Switching Unit for a Fiber Optic Integrated Network

The video switch connects all subscribers wanting to access a CATV, Pay TV, or bidirectional video channel to the appropriate channel, with still picture service handled in the same way. The telephony switch will be likely based on digital multiplex switching principles as is currently being introduced in the telephony networks.

For low speed data transmission, when the traffic is small, it can be treated as a telephony channel. No separate switch would therefore be needed. When the data traffic becomes significant, a separate data switch may be desirable. The control unit directs the operations of the above switches.

At the remote switching unit two CATV type video channels, up to two telephony channels, one data channel, and the transmit portion of a bidirectional video channel are combined and converted into an optical signal at the line interface unit for transmission to the subscriber through the fiber subscriber line. In the opposite direction, the subscriber line will transmit two telephony channels, one video channel, one data channel and one control channel. Economics will dictate whether the subscriber line will transmit each service on a separate fiber or multiplex them all on one fiber. If no multiplexing is used, the interface between the remote switch and the subscriber line will simply be one light source and drive circuit per fiber in the transmit direction, and one photodetector and amplifier in the opposite direction. If multiplexing is used, the choice is between WDM and FDM. Whatever multiplexing is used, it is desirable that no repeaters be used on the subscriber lines. Using FDM, the number of channels given above could be transmitted, assuming a 5 dB/km fiber, up to 4 km with a LED and up to 7 km with a laser. WDM obviates the need for oscillators, channel converters and filters and appears to be a very promising technique for application in this area.

The multiplexer and electro-optic interface at the local trunk side is simply a unit with optical inputs carrying video, data and telephony from the C.O., with detectors and filters as needed to output these signals in electrical form to the video, data and telephony switches, and with circuitry and light sources for reverse operations. As the unit is shared by many subscribers, it will be engineered for high quality and reliability with economy as a secondary consideration.

d) The Subscriber Terminal Unit. The subscriber terminal unit consists of an electro-optic interface and a multiplexer/demultiplexer with complementary properties to those used at the remote switching unit. The unit would be housed in an entrance unit at the subscriber's home which would be connected by metallic conductors to the telephony handsets, data sets, video equipment and video control unit.

2.4.4 Results of Application to Model Distribution Areas

The network models as described above are applied to the four types of population distribution described in Section 2.1, namely a rural strip type distribution, and a rural, a suburban and an urban grid type distribution. The components required for each subscriber are detailed and the components having major effects on the system design and costs identified.

In rural areas, it is found that the amount of fiber needed per subscriber is strongly dependent on the degree of multiplexing in the trunk joining the remote switch to the central office. This is a strong incentive to develop highly linearized light sources with sufficient power to permit a high level of multiplexing. In urban and suburban areas this multiplexing is not critical.

In all areas, the video switch is found to be a dominant component. Hardware development is needed to minimize the cost of crosspoints, together with system design to minimize the number of crosspoints needed. The number of crosspoints may be traded off against the number of channels needed on the trunks. In very sparsely populated areas, and where the number of video channels required is not large, a non-switched star structured network may be employed to avoid the video switch.

Another important factor is the subscriber terminal, both at his home and at the remote switching unit. If the "component count" presented in this report is priced using discrete components, a high figure is obtained.

More detailed analysis on the cost aspect is given in Activity Report No. 6 (summarized in Section 3 here).

2.4.5 Description of the Fiber Optic Integrated Network used for cost evaluation

In this section, a description of the fiber optic integrated network that is used for the cost estimates in Section 3 is given. The network assumes that each subscriber is provided with two main stations of telephony and three video channels at a time. Also, it assumes that the network must interface with the analog telephone and TV sets presently used.

Data is not considered for the cost estimate. The resulting configuration of the remote switching unit is illustrated in Figure 2.14. Note that it is identical to the CATV remote switching unit except for the addition of a remote telephony switch module with its associated digital trunk line equipment. Since telephony is an essential service, back up power must be provided to ensure the service in case of a local power failure.

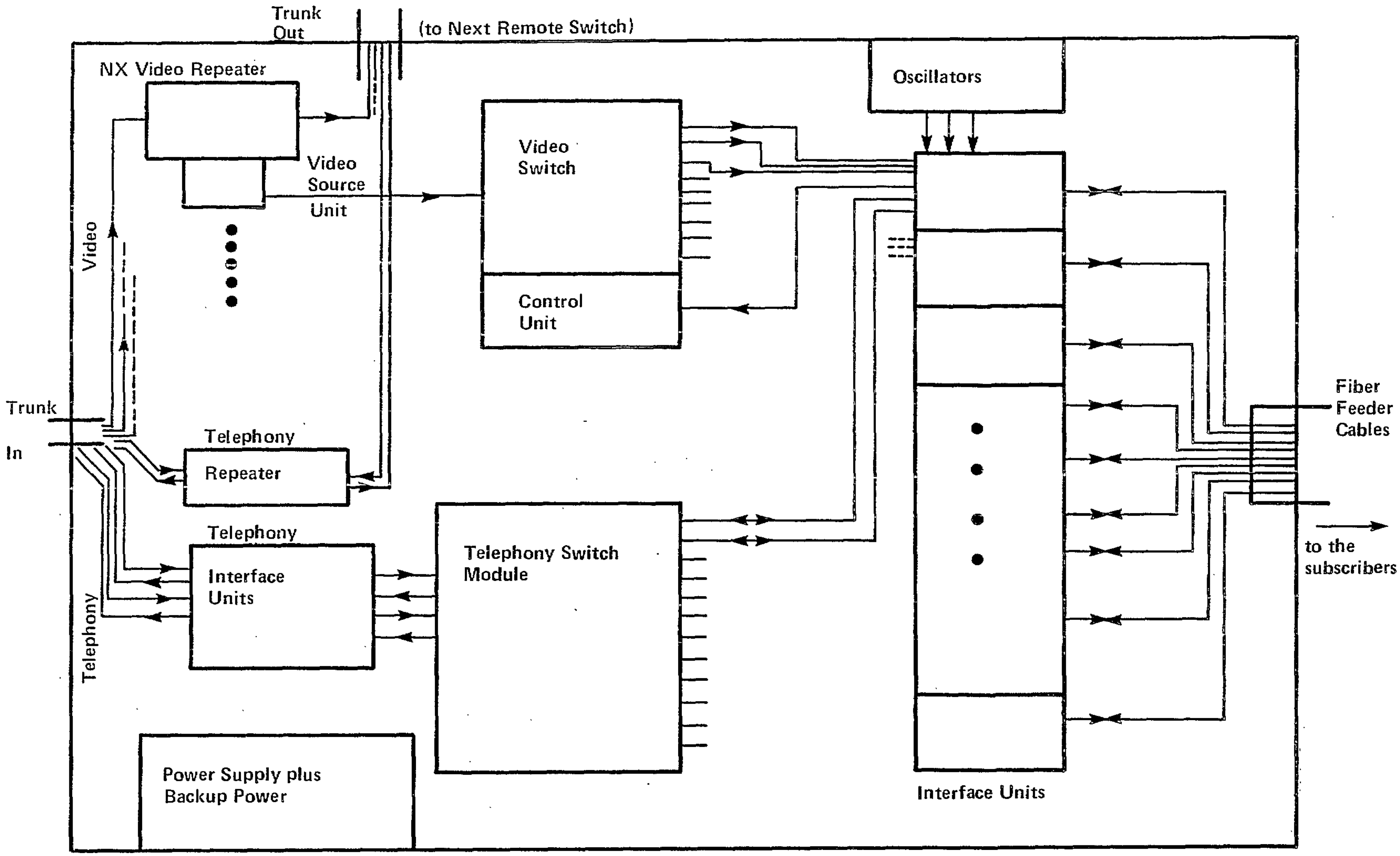

Figure 2.14 Integrated Network Remote Switching Unit Used for Cost Evaluation

For the cost estimates of the interface unit and subscriber terminal in Section 3, it is assumed that the video and telephony signals are transmitted in their conventional analog formats. The block diagrams of these units are illustrated in Figures 2.15 and 2.16.

Note that digital signalling could also be considered for the transmission of the narrow band signals. This could facilitate the addition of supplementary services such as remote meter reading, load shedding, alarms, etc. The use of digital transmission would not affect significantly the cost of these terminals in the case that 500 type telephone sets are used. If electronic telephone sets were used, signalling interface units would not be required in the subscriber terminal and would permit some cost reductions.

Note also that terminals in the remote switching unit associated with CATV are identical to the ones described in Section 2.2.5 for the CATV systems.

2.5 CONCLUSIONS

Various multiplexing schemes and network configurations have been considered for the provision of CATV, asymmetric switched video and integrated video, voice and data services. The most suitable approaches from the standpoints of technical feasibility, complexity, component requirements, etc. for application to the three model areas have been studied and the detailed design for the selected approaches developed.

Due to severe constraint on the number of video channels permissible in a single fiber with the FDM scheme, the FDM, tree-structured distribution system approach, as is commonly employed for coaxial cable based CATV systems, has been rejected as a suitable approach for CATV distribution in the near term. The use of WDM with tree-configuration or star-structured switched distribution is considered to be a better alternative.

For asymmetric interactive switched visual services and for integrated distribution of video, voice and data services, the use of the multi-node star configuration consisting of a central node (or central office) along with a number of remote switching units is found to be most attractive. It circumvents many problems associated with the tree configuration, particularly as it relates to bi-directional transmission and switching.

