Technical Report

# A Systems Study of Fiber Optics for Broadband Communications

Activity No. 2
Methodology of Fiber Optics for CATV

BNR Project TR 6259
April 1977



Bell-Northern Research

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Methodology of Fiber
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SUMMARY

The purpose of this study is to identify possible methods of using fiber optics for distributing CATV service in rural, urban, and suburban areas. The emphasis is placed on rural areas where unique properties of optical fiber transmission could make CATV become a feasible service.

Different systems approaches are examined with their associated network configurations. For the different distribution areas and for different system channel capacities, the relative merits of these approaches are evaluated on the basis of transmission capability and hardware requirements.

Near-term system implementation is considered based on semiconductor injection light sources with multimode fiber transmission as the available technology.

At the present time fiber optics technology for analog broadband communications is not well developed. Consequently some of the approaches considered in this study are not immediately feasible, but could soon become feasible with concentrated development effort.

This study evaluates both the potential of various technical approaches for CATV applications and the development that would be required. These evaluations form the basis for identifying the best systems approach to CATV for different distribution areas, for different types of service, and for different schedules.

This report is divided as follows:

Section 1 - Definitions of Service and Performance Requirements
Section 2 - Transportation Trunks
Section 3 - Systems Approaches
Section 4 - Rural Distribution
Section 5 - Suburban Distribution
Section 6 - Urban Distribution
Section 7 - FM Radio Channels

# CONCLUSIONS

## FIBER OPTICS FOR TRANSPORTATION TRUNKS

### High Quality Transportation Trunks

For high quality transportation trunks, SNR equal to 56 dB, it is found that the best approach is to transmit at baseband one video channel per fiber (SDM). This conclusion is based on signal-to-noise ratio and on general linearity considerations. Following this approach, long transportation trunks can be achieved. In this report trunks as long as 57 km, or equivalent to a total system optical loss of 285 dB are considered.

### Medium Quality Transportation Trunks

In a fiber optics CATV system, signals of very high quality may not be required at some remote distribution points. In these cases, medium quality transportation trunks degrading the signals slightly could be used rather than high quality transportation trunks, without influencing significantly the cost of the distribution system.

For these medium quality trunks, SNR equal to 46 or 43 dB, SDM is a better approach if non-linearity is a limiting factor in the distribution part of the CATV system.

If non-linearity is not a limiting factor, trunk cost savings could be achieved by frequency division multiplexing a low number of video channels per fiber.

Long, medium quality transportation trunks can be achieved by transmitting either at baseband or on low frequency modulated carriers. The longest trunk length considered in this report is 57 km, or equivalent to a total system optical loss of 285 dB.

The choice between transmitting at baseband and transmitting on a low frequency modulated carrrier depends on the particular application. Transmission at baseband permits longer repeater spacings based on signal-to-noise ratio considerations, but transmission on a low frequency modulated carrier may be preferred for reasons of better compatibility with the distribution network.

The preceding conclusions on transportation trunks are mainly based on signal-to-noise ratio and on general linearity considerations. Signal-to-noise ratio considerations favor baseband transmission. However baseband video transmission over long repeatered lines requires further study on the effect of cascading amplifiers on the baseband video signal.

## FIBER OPTICS FOR CATV DISTRIBUTION

### Approaches Presently Feasible

In rural areas the switched video distribution is the best presently-feasible approach to CATV distribution where the subscriber density is uniform.

In some rural areas the population is distributed only along the main roads, with nobody living in the wide spaces between these roads. For this non-uniform subscriber density case, due to the low subscriber density, the low number of subscribers linked to a video switch may have the effect of increasing the switch cost on a per subscriber basis to a prohibitive level. Thus, depending on the exact cost of the video switch, the non-switched SDM-FDM approach using electrical tapping could be preferred to the switched approach, especially for CATV systems having 5 or 12 video channels. For systems having 21 or 35 channels, the switched video distribution system is preferred.

For suburban and urban areas the switched video distribution approach is the best presently-feasible approach to CATV distribution.

The development of a solid state video switch optimized for CATV distribution is highly desirable. Especially for rural areas where the subscriber density is low, it would also be desirable that the cost of the video switch per subscriber not depend strongly on the total number of subscribers linked to the switch.