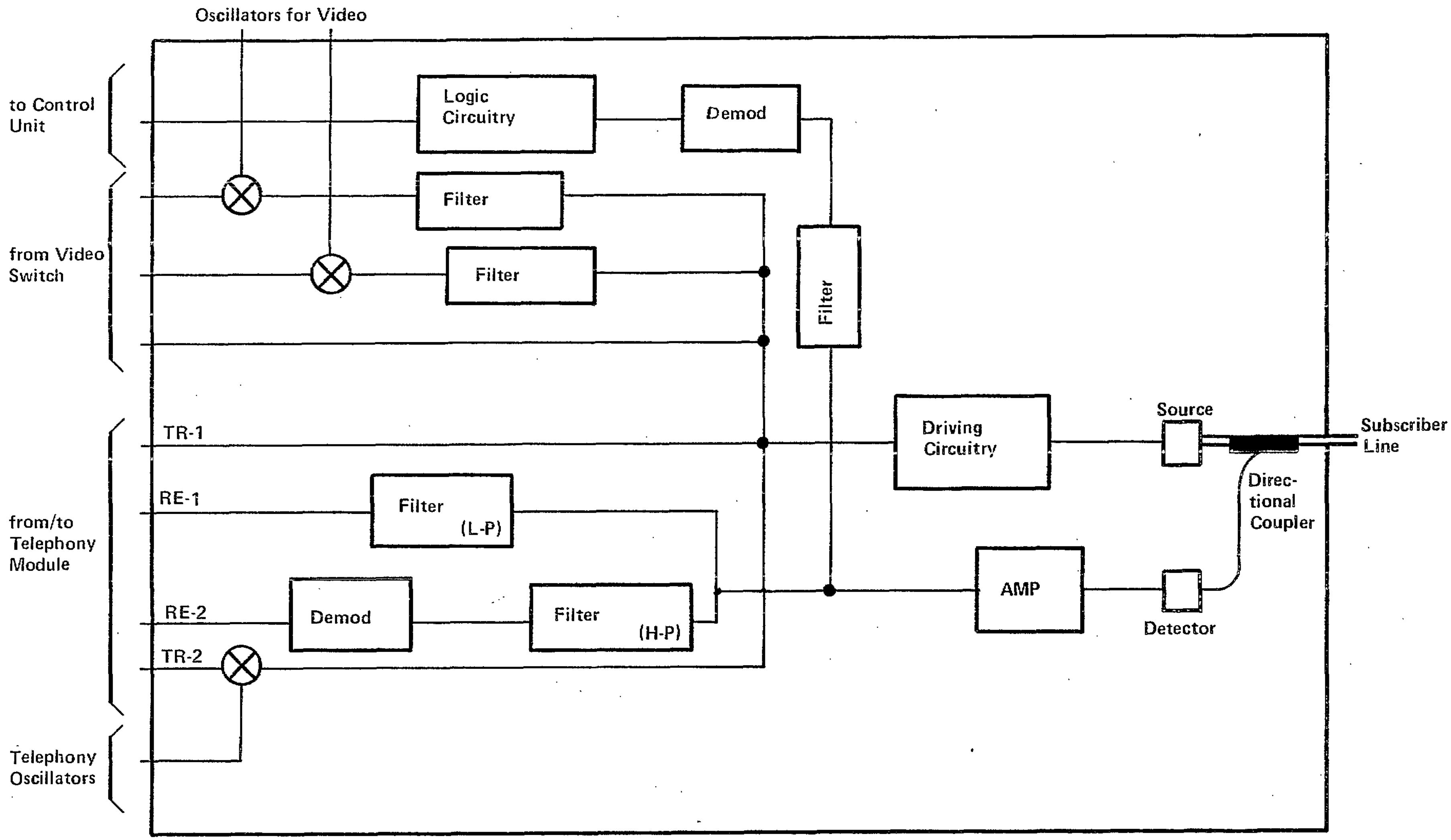

Figure 2.15 Integrated Network Interface Unit at the RSU

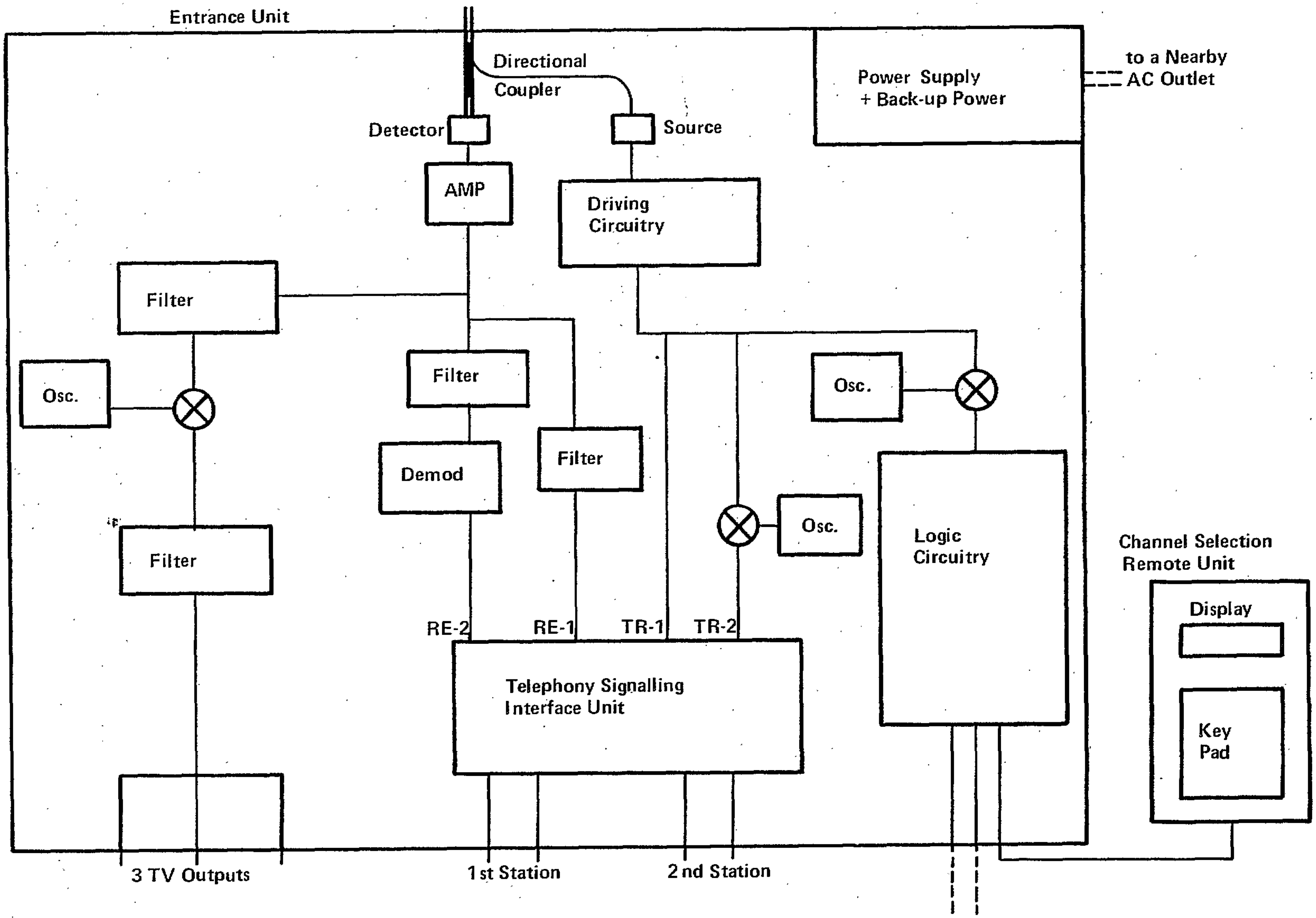

Figure 2.16 Integrated Network Subscriber Terminal

3. COST CONSIDERATIONS

In Section 2 on the methodologies of using fiber optics for CATV, Asymmetric Interactive Switched Visual services, and Integrated Distribution of Video, Voice and Data, the most attractive system configurations are identified for the different application areas based on their service properties and their technical feasibility. However before fiber optic systems can be implemented they must be proven economically attractive in comparison with conventional systems. In this section a comparative initial cost study is performed to evaluate the merits of fiber optics over the technologies presently in use, namely coaxial cable for CATV and copper pairs for telephony. The costs of fiber optic components are first projected along with the expected cable installation costs. The potential cost effectiveness of fiber optics is then assessed for CATV systems and for integrated networks which would provide CATV and telephony services. CATV and telephony services are considered because they constitute a good basis for comparison. The fiber optic cost projections are categorized in this section as low, medium, and high. These projections should be interpreted as optimistic, conservative, and pessimistic views, respectively. The low cost projections do not necessarily constitute a lower bound, since unforeseeable technological break-throughs are not accounted for in the projections. All the costs are given in 1977 dollars. This section is essentially a summary of the Activity Report No. 6.

3.1 COMPONENT AND CABLE INSTALLATION COST ASSUMPTIONS

3.1.1 Cost projections of fiber optic components

Cost projections are given for sources, detectors, fiber, cabling, and connectors. The costs given in this section should be interpreted as costs to purchase from a manufacturer of the component considered. The projections are based on annual volumes of production. This approach is preferred to projections based on time forecasting because the latter would involve guesstimating the time of occurrence of future policy decisions, which in turn will influence the timing of large scale implementation of fiber optic systems. Indications are that the larger volumes of production considered in this section, at best, could only be attained after 1980. Reductions in production costs obtained by economies of scale have been assumed to directly result in proportional reductions in selling price.

a) Fiber Cable

For the purpose of this study the projected cost of fiber cables is divided in two parts, i.e. fiber cost and cabling cost. The cabling cost should be interpreted as the part of the cable selling price which can be attributed to the cabling process itself.

The fiber cost projections assumed a graded index fiber with an attenuation of 4-5 dB/km. This is considered to be the maximum allowable loss for rural applications. The cost projections were derived based on mass production laws. These projections are given in Figure 3.1 as a function of a manufacturer's annual production. In the following sections, the fiber costs assumed for the evaluation of the system costs are based on annual production of 400,000 km. The resulting low, medium, and high projections are 0.03, 0.05, 0.11 dollar per fiber-meter, respectively.

The cabling cost projections are obtained through an analysis of the prices of general telephone cables and with the understanding that fiber cabling is more expensive than copper pairs cabling. The resulting projections for fiber cabling costs are, in dollars per meter, as follows.

Cabling Cost Projections
(dollars per meter)

CABLE	Low	Medium	High
Trunk and feeder	0.55 + 0.004/fiber	0.83 + 0.006/fiber	1.65 + 0.012/fiber
Aerial drop with a steel messenger	0.15	0.23	0.30
Buried drop (armoured)	0.20	0.30	0.40

To obtain the total cable cost, the cost of fibers should be added to the previous figures.

b) Light sources

For the cost projections of light sources, it is assumed that they are supplied with an attached fiber pigtail to reduce subsequent manufacturing efforts. Similarly to all semiconductor devices, their cost is expected to decrease as the volume of production increases. For the higher volumes of production, the packaging, testing, and attachment of the fiber pigtail will ultimately limit the lower costs achievable. The performances of LEDs are not expected to improve significantly from what is obtained now from the best devices available. The cost projections for LEDs are given in Figure 3.2. In the following sections, the LED costs assumed for the evaluation of the cost of terminals are based on an annual production of 200,000 units. The resulting low, medium, and high projections are 3, 5 and 10 dollars per unit, respectively.

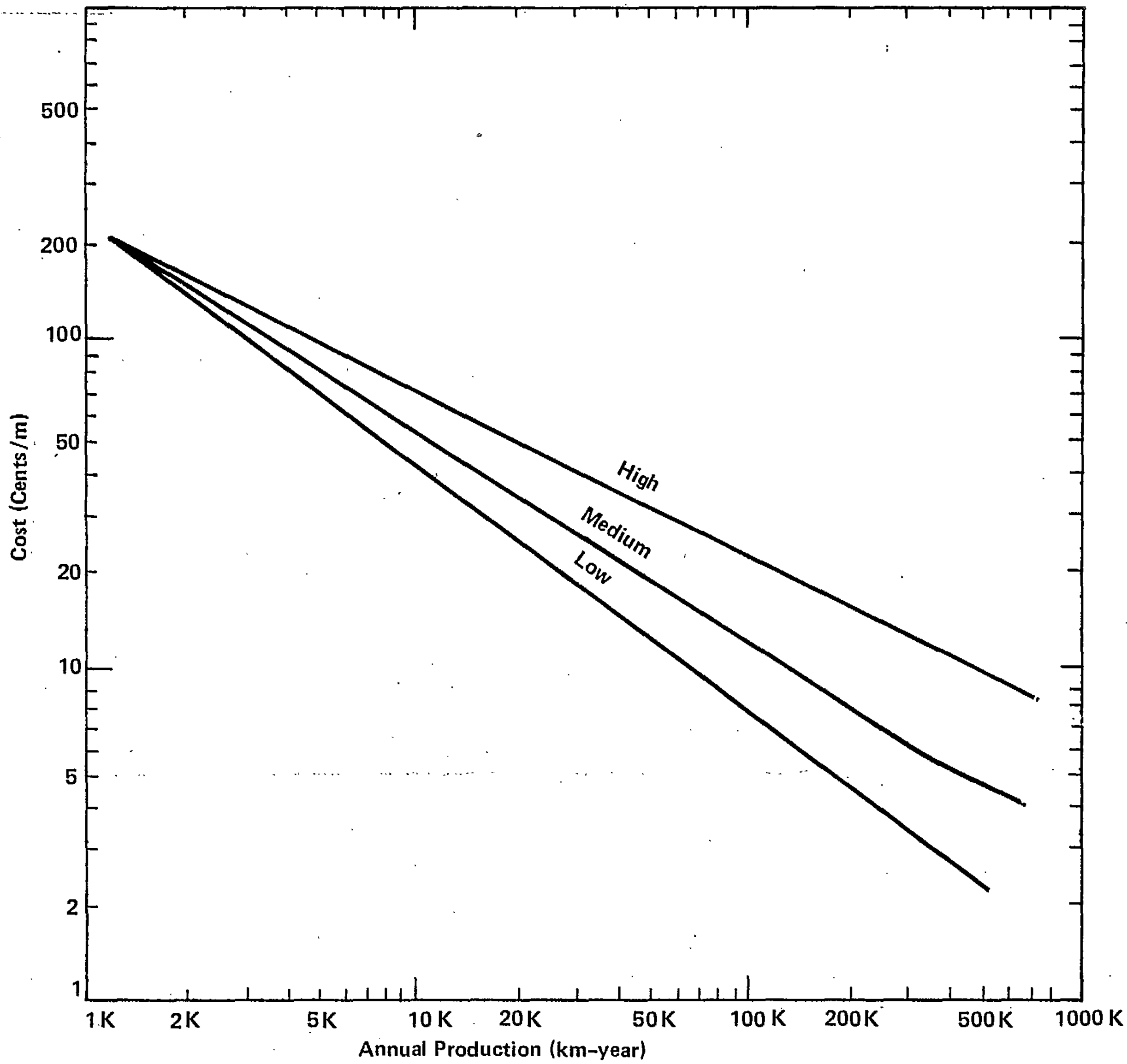

Figure 3.1 Fiber Cost Projections

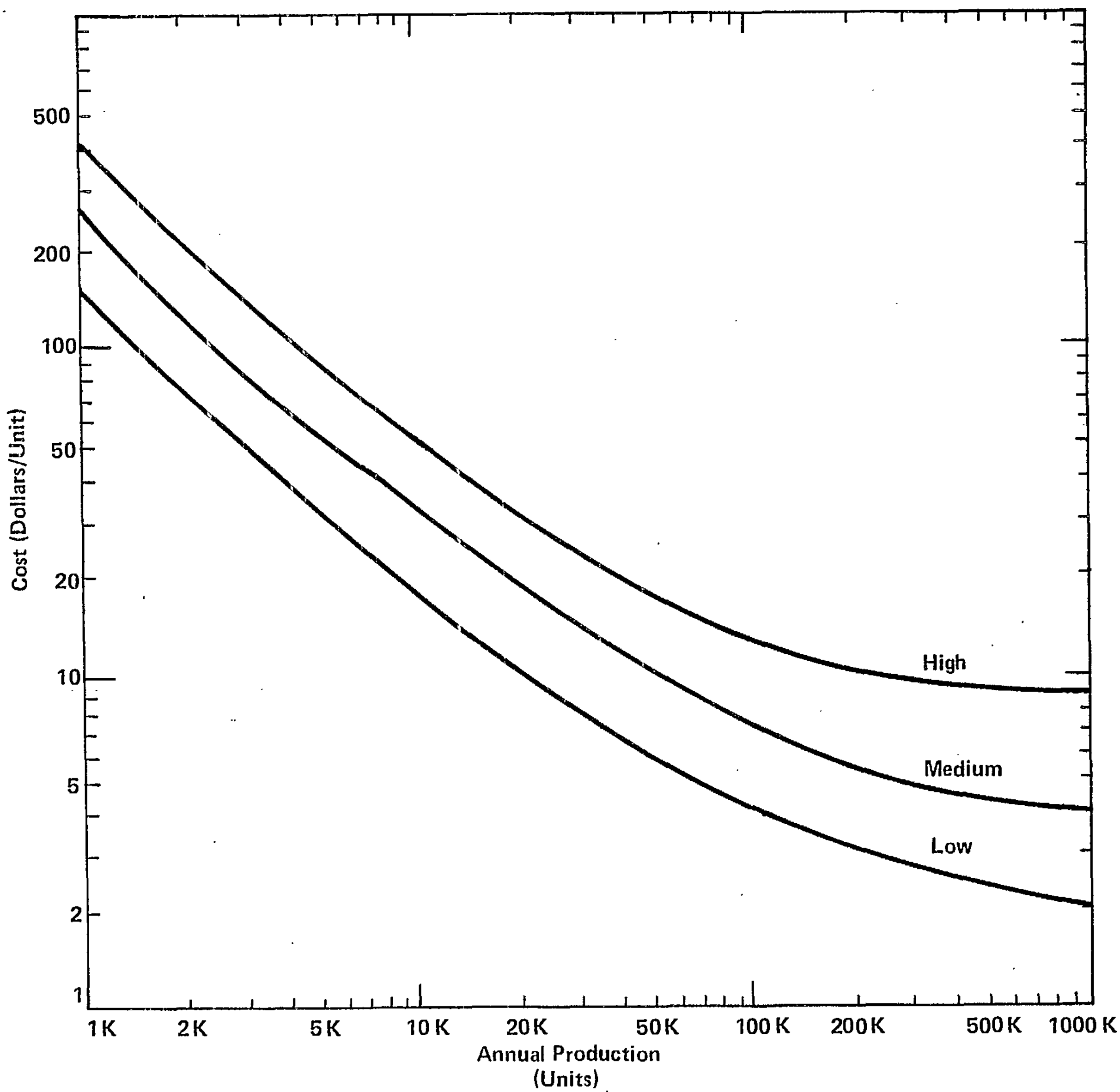

Figure 3.2 LED's Cost Projections
(with Attached Fiber Pigtail)

For semiconductor lasers, improvements in performance, lifetime, and packaging are anticipated as well as some cost reductions. The semiconductor laser cost projections are given in Figure 3.3. In the following sections, the laser costs assumed for the evaluation of the cost of terminals are based on an annual production of 200,000 units. The resulting low, medium, and high projections are 9, 14 and 26 dollars per unit, respectively.

c) Photodetectors

Photodetectors for wavelengths of less than a micron are now mature devices. However further improvements are required in the area of packaging in order to maximize the receiver sensitivity and facilitate the photodetector installation. The cost of photodetectors is expected to follow the typical 70 to 80 percent semiconductor experience curve. Avalanche photodiodes (APDs) are likely to remain significantly more expensive than simpler PIN photodiodes. The cost projections for photodetectors are given in Figure 3.4. The costs assumed for photodetectors in the following sections are based on an annual production of 200,000 units. The low, medium, and high projections for PIN photodiodes are 2, 3, and 7 dollars per unit, respectively, and for APD, 14, 30, and 54 dollars per unit, respectively. APDs are assumed to be used only in digital telephony repeaters.

d) Demountable Connectors

The cost projections for optical fiber demountable connectors are based on a batch production of 10,000 units. No further cost reduction is expected for a higher production. The cost of connectors will strongly depend on the performance expected from them: insertion loss, number of de- and re-matings, operating conditions, etc. Metal connectors are not expected to sell for less than five dollars per unit. Injection molded plastic connectors could represent a cheaper alternative, if the performance of these prove satisfactory. The corresponding cost projections for single fiber connectors are, in dollars per unit

low:	0.75
medium:	1.50
high:	5.00

3.1.2 Cable Installation Costs

Cable placing

Cable placing costs vary significantly according to the type of construction and from one area to another. They depend on many factors, like soil conditions, working area, local wages, local productivity, local regulations, weather conditions, etc. Therefore, the estimated costs given in this section should be considered as typical figures, and not as average or precise costs.

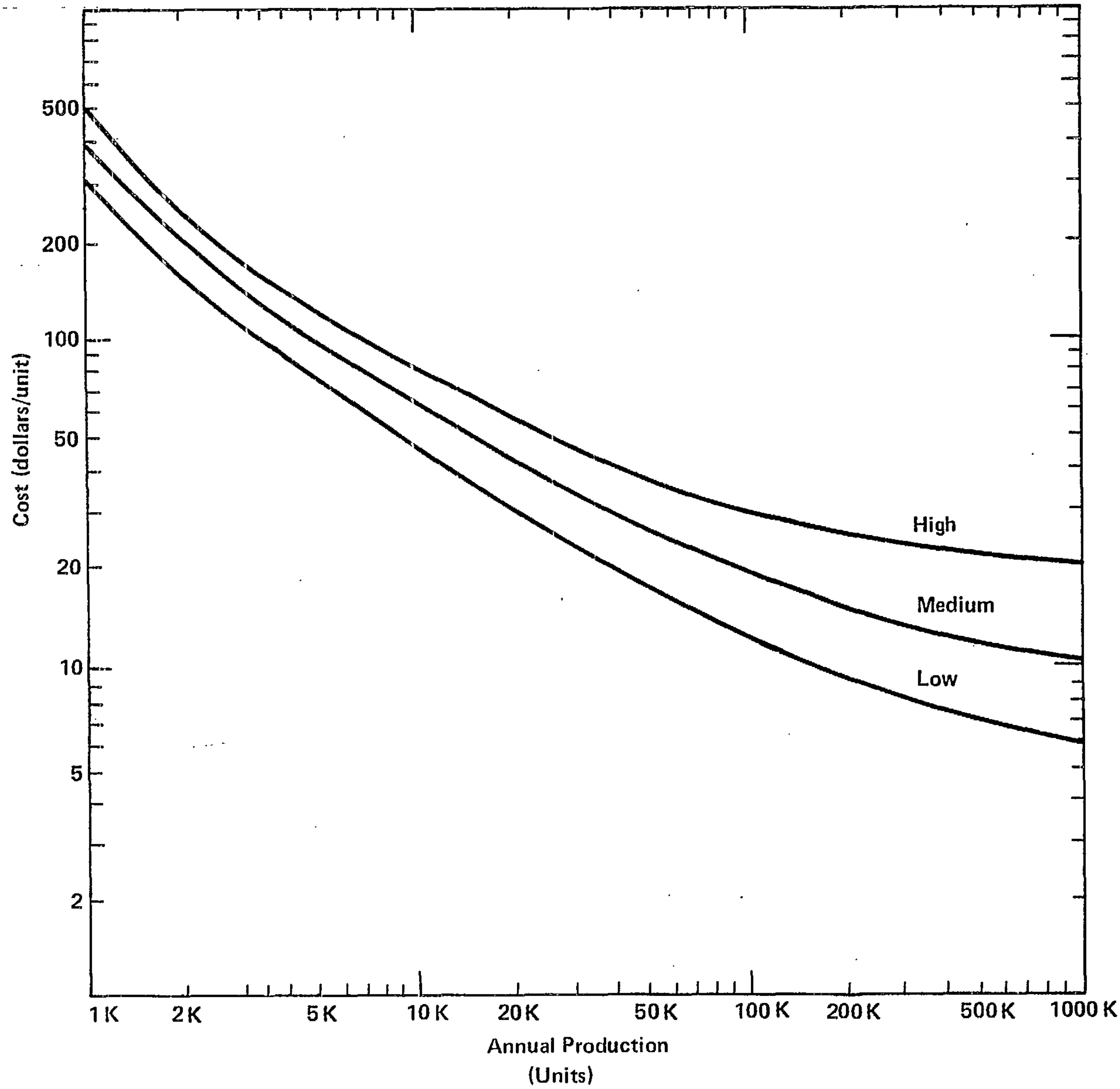

Figure 3.3 Lasers Cost Projections
(with Attached Fiber Pigtail)