APPROACHES THAT COULD BECOME FEASIBLE IN THE NEAR TERM FUTURE

The use of a uni-fiber, non-switched distribution approach, FDM or WDM, with optical tapping would result in major savings for CATV distribution, particularly in rural and suburban areas. In urban areas the cost of fiber is not predominant, as opposed to rural and suburban areas where it is a major cost factor. Therefore it is not so likely that the use of these techniques will result in a cheaper system. The switched video distribution approach could be the best approach to CATV for urban areas, even if FDM, WDM and optical tapping were feasible techniques.

FDM, WDM and optical tapping are techniques that have a great potential for CATV distribution in rural and suburban areas. These techniques are not presently feasible, but it is believed that they could become feasible in the near term future if their development is oriented towards CATV applications. At least their potential justifies further investigations.

Development Required

For optical tapping, directional couplers with low insertion loss and with various coupling ratios can be fabricated in the laboratory. However a device rugged enough to be used in a CATV field environment has to be developed.

In using FDM over long repeatered lines the source linearity at reasonable optical output power is the major problem. Presently, the development in linearizing optical transmitters is oriented toward the production of high quality video-transportation trunks. Their capabilities for CATV distribution should be verified.

If the development in the transmitter linearity follows the present trend, FDM could be a possible candidate for 5-channel systems in rural areas and for 12-channel systems in suburban areas. Furthermore the use of SDM-FDM would become more attractive if more video channels could be multiplexed on the same fiber.

WDM is very attractive for non-switched CATV distribution, especially for rural areas and for systems having a high number of video channels where FDM is not feasible. Although there is no objection to it in theory, practical realization of an analog broadband WDM system still has to be made.

# 1. DESCRIPTION OF CATV SERVICE TO BE PROVIDED

## 1.1 DEFINITION OF THE SERVICE

The service of a CATV system is defined for this report as the number of video channels that are made available to the subscriber. For suburban and urban areas, systems providing 12, 21 and 35 video channels are considered. These are typical of standard 12-channel and extended channel capacity 21- and 35 channel coaxial cable systems presently used. This provides a basis for comparison of optical-fiber-based CATV systems with present systems. For rural areas, systems providing 5, 12, 21, and 35 channels are considered. The consideration of a low capacity, 5-channel system is justified for rural areas because in some of these areas it is not possible to receive good-quality signals on 5 channels by air. Therefore the provision of 5 good-quality video channels would be a considerable improvement of the present service.

Similarly to some present CATV system, FM broadcast channels could also be distributed.

## 1.2 PERFORMANCE REQUIREMENTS

In terms of performance, fiber optic based CATV systems should meet DOC-BP23 standards at the subscriber set, or yield an equivalent picture quality where BP23 definitions do not apply, e.g. baseband transmission. Requirements of BP23 are summarized in Table 1.1.

TABLE 1.1
Video Transmission Performance Requirements DOC-BP23

| | |
|---|---|
| Signal-to-noise ratio | 40 dB |
| Cross modulation | -48 dB |
| Echo rating | -40 dB |
| Single frequency interference | -57 dB |
| Delay distortion | ±45 ns |
| Amplitude distortion | ± 1 dB |
| Differential gain | ± 2 dB |
| Differential phase | ± 5° |
| Hum | -34 dB |
| Gain Stability | ±10 dB |

# 2. FIBER OPTICS FOR TRANSPORTATION TRUNKS

A transportation trunk is defined as a video transmission line joining two points and introducing negligible or little degradation to the transmitted signals.

Transportation trunks are only point-to-point transmission lines and their cost is relatively unimportant compared to their transmission objectives. Therefore finding the best way to build transportation trunks using optical fibers is a transmission study rather than a question of methodology. However, optical fiber transportation trunk capabilities, based on signal- to-noise ratio considerations, are evaluated in Appendix A to indicate the possibilities and to permit definition of the best design approaches. Other transmission considerations, such as the linearity requirements, are treated in Activity No. 5.