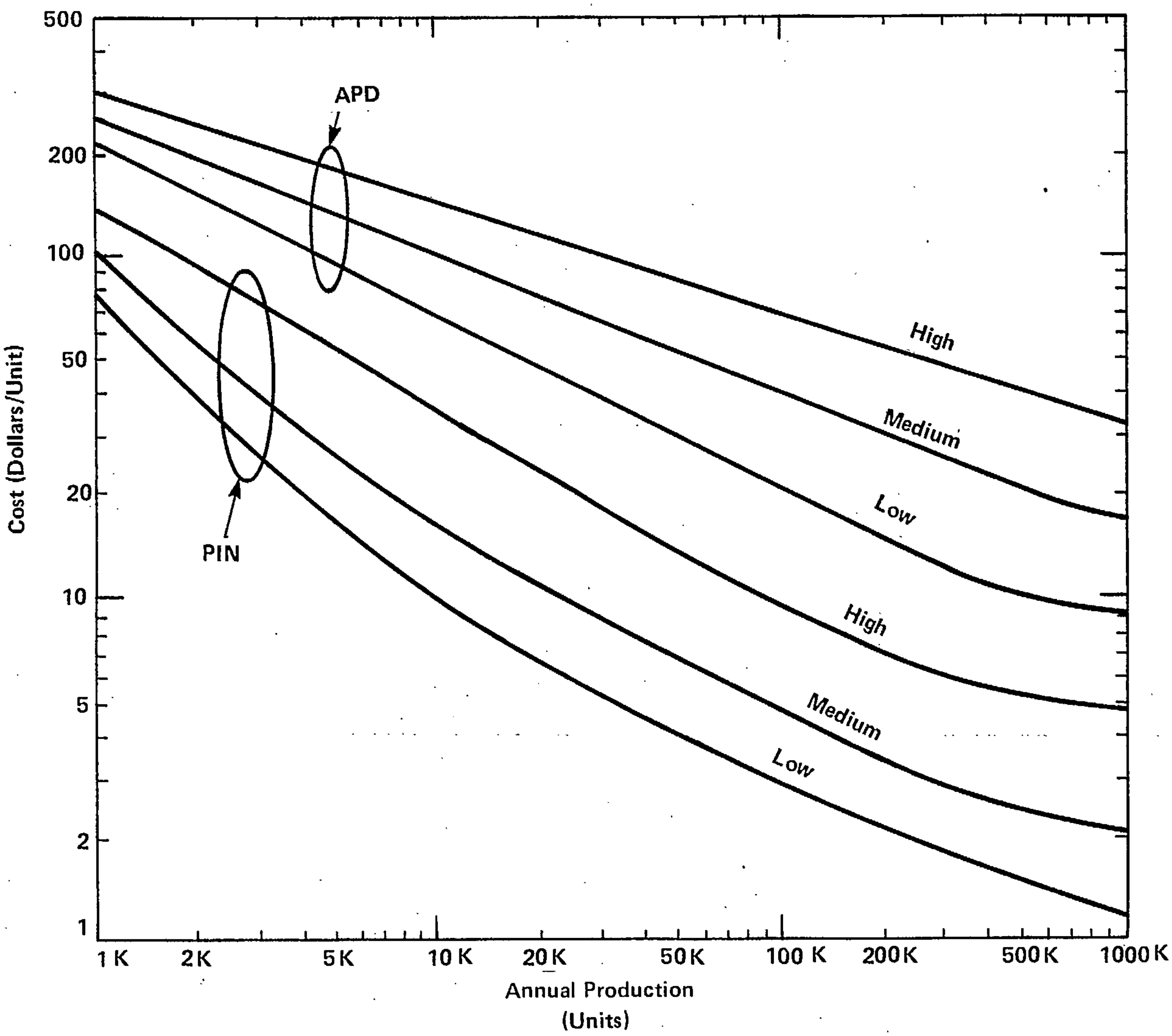

Figure 3.4 Detectors Cost Projections
(with Attached Fiber Pigtail)

Installation costs of fiber optic cables should be comparable to the costs for installing the smaller size copper cables. For copper cables having a diameter of less than one inch, the installation cost does not vary significantly with changes in cable diameter or weight. The cable size and weight start to influence the installation productivity when cable diameters are more than one inch. The use of fiber cables could represent savings in cable placement cost if the capacity of the cable is taken into account. For example the placement of a fiber cable having the capacity to serve 200 subscriber could be cheaper than the placement of a telephony paired cable of the same capacity.

Three types of construction are considered, namely aerial, buried, and underground. The cable placing costs assumed in this study are given in Table 3.1. The amount of aerial construction will decrease in the future for aesthetic and economic (in new installations) reasons. However, it is not expected to disappear completely.

Only buried and aerial constructions are considered for rural areas, because underground construction is neither required or economical in these areas. Underground, buried and aerial constructions are considered for suburban areas. For urban areas, only underground and buried constructions are assumed, as this is the trend now.

Installation costs are higher for urban areas than for suburban and rural areas because obstacles are more frequent, utility alleys are more congested, automobile traffic interferes more with the construction, etc. Similar considerations explain the cost differential between suburban and rural areas.

For rural areas, it is assumed that aerial construction will always be an alternative to buried construction involving trenching in rock over long distances. Otherwise, construction will be prohibitive. Plowing distribution feeder cables is considered only for rural and suburban areas because it is believed that in the urban areas there would be too many interruptions in the process to make the method practical.

The costs of buried drops are determined based on the average drop length in the model area considered, the usual conditions of soil, and the expected frequency of obstacles. The installation costs assumed for aerial drops are based on the average drop length and the expected conditions of installation.

Finally, the costs given in Table 3.1 are based on the installation methods presently used. Forseeable improvements in the methods and equipment used could permit some cost reduction, especially for buried installations. Furthermore, the joint use of trenches with other utilities is not considered in Table 3.1.

For buried and underground installations, a composite figure for the cable placement cost is used for the different areas depending on the relative use of each method of installation. These composite figures, along with the assumed percentage of utilization of each method, are given in Table 3.2

TABLE 3.1 Fiber Optic Cable Placing Cost[1] ($/meter)

Type of Construction	Rural	AREAS Suburban	Urban
Trunk and Feeder cables			
Aerial first cable[2]	1.15	1.50	-
- second cable[3]	0.35	0.50	-
Buried			
Plowed	1.65	2.45	-
Trenched in soil	4.95	5.60	6.55
Trenched in rock	-	18.85	24.60
- second cable	0.30	0.40	0.50
Underground[4]	-	1.65	1.65
Drop Cables			
Aerial	0.26	0.52	-
Plowed	1.00	1.00	1.30
Trenched	3.30	4.10	4.90

1. Cost includes labor, equipment amortization, ancillary hardware if required, engineering, and overhead.
2. Cost of poles not included, but cost of strand included
3. In the case of simultaneous placement
4. Cost of the duct structure not included.

TABLE 3.2 Composite Cost Figures for Buried and Underground Cable Installations ($)

ITEM	RURAL		SUBURBAN		URBAN	
	Relative use	Composite Figure	Relative use	Composite Figure	Relative use	Composite Figure
TRUNK		1.98/m		7.46/m		1.65/m
Plowed	90%		-		-	
Trenched in soil	10%		60%		-	
Trenched in rock	-		20%		-	
Under-ground	-		20%		100%	
FEEDER		1.98/m		6.00/m		12.00/m
Plowed	90%		50%		-	
Trenched in soil	10%		35%		70%	
Trenched in rock	-		15%		30%	
Under-ground	-		-		-	
DROP (front-lot feed)		1.11/m		2.55/m		4.54/m
Plowed	95%		50%		10%	
Trenched	5%		50%		90%	
DROP (rear-lot feed)		-		1.31/m		-
Plowed	-		90%		-	
Trenched	-		10%		-	

Cable jointing

The techniques used in jointing fibers differ significantly from the ones presently used for copper pairs. Therefore it is anticipated that the costs involved in jointing fiber cables will be quite different from those incurred presently with copper paired cables. The costs given below apply to distribution feeder cables or cables having more than 10 fibers, typically.

The costs of jointing cables are evaluated following an A + Bx type of equation, where:

A is a fixed cost incurred every time cables are jointed,
B is the incremental cost incurred for every fiber jointed,
and x is the number of fibers jointed.

Both A and B are composed of labor and material, both of which depend on the type of construction and the jointing technique. The fibers in a cable could be jointed either with splices or demountable connectors, depending on the need for easy rearrangement in the future. The fixed cost A is assumed to vary only with the type of construction and the kind of closure required. The incremental cost B is assumed to depend only on the fiber jointing technique used. The cable jointing cost projections are summarized in Table 3.3 and 3.4.

3.2 COSTS OF FIBER OPTIC CATV SYSTEM

For the cost evaluation of the CATV system configurations described in Sections 2.2.5 it is assumed that three TV channels per subscriber will be supplied, allowing simultaneous and independent viewing of the three channels. The provision of FM broadcast channels is not explicitly considered. However, it is believed that this service could be added without a significant cost impact for both the switched and non-switched approaches.

3.2.1 Hardware and Equipment Costs

The cost projections of the hardware and equipment required in a switched fiber optic CATV are given in Table 3.5. The items listed in this table refer to the description of the remote switching unit (RSU) and subscriber terminal given in Section 2.2.5. The figures in Table 3.5 are rounded to the nearest five dollars when the cost is higher than $10.

The cost projections for the video switch assume modularity of the switch. The cross-points are estimated at 0.10, 1.00, and 1.50 dollar per cross point for low, medium and high projections, respectively. The low projection might be typical of a semiconductor cross-point produced in large quantities, while the high projection might represent a reed relay. The low and medium cost projections for the video switch assume distributed control with low start-up cost. The high projection assumes a central control unit with high start-up cost.

TABLE 3.3 Cable Jointing Cost Projections (dollars)
Splicing Fibers

Type of Construction	Fixed Cost (A)	Incremental Cost (B)		
		Low	Medium	High
Underground	60.5	0.20	0.40	0.90
Buried	49.9	0.20	0.40	0.90
Aerial	60.5	0.20	0.40	0.90

TABLE 3.4 Cable Jointing Cost Projections (dollars)
Jointing Fibers with Demountable Connectors

Type of Construction	Fixed Cost (A)	Incremental Cost (B)		
		Low	Medium	High
Underground	63.5	1.45	2.20	5.70
Buried	91.5	1.45	2.20	5.70
Aerial	63.5	1.45	2.20	5.70

TABLE 3.5 Hardware and Equipment Cost Projections for a Switched CATV System

ITEM	COST PROJECTIONS ($)		
	Low	Medium	High
RSU			
- Video switch	50 + 20NS + 0.1 x 3N	100 + 10NS + 1.0 x 3N	5000 + 1.5 x 3N
- Interface unit (LED source)	60	90	120
- Cabinet repeater	80N	120N	160N
- Video Source	20N	35N	40N
- Oscillators	75	200	500
- Cabinet	500 + 10NS	1000 + 20 NS	1500 + 30NS
- Power supply	2NS	5NS	20NS
- Installation	150 + 5N + 5NS	300 + 10N + 10NS	600 + 21 N + 21 NS
Field repeater	200 + 80N	270 + 120N	350 + 160N
Subscriber Terminal	50	75	100

N: Number of channels in the system
NS: Number of subscribers served from a remote switching unit

The remote switching unit is assumed to be located in a temperature controlled cabinet. The cost of this cabinet depends on the space needed and on the maximum temperature variations allowed inside the cabinet. The medium projection for the RSU power supply is based on a power consumption of two watts per subscriber. The cost of the electro-optic components contained in the interface unit and the subscriber terminal represents less than 20 percent of the terminal cost.

The projected costs of the hardware and equipment required in a non-switched fiber optic system are listed in Table 3.6. The cost of repeaters are based on the present cost of CATV repeaters to which the costs of the optical transmitters and receivers are added. It is assumed that linearization techniques such as quasi-feedforward, are used in the transmitters. The cost of the feeder transmitters should be added to the basic cost of the repeater in order to obtain the total cost of the fiber optic repeater, which, in this case, is the equivalent of a coaxial cable bridger amplifier.

The variations between the low, medium, and high projections for the terminals used in the non-switched approach are not as pronounced as for the switched approach. Since most of their costs can be attributed to the electronic circuitry which should be very similar to the circuitry presently used in CATV repeaters, large cost variations are not expected.

When Space Division Multiplexing (SDM) is used, the optical taps may consist of many directional couplers depending on the number of fibers used to carry the total system number of channels (SDM factor K in Table 3.6).

3.2.2 Cost Comparison of Switched and Non-Switched Fiber Optic CATV Systems

In this section, the initial capital costs of switched and non-switched fiber optic CATV systems are evaluated for different number of video channels using the installation costs of Section 3.1 and the hardware and equipment costs of Section 3.2.1.

The costs per subscriber of CATV systems given in this section do not include the headend and the structures (poles and ducts), since they are common to both switched and non-switched approaches.

Also, practical cable sizes are assumed for the evaluation of the cost. For the switched approach, fiber cables are assumed to be available in different sizes comparable to the present sizes of telephony paired cables. The feeder cables are tapered at splicing points when the savings in cable are greater than the supplementary splicing cost plus a $75 penalty in cable placement. This penalty is used to reflect the costs associated with the change of cable reels and the supplementary engineering required. For the non-switched approach, since a low number of different cable sizes will be required, the fiber cables are assumed to be available with any required number of fibers.

TABLE 3.6 Hardware and Equipment Cost Projections For a Non-Switched CATV System

ITEM	COST PROJECTIONS ($/unit)		
	Low	Medium	High
REPEATER			
- 5 channels/fiber	1186 + 523 K	1507 + 657 K	1855 + 806 K
- 12 channels/fiber	1334 + 628 K	1697 + 797 K	2076 + 981 K
FEEDER TRANSMITTER			
- 5 channels/fiber	105	157	220
- 12 channels/fiber	154	227	311
SUBSCRIBER UNIT			
- 5 channels/fiber	82 + 28 K	105 + 30 K	128 + 37 K
- 12 channels/fiber	82 + 38 K	105 + 40 K	128 + 47 K
OPTICAL TAP			
- rural (1 sub./tap)	10 K	15 K	25 K
- suburban (4 sub./tap)	20 K	30 K	50 K
- urban (16 sub./tap)	100 K	150 K	150 K

K: SDM factor

a) Rural areas

The costs of the switched and non-switched approaches are given in Table 3.7 for the rural strip and grid models. For the strip model it is assumed, for both approaches, that the trunk and feeder cables are installed at the same time.

The results clearly show that the switched video approach is generally less expensive approach for fiber optic CATV in the rural grid model. This is particularly true for larger (21,35) numbers of channels and for low and medium cost projections.

For the strip model, the non-switched approach could be more economical. However, as the projections move to the low side, the switched approach becomes more competitive, especially for the higher number of channels.

The costs given in Table 3.7 assumed aerial construction. The conclusions are not different if buried construction is assumed.

b) Suburban Areas

The switched and non-switched CATV systems for the suburban model are compared in Table 3.8, aerial construction is assumed. For 12 channel systems, the switched and non-switched approaches are about equivalent. For 21 and 35 channels, the switched approach is more economical. The use of buried construction is slightly at the advantage of the switched approach, since the increase in the trunk cable installation cost is divided among more subscribers, the distribution cell being larger for the switched approach than for the non-switched approach.

c) Urban Areas

The switched and non-switched approaches are compared in Table 3.9. The switched approach is definitively more cost effective in urban areas.

It is seen in most cases that even with optimistic performance assumptions, the SDM-FDM non-switched CATV systems are more expensive than switched systems on an initial cost basis. Furthermore, non-switched networks would have higher maintenance expenses than switched network because they contain more than twice the number of unprotected active distribution points. For these reasons, the switched video approach is preferred to the SDM-FDM non-switched approach.

3.2.3 Comparison of Optical Fiber and Coaxial Cable Based CATV Systems

The cost of providing CATV with coaxial cable in the different model areas is evaluated in appendix A of the Activity Report No. 6. The design of coaxial cable systems was done using the amplifier nominal gain and the cable attenuation at the highest video frequency involved, care

TABLE 3.7 Rural Fiber Optic CATV*
Cost per subscriber ($)

Area Model	Number of Channels	Approach	Projections Low	Medium	High
Grid	5	switched	718	947	1439
		non-switched	805	969	1327
	12	switched	730	986	1506
		non-switched	883	1069	1461
	21	switched	746	1036	1592
		non-swtiched	1023	1267	1760
	35	switched	771	1115	1725
		non-switched	1158	1467	2058
Strip	5	switched	818	1107	1836
		non-switched	757	936	1326
	12	switched	872	1120	2044
		non-switched	802	994	1400
	21	switched	942	1365	2311
		non-switched	940	1183	1678
	35	switched	1050	1590	2729
		non-switched	1072	1373	1956

*Aerial construction assumed

TABLE 3.8 Suburban Fiber Optic CATV*
Cost per subscriber ($)

Number of Channels	Approach	Projections Low	Medium	High
12	switched	319	462	684
	non-switched	339	408	519
21	switched	323	492	730
	non-swtiched	420	510	656
35	switched	331	539	802
	non-switched	405	612	792

*Aerial installation assumed

TABLE 3.9 Urban Fiber Optic CATV*
Cost per subscriber ($)

Number of Channels	Approach	Projections Low	Medium	High
12	switched	358	470	611
	non-switched	486	531	597
21	switched	362	499	654
	non-swtiched	541	596	681
35	switched	368	545	723
	non-switched	590	661	765

*Buried and underground constructions assumed was taken that BP-23 requirements were met at the subscriber's set. A cost of $75 is assumed for the frequency converters required in 21 and 35 channel systems. The cable placement costs are the same as those used for the costing of fiber optic systems. In Table 3.10, the costs of fiber optic switched CATV systems are compared with the costs of coaxial cable systems for the different number of channels and for the rural models.

For the rural grid model, fiber optics is comparable in cost with coaxial cables only for the higher number of channels, i.e. 21 or 35, and if the low cost projections are attained. For the strip distribution model, fiber optics is less costly for any system number of channels if the low cost projections are attained. Fiber optics has an advantage over coaxial cable for the strip model because coaxial cable repeaters become significantly more expensive on a per subscriber basis due to the short repeater spacing in these systems. A remote switching unit serves more subscribers due to its longer range and the cost per subscriber is not affected as much when a strip model is used rather than a grid one.

For the suburban and urban models, it is found that a fiber optic CATV system cannot compete with presently used coaxial cable CATV systems, as shown in Tables 3.11 and 3.12. Since the emphasis in this study is on rural areas, the equipment configuration for fiber optic system are primarily optimized for application in these areas. Therefore for application in suburban and urban areas, further cost reduction could be expected. It should also be noted that a $25 frequency converter unit cost is assumed for the coaxial cable systems. Should remote TV converters be assumed, this cost would at least double.

3.3 COSTS OF FIBER OPTIC INTEGRATED NETWORKS

The integrated network which is considered in this section is one that provides a subscriber two main stations of telephony and three CATV channels at a time. An additional system requirement is that the system must interface with the analog telephone and TV sets presently used. The system is described in detail in Section 2.4.5.

3.3.1 Hardware and Equipment Cost Projections for an Integrated Network

The cost projections for the terminals of a fiber optic integrated network are listed in Table 3.13. For the purpose of this comparative cost study it is assumed that remote telephony modules would be used if telephone service had to be provided on copper pairs. The costs given in Table 3.13 represent only the incremental costs which are due to the provision of CATV or to the use of fiber optics.

The costs of the equipment associated with CATV are identical to the ones used for CATV systems in Section 3.2. APDs and lasers are assumed to be used in the telephony trunk repeaters and terminals. The power supply costs are higher than the ones used for CATV only, because supplementary back-up power has to be provided.

TABLE 3.10 CATV Cost Comparison for the Rural Models
($/subscriber)

Type of Construction	Distribution Model	Number of channels	Coaxial cable	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
AERIAL	grid	5	630	718	947	1439
		12	650	730	986	1506
		21	725	746	1036	1592
		35	791	771	1115	1725
	strip	5	945	818	1107	1836
		12	1075	872	1220	2044
		21	1150	942	1365	2311
		35	1224	1050	1590	2729
BURIED	grid	5	945	1013	1245	1741
		12	988	1025	1284	1808
		21	1063	1041	1334	1894
		35	1125	1066	1413	2028
	strip	5	1492	1022	1315	2048
		12	1606	1076	1428	2257
		21	1681	1146	1573	2525
		35	1743	1254	1798	2942

TABLE 3.11 CATV Cost Comparison for the Suburban Model
($/subscriber)

Distribution Model	Number of channels	Coaxial Cable	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
Aerial	12	128	319	462	684
	21	203	323	492	730
	35	206	331	539	802
Buried rear lot feed	12	409	498	641	861
	21	484	502	671	908
	35	495	510	719	980
Buried front lot feed	12	614	749	913	1188
	21	689	753	943	1234
	35	698	761	990	1306

TABLE 3.12 CATV Cost Comparison for the Urban Model
($/subscriber)

Number of Channels	Coaxial Cable	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
12	110	358	470	611
21	185	362	499	654
35	188	368	545	723

TABLE 3.13 Hardware and Equipment Cost Projections for an Integrated Network

ITEM	COST PROJECTIONS ($) Low	Medium	High
RSU			
- Video switch	50 + 20NS +0.1 x 3N	100 + 10NS + 1.0 x 3N	5000+ 1.5 x 3N
- Interface unit	85	115	145
- Cabinet video repeater	80N	120N	160N
- Telephony trunk interface units			
- receiver	50N	70NT	105NT
- transmitter	30NT	35NT	50NT
- Telephony trunk repeater	90	125	185
- Video source	20N	35N	40N
- Oscillators	75	200	500
- Power supply	3NS	7NS	25NS
- Cabinet	10NS	20NS	30NS
- Installation	150 + 5N + 5NS	300 + 10N + 10 NS	600 + 21N + 21NS
Field Video Repeater	200 + 80N	270 + 120N	350 + 160N
Subcriber Terminal	80	115	170

N: Number of channels in the system
NS: Number of subscribers served from a remote switch
NT: Number of telephony trunk lines required for serving the subscribers contained in the distribution cell.

3.3.2 Cost Comparison of Fiber Optic Integrated Network With Separate Conventional Facilities

In this section, the initial capital costs of fiber optic integrated networks are evaluated for different number of video channels using the installation costs of Section 3.1 and the hardware and equipment costs of Section 3.3.1. The cost of fiber systems in this section are evaluated using the same method that is used in Section 3.2.2 for the evaluation of the switched video CATV systems.