## 2.1 TYPES OF TRANSPORTATION TRUNKS AND THEIR PERFORMANCE REQUIREMENTS

In most present CATV systems, transportation trunks are used between the community antenna and the system hub. There are no specific performance requirements for these high-quality transportation trunks because they are usually tailored individually to meet the signal quality required at the subscriber set considering the degradation introduced by the distribution network. However for most CATV applications a link achieving a SNR of 56 dB is considered transparent. Other possible requirements are summarized in Table 2.1. It should be noted that there is no standard requirement for transparent transportation trunks and that the linearity requirements given in Table 2.1 are believed to be the most stringent presently used in the TV industry.

TABLE 2.1

Video Transmission Performance Requirements *
Transparent Trunk for CATV

| | |
|---|---|
| SNR | 56 dB |
| Cross modulation | -61 dB |
| Echo rating | -49 dB |
| Single frequency interference | -66 dB |
| Delay distortion | ±10 ns |
| Amplitude distortion | ±0.1 dB |
| Differential gain | ±0.4 dB |
| Differential phase | ±0.5° |
| Hum | -51 dB |

* Parameters defined as in BP23.

Fiber optics CATV systems may also need transportation trunks as indicated in Sections 4, 5 and 6 to carry signals between master and secondary distribution centers. These could be high quality trunks (SNR = 56 dB) or lower quality trunks (SNR = 46 or 43 dB) with little difference in the cost of the distribution network.

The length of transportation trunks affects their design. The lengths of the trunks considered in this report ranges up to 57 km.

## 2.2 TRANSPORTATION TRUNK DESIGN APPROACHES

Some general design considerations are outlined here for building transportation trunks. A more detailed analysis is made in Activity No. 5.

The signals in a CATV transportation trunk should be, as far as possible, compatible with the signals used in the distribution network. This means that digital and FM video transmission should be considered only when baseband or AM-VSB transmission cannot meet the transmission requirements, e.g. for long haul, high quality video transmission.

### 2.2.1 High Quality Transportation Trunks

For high quality transportation trunks only one channel per light source should be transmitted, because these trunks have very stringent linearity requirements (Table 2.1). It is assumed that directly modulated sources will not be linear enough to permit any frequency division multiplexing.

It is assumed that each source couples into the fiber 1 mW of peak-to-peak signal power and that there is a 5 dB/km fiber attenuation (including splices and connector losses). On this basis the required number of repeaters is evaluated for different trunk lengths and for different signalling schemes, i.e. baseband or on a low frequency modulated carrier. Calculations are based on the analysis given in Appendix A and results are given in Table 2.2

High quality trunks of 57 km can be achieved only with baseband transmission since, in general, baseband transmission requires far fewer repeaters than modulated carrier transmission. For a 40 km trunk using transmission on a modulated carrier there may also be problems in meeting the trunk linearity requirements, because of the large number of repeaters in tandem (32). Thus transmission on a modulated carrier should be considered only for short trunks.

With baseband trunking, if the signals are not distributed at baseband, modulators will be required at the receiving end. With modulated carrier trunking, frequency converters may be required at the receiving end.

### 2.2.2 Medium Quality Transportation Trunks

Linearity requirements are less stringent in this case than for high quality trunks, so it should be possible to multiplex up to three channels per light source.

It is assumed that each light source couples into the fiber 1 mW of peak-to-peak signal power and that there is a 5 dB/km fiber attenuation (including splices and connector losses). The analysis of Appendix A gives the required number of repeaters and repeater spacing for different trunk qualities, for different trunk lengths, and for different signalling schemes. Results are given in Tables 2.3 and 2.4.

TABLE 2.2

HIGH QUALITY TRANSPORTATION TRUNKS

SNR = 56 dB

| SIGNALLING SCHEME | TRUNK LENGTH (km) 10 | | 40 | | 57 | |
|---|---|---|---|---|---|---|
| | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) |
| BASEBAND TRANSMISSION | 2 | 5.0 | 9 | 4.4 | 14 | 4.1 |
| TRANSMISSION ON A LOW FREQUENCY MODULATED CARRIER | 3 | 3.3 | 32 | 1.3 | NOT POSSIBLE | |