The costs of providing the single party telephone service on copper pairs are estimated for the different distribution cells using the same cable installation costs as for fiber optics and assuming that 24-gauge paired filled cables are used. The telephony cost includes the trunk line from the remote telephony switch to the Central Office and the distribution part of the network from the remote switching unit to the subscriber. The resultant estimates are rounded off to the nearest $25.

The costs given for fiber optics and conventional technologies do not include the CATV headend and program center, the telephony switches, both at the Central Office and at the remote switching unit, the structures (e.g. poles and ducts), and the subscriber's station equipment (e.g. telephone and TV sets). These are assumed to be common.

The combined cost for the separate provision of CATV and telephony using conventional technologies assumes that, although they can share the same structures, the cables are installed at different times.

a) Rural areas

For the grid and strip models, the initial costs of a fiber optic integrated network are evaluated as a function of the total number of CATV channels and the type of construction. These costs, as well as the costs of providing the same service over separate conventional facilities, i.e. copper pairs for telephony and coaxial cables for CATV, are given in Table 3.14.

For the aerial installation, it is found that for the medium cost projections, a fiber optic integrated network would be approximately 23 percent cheaper for the grid model and 25 percent cheaper for the strip model, in comparison with conventional separate facilities. For the low cost projections the relative benefit would be between 43 and 50 percent. Fiber optics would not be comparable in cost only if the cost projections remained at the high level.

For the buried installation, the benefits are even greater due to the cable installation factor. Service integration with fiber optics is lower in cost even for the high cost projections in some cases.

TABLE 3.14 - Cost Comparison of Fiber Optic Integrated Network with Separate Facilities for the Rural Models ($/subscriber)

Area Model	Construction Type	Number of CATV Channels	Telephony on Pairs	CATV on COAX	Telephony on Pairs +CATV on COAX	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
GRID	Aerial	5	800	630	1430	816	1085	1685
		12		650	1450	829	1125	1752
		21		725	1525	845	1175	1838
		35		791	1591	870	1254	1971
	Buried	5	1075	945	2020	1111	1383	1987
		12		988	2063	1123	1423	2054
		21		1063	2138	1139	1473	2140
		35		1125	2200	1164	1552	2274
STRIP	Aerial	5	850	945	1795	913	1240	2082
		12		1075	1925	967	1352	2290
		21		1150	2000	1037	1497	2558
		35		1224	2074	1145	1722	2975
	Buried	5	1075	1492	2567	1118	1447	2294
		12		1606	2681	1172	1560	2503
		21		1681	2756	1242	1705	2771
		35		1743	2818	1350	1930	3188

For the grid model and the low projections, the fiber optic integrated network is within $100 of the cost for the provision of telephony on copper pairs, while for the medium projections it is between $280 and $450 more expensive. These figures are comparable to the cost of providing CATV on coaxial cable in the urban or suburban areas.

b) <u>Suburban areas</u>

For the different types of construction considered, the cost of a fiber optic integrated network is evaluated as a function of the number of video channels available. In Table 3.15, these costs are compared with the costs of providing the same service with separate facilities.

For aerial installation, a fiber optic integrated network is found competitive on an initial cost basis with conventional technologies at the low cost projections. For buried installations, fiber optic integrated networks are 10 to 20 percent cheaper at medium cost projections, and 30 to 40 percent cheaper at low cost projections. It should be remembered that the cost of structures is not taken into account. Should the cost of structure have been included, more advantages would have accrued to the integrated network approach.

c) <u>Urban areas</u>

In Table 3.16, the cost of an urban fiber optic integrated network is compared with the cost of providing telephony and CATV on separate facilities. Fiber optic integrated networks are competitive with the conventional technologies for 21 and 35 channel systems at low projections. It should be noted that in these cost figures the duct structures are not taken into account. The compactness of fiber optic cables could possibly represent significant savings. However, this subject needs further study.

3.4 CONCLUSIONS

3.4.1 Cost projections

Cost projections for components are made by applying mass production laws to the present technology. Based on these projections, the cost of the detectors and sources usually represents less than 20 percent of the terminal cost for the systems considered. It is also found that when the volume of application develops, the fiber cost can reach levels where it is comparable to the cost of copper pairs. At these fiber price levels, cabling becomes a sensitive cost factor. However, there are limits to which higher volume will result in lower costs. These limits depend on the particular manufacturing process and are difficult to quantify at this time, especially for the fiber cable.

TABLE 3.15 - Cost Comparison of Fiber Optic Integrated Network with Separate Facilities for the Suburban Model ($/subscriber)

Model	Number of Channels	Telephony on Pairs	CATV on COAX	Telephony on Pairs +CATV on COAX	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
AERIAL	12	225	128	353	383	543	813
	21		203	428	398	573	859
	35		206	431	395	620	931
BURIED							
- rear lot feed	12	400	409	809	562	722	990
	21		484	884	567	752	1037
	35		495	895	574	800	1109
- front lot feed	12	650	614	1254	813	994	1317
	21		689	1339	818	1024	1363
	35		698	1348	825	1071	1435

TABLE 3.16 Cost Comparison of Fiber Optic Integrated Network with Separate Facilities for the Urban Model ($/subscriber)

Number of channels	Telephony on pairs	CATV on COAX	Telephony on prs. +CATV on Coax	Fiber Optics Low	Fiber Optics Medium	Fiber Optics High
12	225	110	335	417	542	720
21		185	410	421	571	764
35		188	413	428	617	832

Installation costs for fiber optic cables are also projected. The fiber cable installation costs are not expected to be significantly different from the installation cost of coaxial cables or small telephone cables. However, fiber cables could represent savings in placement cost when compared to the larger telephone cables. The cost of jointing fibers is also estimated, but is not found to have a major impact on the total system cost.

3.4.2 Rural Applications

Fiber optic CATV systems could become competitive in rural areas with coaxial cable systems. However, the fiber system costs, in the order of $1000 per subscriber, are not believed to be sufficiently attractive to encourage the provision of CATV in rural areas on a stand alone basis.

A fiber optic integrated network shows indications of being economically attractive for rural areas. It could represent savings of more than 50 percent in comparison with the separate use of telephony paired cables and CATV coaxial cables. It could supply rural subscribers with CATV, in addition to single-party telephony, at an incremental cost comparable to the cost of providing CATV in suburban or urban areas with coaxial cables. Thus rural CATV could become economical and fiber optics could facilitate the introduction of CATV in these areas.

3.4.3 Suburban and Urban Applications

For CATV service, dedicated fiber optic systems are not comparable in cost with the coaxial cable systems presently in use. Fiber optic integrated networks, however, could be comparable in cost with the separate use of telephony paired cable and CATV coaxial cable systems, especially for systems that provide 21 or 35 video channel CATV service. Further studies are required to quantify the potential savings in structure, operational, and maintenance costs that could result from the use of fiber optics in these areas.

4. IMPLEMENTATION AND OPERATIONAL CONSIDERATIONS

4.1 INTRODUCTION

4.1.1 Objectives

This section deals with the operational and administrative aspects of the introduction of fiber optics. Questions related to compatibility with the existing networks and with other fast developing technologies, maintenance and administrative philosophies, and implementation implications are examined. Answers or solutions are provided wherever appropriate. In all instances, the main objective is to establish a sound data base on some of the key factors affecting the development, manufacturing, marketing, installation and operation of fiber optic systems. Thus, rather than providing a detailed discussion on many specific areas, the study attempts to address primarily the problem areas or potential problem areas that are recognized to date.

4.1.2 Scope

While most of Sections 2 and 3 of this Final Report can be directly related to their corresponding Activity Reports, the format adopted for this section deviates substantially from that approach. Instead, the section is organized to present a structured and correlated view of the overall picture. To achieve this goal, new information is included as appropriate and the findings of Activity Reports Nos. 7, 8 and 9 are discussed in an unified manner. Thus Section 4.2 concentrates on the evolution of local distribution networks and what role fiber optics can play in terms of timing and service integration. Section 4.3 turns to the compatibility problems that must be overcome if and when a service integrated fiber optic distribution network is to be realized. Problems on co-existence with copper based networks are also addressed. In Section 4.4, operational considerations such as reliability, maintainability, and administrability are reviewed.

4.1.3 Definition of the Network and its Elements

To avoid over generalization when discussing compatibility and operational problems, it is necessary to single out one fiber optic distribution network in terms of service and network architecture so that meaningful comparisons and analysis can be made.

The study results have indicated that a multi-node star configuration appears to be optimum or near optimum for most applications. (Refer to Figure 2.12 for the configuration of such a network). It should be pointed out however that the creation of remote switching units (RSU) has essentially added a new element to the existing telephone network. It is in essence, in telephone network parlance, a class 6 office as compared to a class 5 central office. Thus, the fiber optic service-integrated network would be composed of the following network elements.

1) Terminal Hardware (at the C.O. and RSU)
2) Remote Switching Unit (RSU)
3) Trunk (transmission)
4) Loop (distribution)
5) Subscriber Terminal Units (STU)

4.2 FIBER OPTICS AND LOCAL NETWORK EVOLUTION

4.2.1 Incompatibility Between the Telephony and CATV Networks

All telecommunication networks, particularly at the local level, evolve continuously. The pace of that evolution depends on a number of factors, of which the most dominant ones are:

1) growth in the number of subscribers and volume of traffic
2) equipment modernization for replacement or upgrading
3) demand for better service or new services
4) the amount of capital allocatable due to financial constraints.

To date, local distribution networks of telephony and CATV co-exist as two independent functional entities. There are many reasons for this phenomenon. One of the main reasons lies in the major distinctions between the two networks. These distinctions are summarized in Table 4.1. The comparison given is by no means exhaustive; it is only provided to give some insights into the underlying factors that have dictated, to a large extent, the network topologies as they stand today.

Basically, the telephony network follows a star distribution format, whereas most CATV networks utilizes a tree structure. In the former case, there is a need to connect every subscriber to its associated central office (C.O.) on a dedicated path that allows the user to carry out an un-interrupted two-way conversation with any other subscriber within the accessibility of the network. Thus every subscriber has an appearance at the C.O. irrespective of the transmission format or level of concentration. In the CATV case, each subscriber is drawing from the same information source and the problem is simply one of tapping the signal within some economic and performance restrictions. A tree structure is compatible with this type of application.

Since the two network architectures and transmission requirements are different, there has been no need for the two networks to be compatible. Except for occasional sharing of outside plant structures above ground (poles) or below ground (ducts or utility tunnels) and right-of-ways, the two plants are totally separate both maintenance-wise and administration-wise.

4.2.2 Network Evolution Due to Digitization and Integration

The existing analog telephone network is expected to undergo significant changes in structure, hiearchy and configuration as more and more digital communication equipments become available. With the development of both local and toll digital transmission systems in the 1960's

TABLE 4.1 Major Distinctions Between Telephony and CATV Networks

Characteristics	Telephony	CATV
Directionality	Two-way	Downstream only
Network Access	Global	Local
Control	Distributed	Centralized
Utilization	Traffic Dependent	Traffic Independent
Bandwidth	4 KHz	200 MHz plus
Distribution Mode	Switched	Non-switched
Existing Transmission Medium	Copper Pair	COAX
Service Nature	Essential	Entertainement

and the introduction of digital switching systems in the late 1970's, the ultimate objective of an all-digital network to replace the existing predominantly analog network can become a reality in the not-too-distant future. The advantages of digital transmission are numerous, of which the most important ones are lower cost, better performance and greater flexibility. From the performance viewpoint, transmission quality can be achieved virtually independent of system length. In terms of flexibility, a digital format opens up new possibilities for providing voice, data, and other non-voice services. The fact that both voice and data have identical characteristics after the former is coded into a digital stream paves the way for joint transmission and switching.

On the CATV front, the implication of digital techniques are less pronounced. Unlike its telephony counterpart, transmitting a conventional video signal in digital mode requires a very large bandwidth capacity (up to 90 Mb/s per channel) and consequently very expensive terminal (codec) and line (repeater) equipment. Bandwidth compression is possible to some degree, but this results in even higher terminal costs.

As the society evolves, so does the demand for new and improved service. The most important impact on services other than telephony and CATV comes from the market demand for data transmission and computer communication. With improvements in computer terminal hardware and telemetry equipment there is an increasing requirement for a multi-service oriented (point of sale verification, banking, remote alarm monitoring, etc.) data distribution network. The telephone operating companies accommodate some of the demands by the construction of dedicated facilities (Dataroute/Datapac) and the conditioning of the existing outside plant wherever demands warrant capital investment. Concurrently, the CATV operators also recognize the opportunity to penetrate into this potential market by taking advantage of the unused spectrum between 0 to 45 MHZ in their existing networks. In both instances, items like types of service required and subscriber penetration have to be thoroughly understood and resolved before any plan can be established for full-scale offering at the local distribution level.

4.2.3 How Does Fiber Optics Fit In?

Limitations in the quality of service that can be provided by the existing telephone and CATV networks, particularly in the rural areas, have made it clear that a better broadband medium can find application. Fiber optics fits very well into this definition mainly because of its large bandwidth, low attenuation and potential low cost. There appears to be a general consensus in the telecommunication industry that in due time, fiber based technology can and will replace conventional copper based technology. Already, manufacturers in many countries have recognized the opportunities of fiber optic inter-office trunking sytems and are actively pursuing their development for introduction in the early 1980's. Application of fiber optics in the loop plant would be a logical next step for the penetration of second generation fiber optic products.

The degree of optimism expressed so far is not without rationalized supports. First, the introduction of digital switching has revolutionized the loop plant designs to the extent that digital transmission all the way to the subscriber set can be made cost effective. This implies revamping the existing outside plant on a phased basis and fiber optic cables can be used as a replacement. In the second place, the optical fiber, being a transmission medium with characteristics virtually independent of bandwidth, allows service integration and expansion to be performed in different time frames with minimum incremental cost and hardware rearrangement. Lastly, the fact that fiber optic cables are non-conductive, free of crosstalk and electro-magnetic interference makes them even more attractive for new plant construction. However, it also introduces some limitations in the areas of powering, handling and terminal sophistication. Section 4.3 and 4.4 will address some of these limitations in an attempt to provide some insight into the problems and potential solutions.

4.2.4 Fiber Optics for Integrated Distribution of Video, Voice and Data

Based on discussions in the previous sections, the advantages of a fiber optic integrated network for the distribution of video, voice and data, can be stated as follows:

1) Since cable placement has always been a major portion of the outside plant cost, reducing placement cost by an integrated plant would represent lower subscriber cost per service.

2) Areas (like rural) where certain services cannot be provided at the current level of cost and technology can receive these services at a cost slightly higher than the cost for a single service (like telephony) as indicated in Section 3.3.2.

3) Additional revenues can be accrued from new services to defray the high cost of initial installation.

4) An integrated system can reduce significantly the amount of overhead involved in the day to day operation of separate services on separate facilities. This is particularly true in the area of administration and maintenance.

4.3 COMPATIBILITY WITH EXISTING NETWORKS

4.3.1 Overview

In conducting the study activity on compatibility with existing facilities, it has been found that meaningful comparison at the network level cannot be made due to the lack of a common reference point. In the first place, no integrated local broadband distribution network using conventional technologies has been implemented to date. In the second place, CATV distribution in the rural environment is almost non-existent because of the cost and performance limitations. Thus comparison with paired systems and existing telephone network appears to be more appropriate. This approach is further reinforced in view of the multi-node star network envisaged for fiber optics. Even within that context, caution must be exercised to ensure that likes are compared with likes. This is particularly true when the fiber optic integrated network offers a much higher level of service and equipment integration than is possible with the existing facilities. When the conditions are appropriate, comparisons will also be made with CATV plants as well.

This section is organized by first addressing the compatibility problems by network elements as identified in Section 4.1.3. Cabling, Cable Placement and Powering are also included as they represent three items that would require a great deal of attention before any fiber system can be implemented in the field.

4.3.2 Terminal Hardware

The basic incompatibility between the terminal hardware to be used with the fiber optic integrated network and the existing terminal hardware used for telephony lies in the need of electro-optical conversion for both transmitted and received signals. This increases the complexity of the terminal equipment but will not require more space as proper packaging and standardization of frame and shelf size can be made. As a matter of fact, integration with switching and transmission equipment from both functional and physical layout points of view can result in overall saving of space and inter-equipment cabling. Another area of incompatibility results from the amount of multiplexing/demultiplexing associated with the combining and splitting of various information and control signals. The presence of both video and data interface equipment compounds the engineering aspects of floor planning, interconnecting and powering.

The comparison between the terminal hardware of fiber optic integrated networks and those used in tree-structure coaxial cable CATV systems is not relevant. If one takes away the common equipment like antenna, local programming center, etc., the remaining terminal equipment is totally incompatible as different transmission (trunking) and distribution (feeder and drop) format are employed by the fiber optic integrated network.

4.3.3 Remote Switching Unit (RSU)

The impact of digital switching has been studied quite extensively in recent years independent of fiber optics. It has been shown that the total system cost of digital switching and transmission can be significantly lower than its analog counterpart, depending on the subscriber density and cabling pattern. Thus, the combination of remote digital switching with digital carrier is expected to penetrate into the loop plant. In this respect, the telephony switch of the RSU is fully compatible with the evolution of local network digitization, except in the case where a combined voice and data switch is adopted for the fiber optic integrated network. Another deviation may result if the digital format is extended from the RSU to the subscriber's premises. If this happens, all signals other than video would be combined into one digital stream and transmitted simultaneously with a number of standard NTSC analog video signals. The bandwidth and signal processing requirements of digitizing video signal do not appear to warrant a total digital transmission scheme in the loop plant even with the introduction of fiber optics unless very inexpensive video codecs with reduced bit rates become available.

Thus the major incompatibility with existing telephone and CATV networks is the inclusion of remote video switching into the RSU. Not only does it imply a brand new piece of hardware, but also the new CATV distribution system will bear no resemblance to that of the present day CATV system. With its presence, introduction of new services like Pay TV or visual library can be implemented more easily, with no need for signal scrambling or additional administrative procedures.

4.3.4 Trunk (Transmission)

Trunking systems within a local distribution network for telephony are traditionally associated with inter-office transmission (between a C.O. and another C.O. or a toll office) as compared with distribution systems covering the path between the subscriber terminal to its C.O. However, this definition is no longer adequate with the advent of digital subscriber carrier systems and remote units of digital switchers where a portion of the current distribution plant is replaced by transmission facilities very similar in characteristic to existing trunking systems, including concentration, multiplexing, and signalling. Thus within this new network topology, transmission systems will play a more important role in future network design and implementation. Similarly, transmission facilities for CATV distribution network are restricted to trunking between remote antenna site and headend, and occasionally be- tween headend and hubs. This definition too is expected to be modified if video switching for local distribution is realized.

Since an integrated network using fiber optics has firmly established the utilization of the concept of remote switching units, trunking would be extended beyond the conventional C.O. boundary. This aspect of incompatibility is covered in detail in Section 4.3.5. From a pure digital transmission standpoint, incompatibilities exist in the area of coding scheme, error detection and cross-connecting at the C.O.

1) Coding Scheme - Standard digital transmission in North America employs AMI (alternate mark insertion coding) or bipolar format to eliminate DC component and facilitate error detection. Block codes of the type nBmB (n binary bits are encoded into m bits with n less than m) are preferred with fiber optics to avoid stringent demands on linearity and DC level control. This creates the need for an extra stage of coding/decoding if the current AMI coding scheme is retained for all other digital transmission equipments.

2) Error Detection - Closely related to the coding scheme is the method of error detection and monitoring. In the case of fiber optics, errors can originate at the unipolar, bipolar or block code level, thus introducing an extra level of complexity in isolating equipment faults and hence activating the appropriate alarm and recovery actions.

3) Cross-Connecting - To allow for orderly growth of digital transsmission facilities, a stand-alone digital cross-connecting frame is recommended in the C.O. for centralized monitoring, testing, restoration, and fault locating. Because of the inherent characteristics of optical signals as compared with electrical signals, fiber optics systems cannot share the proposed frame to carry out the same functions. In fact, even with its own cross-connecting hardware, problems will be encountered to handle the various combination of terminating traffic vs through traffic, multiplexing/demultiplexing, automatic switching against manual patching, connection to toll-connecting facilities, etc.

4.3.5 Loop (Distribution)

The most distinctive difference between a copper based loop plant and a fiber based loop plant lies in the area of loop signalling. Existing signalling schemes rely heavily on DC current flow to perform functions like on-hook/off-hook detection and dialling. In other words, the existence of a metallic path betwen the C.O. and the subscriber's set is essential to the signalling schemes of present-day loop plant, as well as the provision of power to operate the telephone set itself. To adopt the DC signalling scheme with fiber optics require both good DC response at the photodetector amplifier and stable output signal level independent of subscriber drop length, which are both difficult and costly to achieve. It is therefore necessary to consider the provision of additional interface equipment between the conventional handsets and the fiber optic link, or the introduction of new telephone set or new signalling scheme. However, should voice signals be transmitted in digital form to the subscriber, the signalling information would almost surely be encoded as part of the digital bit stream and hence no incompatibility problem would be of importance.

A second major difference lies in the flexibility of cross-connecting for subscriber movement. A copper based jumper wire interface (JWI) introduces negligible transmission loss, whereas in the case of a fiber plant, two connectors are required to implement a patch panel. Fortunately, the added losses are more tolerable over the shorter loop lengths encountered in urban and suburban areas. In rural application, a permanent splice type of distribution is preferred due to the characteristics of the subscriber movements. Similarly, new optical distributing frame has to be installed at the C.O. or RSU in place of conventional Main Distributing Frame (MDF). Connector losses would again impose additional transmission requirements.

4.3.6 Subscriber Terminal Unit (STU)

Probably the highest degree of incompatibility between a fiber based plant and a copper based plant results from the complexity of the hardware required, its location and its maintainability at the subscriber's premises. With copper based installation on single family dwelling, the subscriber's drop normally terminates at a protector block located in the basement. From these, wires are run to the telephone set or jack outlets. The process is almost identical for CATV, with the coaxial drop cable connected either to a matched filter or a frequency converter.

With fiber optics, electro-optical interface units are required. Moreover, since all the electrical signals are multiplexed after detection, additional hardware is needed to demultiplex the signals and to condition them to the proper level and format. The criterion recommended in the fiber optic integrated network is to provide a STU that can perform all three functions and locate it near the hydro main in the basement. Signals are then distributed over copper facilites to the rest of the house. While such an approach might appear to deviate from the concept of total fiber based plant, it does eliminate the presence of interface units for every conventional telephone set, TV and data terminals. As the technology evolves, and as customer display units (baseband or sub-VHF TV, for example) in future are likely to be built to complement a switched type integrated network, the STU can be simplified considerably and its location can become more flexible. It is noted that maintenance of the STU will necessitate access to the subscriber's premises.

4.3.7 Cabling and Cable Placement

As a cable design objective, fiber optic cables, irrespective of size, form and shape, should achieve the same performance as metallic cables and hence should not require special craftsmen, installation equipment and new cable placement methods. Since optical fibers have different characteristics than metallic conductors, incompatibility between the existing cabling and installation techniques and those of fiber optics cannot be totally avoided. Some of the fundamental features of fiber optic cables are addressed here.

Despite the diversity that already exists among fiber optic cable designs, cable components can be classified as follows:

1) coated fibers
2) tensile strength member(s)
3) sheath, including armour and moisture barriers
4) cushion layer and fillers
5) insulated metallic conductors for powering
6) core wraps

The most critical of these components are the coated fibers and tensile strength members, as the basic requirements for cable design are to provide adequate tensile strength and flexibility without straining fibers, plus adequate protection from adverse mechanical effects and environmental influences. A good cable design must ensure that the optical performance and mechanical integrity of the fibers are maintained according to specification in all the intended application environments.

Turning to cable placement, it is found that proper cable design can allow almost full utilization of current installation methods, tools and materials. For certain rural installations, it may be cheaper to bury than to place above ground. This is particularly true in areas where there is sufficient soil cover to permit plowing, as plowing is the cheapest, fastest and most environmentally acceptable method of installing cable presently available. In terms of "structures", cabinets and huts will see wider application for housing RSU's of the fiber optic integrated networks.

Another difference between a basically dielectric fiber optic cable and its metallic counterpart occurs in cable jointing and installation testing. In the first case, the decision to field splice or to connectorize the cable is dependent on the application. The major need for splicing is in the jointing of cable lengths. Connectors, on the other hand, are used where a mate/remate type of joint is required. Since allowance has to be made within the accuracy of fiber alignment to accommodate remating, connectors are typically more lossy than splices. For both connectors and splices, the requirement is to provide low loss devices at a reasonable cost that can be implemented under field conditions. Techniques and tooling involved in cable sheath removal, fiber preparation, installation and splice closure should be developed so that existing personnel can attain the skill level required readily without extensive training.

In the second case, fiber identification, fiber and splice attenuation testing, fiber fault location, and sheath insulation/continuity testing have to be performed during initial installation. It is anticipated that most testings can rapidly evolve into standard routines easily handled by existing construction personnel. The only exception would be in the physical location of fiber faults. Distance-to-fault equipment based on time-domain-reflectometry technique can be used to yield a figure adequate for sectionalization of a fault. However, more development work is required before the technique and the associated equipment can be available for use in the field.

4.3.8 Powering

The metallic wires in existing telephony plant transmit power from the C.O. to the field repeaters and subscriber sets. When fiber optics is used, power distribution must be separated from signal transmission. This implies that an alternate form of powering has to be employed. In a fiber optic integrated network, power is required at each of the following installations:

1) Remote Switching Units
2) Repeater Sites (if any)
3) Subscriber's Premises

To meet the power requirement, additional hardware and/or cost is incurred as compared with the conventional power distribution scheme. This represents a major area of incompatibility with existing telephone and CATV networks from an overall system design point of view. In the first two installations, six different powering schemes were investigated. They are

1) On site commercial AC
2) Distributed AC
3) Distributed DC
4) On site solar power
5) On site wind power
6) On site thermo-electric power

For both installations, it is found that the most cost-effective alternative is on site commercial AC with appropriate battery back-up.

On subscriber's premises, power has to be provided to the STU and other peripheral units (like telephone set). If commercial AC is used to power both essential and non-essential services, a full 8-hour, no-break, battery back up on the essential services is required in case of power failure. An alternative is to distribute power from the RSU on separate copper pairs.

4.4 OPERATIONAL CONSIDERATIONS

4.4.1 Availability and Reliability

To provide equal or better grade of service objectives for a new network as compared to existing ones, which is a definite requirement, one must match the availability and reliability factors of all individual network elements or subsystems and define suitable performance objectives for them so that the overall network can be properly maintained and administered. Since more than one service will be provided, and the performance requirements of many new services are not yet defined, the total network should be designed to meet the most stringent requirement among existing services. Care must be taken however that the network can accomodate the anticipated requirement on new services without jeopardizing the overall economic viability. On the other hand, the start up cost should not be penalized because of excessive built-in margins. These engineering design aspects, however, will not be discussed further as they are beyond the scope of this study. Instead, factors that will affect the operation of the fiber optic integrated network will be addressed.

Availability is defined as the probability that the network will meet the demands of the customer when he needs it. It is a function of the inherent reliability of every individual component and the maintainability of the network. Therefore given an objective for availability, it cán be achieved by using highly reliable components or providing the necessary maintenance features, or both. Although one always aims at virtually trouble free equipment, the trade-off invariably comes back to incremental cost on equipment (capital intensive) versus incremental maintenance cost (annual charge).

The two quantifiable parameters associated with availability and reliability are Mean Time Between Failure (MTBF) and Mean Time To Restore (MTTR). Figures that should be set on these parameters are dependent on a number of factors. Among these are:

1) The extent that service would be affected
2) The number of subscribers that would be tied up
3) The location of the equipment
4) The degree of difficulty in fault location
5) The cost of redundancy (i.e duplicated central control or protection switching)

Thus each network element has to be specified considering all these factors before an overall figure can be arrived at. In the case of fiber optics, components like light source, fiber, light detector, etc., should possess adequate reliability such that the overall reliability of the network should be no worse than the existing networks. In that respect, lifetime of light source, stability of directional couplers, and practical field splicing methods would definitively require considerably more research and development work before the network can be implemented.

4.4.2 Maintenance

Maintenance actions are usually required both periodically (routine testing) and on a need-to-do basis (emergency repair) to complement and support the built-in reliability of the various network elements. Broadly speaking, maintainability is a measure of the ease and cost of upkeeping all the equipment (both hardware and software) that constitutes the total network. For a network which is service integrated as well as equipment integrated, it is essential to develop a sound maintenance philosophy and strategy to ensure full control even when the network is operating at full load during adverse conditions. This is particularly important when attempting to provide improved telecommunication services in a rural environment where sophisticated equipment might have to be placed in the field and in the customer's premises far away from the maintenance centre.

Traditionally, the maintenance of each network subsystem performing different functions like transmission, switching and distribution is under separate departments not necessarily co-located or sharing the same data base. In recent years, the concept of centralized maintenance has convinced enough people that the first generation of this product idea has been successfully marketed (CALRS, or Centralized Automatic Loop Reporting System, is one example). With the arrival of stored program control digital switching machines utilizing high speed processors, the second generation of centralized maintenance function will become a major feature of these machines. Within that framework, this network element will carry out both internal maintenance as well as external ones (like loop maintenance, remote loop maintenance, digital carrier maintenance, etc.) by means of software programs. Faults are detected, located, reported, diagnosed, and the proper recovery procedure is recommended. The main criterion is to reduce human participation to a minimum. A fiber optic integrated network fits very well to this maintenance concept. In fact, one might even see it as a necessity in view of the network size and complexity.

4.4.3 Administration

Administrative functions related to operating a telecommunication network generally consist of business planning, accounting, network management, traffic and operation measurements, and performance evaluation. Only the last three items will be covered, as they are more technology oriented. In a broader sense, network management covers almost all the functions involve in the day to day operation of the network. But the term is normally referred in telephony as the supervision and control of the communication path with the objective of maintaining the capabilities of the network as close as possible to its design capacity, even during periods of adverse traffic conditions. These conditions could result from significant facility failures or general network overload. For the network in question, features like dynamic overload controls, adequate man/machine interfaces, and remote surveillance and interrogation are essential.

In order to stratify the utilization of the fiber optic integrated network, both traffic and operational measurements should be part of the overall software package, the frequency of each measurement would be related to its usefulness and the requirement on real CPU time. In general, most of them can be performed during off-hours, since they do not require human initiation or supervision. On the other extreme where portable equipment has to be assembled, calibrated, measured and manually documented, they should be kept to a barebone minimum. These data would then be used to evaluate the performance of the network. Besides providing a good indication on actual vs forecast, irregularities, marketability of new or enhanced features, they usually constitute the base on the magnitude and timing of network extension.

4.4.4 Growth and Flexibility

Any local distribution network must be designed to handle all the basic customer changes like subscriber movements, additions or deletions with minimum amount of rearrangement on the outside plant as well as the inside plant. Even more important it should have the capacity to accommodate population growth, feature additions or service expansion. In the past, equipments were added or modified on each network element on a singular basis depending on the operating budget and priority. This normally results in service disruption and under-utilization of some network elements which probably can be prevented with a more co-ordinated approach. On a network like the one under discussion where one single fiber-based transmission medium is required to carry all the established, planned and potential services, the maximum usable communication bandwidth of a single fiber should match the ultimate information requirement. This is very important because cable placement, being labour intensive, contributes very heavily to the total cost and should be avoided.

Modular design, engineering and packaging of each network element could increase substantially the ability of the network to face growth and changes. Firstly, unnecessary common equipment could be delayed so that the much needed capital can be freed for other use. Secondly, equipment can be salvaged if it is relocatable. Thirdly, power, space and cabling requirements, which contribute strongly to the overhead cost, can be minimized. Fourthly, equipment can be added with a whole range of increment that greatly facilitates the plant engineer to optimize his decision. Naturally the degree of modularity has its limitations and drawbacks. However, for a fiber optic integrated network where centralized administration and maintenance is favorable, it is important that these factors are considered in the development and design phase.

Another area that could significantly impact on the flexibility and growth is the requirement and method adopted on cross-connection. The situation is much more acute for telephone network where all types of equipment have to be interconnected and re-interconnected. MDF (Main Distributing Frame) administration for large Central Offices has always been a headache to the operating company. This problem could be compounded for the fiber optic integrated network since more cross-connection would be required on a per subscriber basis.

4.4.5 Outside Plant Considerations

The first and most important factor in installing a fiber cable is to determine the type of plant. At present, the policy of out-of-sight plant becomes more and more prevalent in urban/suburban areas, and extends even to small town locations. Thus below ground installation will probably dominate the scene for years to come. Fiber optic cable design should therefore be optimized for ducting, plowing, and trenching. As well, more innovative installation methods like high pressure water jetting and rock melting subterrenes should be seriously assessed.

The second factor is pressurization. Pressurization is a standard telephony practice for trunk and feeder cables and has been a feature employed in several fiber optic trials. The process utilizes dry air or nitrogen to inhibit ingress of water and assist in drying out the core. Also, by monitoring the airflow, the pressurization system can be used as a sheath fault alarm and as a method for limited fault location. While the ingress of water does not pose a major problem in experimental results obtained to date, ice formation in the cable can severely degrade transmission performance of the cable, or even damage it.

The third factor addresses cable size, reel length, and cable jointing techniques. Although there is no reason to believe that a large size (greater than 300 fibers, for example) fiber optic cable cannot be manufactured, field splicing every 1000 meters or so of each of the 300 fibers one at a time could be both costly and impractical. Interconnection between distribution and drop cables poses similar problems, and is compounded even further if the lack of flexibility of permanent splices turns out to be critical.

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