TABLE 2.3

MEDIUM QUALITY TRANSPORTATION TRUNKS

SNR = 46 dB

| SIGNALLING SCHEME | TRUNK LENGTH(km) | | | | | |
|---|---|---|---|---|---|---|
| | 10 | | 40 | | 57 | |
| | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) |
| BASEBAND | 2 | 5.0 | 7 | 5.7 | 10 | 5.7 |
| 1 MODULATED CARRIER | 2 | 5.0 | 10 | 4.0 | 15 | 3.8 |
| 2 MC | 3 | 3.3 | 12 | 3.4 | 19 | 3.0 |
| 3 MC | 3 | 3.3 | 15 | 2.7 | 23 | 2.5 |

TABLE 2.4

MEDIUM QUALITY TRANSPORTATION TRUNKS

SNR = 43 dB

| SIGNALLING SCHEME | TRUNK LENGTH (km) | | | | | |
|---|---|---|---|---|---|---|
| | 10 | | 40 | | 57 | |
| | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) | NUMBER OF REPEATERS | REPEATER SPACING (km) |
| BASEBAND | 2 | 5.0 | 6 | 6.7 | 9 | 6.3 |
| 1 MODULATED CARRIER | 2 | 5.0 | 9 | 4.4 | 13 | 4.4 |
| 2 MC | 2 | 5.0 | 10 | 4.0 | 16 | 3.6 |
| 3 MC | 3 | 3.3 | 12 | 3.3 | 18 | 3.2 |

This analysis shows that 57 km trunks can be achieved using any of the four signalling schemes. Baseband transmission permits the longest repeater spacings.

Multiplexed trunks of more than 40 km require a relatively large number of repeaters (10-23). This large number of repeaters in cascade places fairly stringent requirements on the linearity of individual transmitters. Note, however, that these requirements depend also on the overall transmission objectives of the trunk, which have not yet been fixed for medium quality trunks.

As in the case of high quality transportation trunks, it appears that the transmission of one channel per light source would be a better approach. For the same source linearity, a more linear trunk could be realized in this way due to the smaller number of repeaters in cascade and also to the absence of non-linear distortions such as intermodulation and crossmodulation. A linear transportation trunk would permit the major part of the signal degradation due to non-linearities to be allocated to the distribution part of the system. Thus a higher quality transportation trunk permits a lower quality distribution system. Since most of the investment in a CATV network is in the distribution system, this can result in higher savings than could have been achieved by multiplexing on the trunk.

## 2.3 CONCLUSIONS

Based on the analysis of Appendix A and on some general linearity considerations, it is found that the best design approach for transportation trunks is to transmit one channel per light source. This implies that space division multiplexing (SDM)* or wavelength division multiplexing (WDM)* should be used for transportation trunks. However, since WDM is not presently feasible, SDM should be preferred for transportation trunks.

### 2.3.1 High Quality Transportation Trunks (SNR = 56 dB)

Long, high-quality transportation trunks (57 km), can be achieved only with the use of baseband transmission. Transmission on a modulated carrier should be considered only for trunks of less than 10 km and for reasons of better compatibility with the distribution network, i.e. preferred use of frequency converters instead of modulators.

### 2.3.2 Medium Quality Transportation Trunk (SNR = 46 or 43 dB)

For medium quality trunks, the transmission of one video channel per light source is preferred because it permits greater linearity. Very linear trunks permit the allocation of the major part of the allowed signal linearity degradation to the distribution network, which is a better practice when non-linearities are significant in the distribution network.

Baseband transmission can achieve greater repeater spacings. However, transmission on a low frequency modulated carrier may be preferred for reasons other than the minimization of the required number of repeaters. The effect

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* For readers not familiar with these multiplexing schemes, they are treated in more detail in Section 3.1.3.

upon the transmitted baseband video signal of cascading many amplifiers may be a problem and would require further study.

If the distribution network can tolerate a less linear transportation trunk without being affected, some trunk cost savings could be obtained by frequency division multiplexing a small number of video channels.

# 3. SYSTEMS APPROACHES FOR CATV DISTRIBUTION

The term 'distribution center' in this report refers to the location from which signals are distributed to subscribers. It is equivalent to a hub in present coaxial cable CATV systems.

This Section shows how pieces of a system could be put together to provide CATV service to subscribers. Special attention is given to the interface between the subscriber set and the CATV system as a function of the approach used. These general considerations apply as well for each of the three distribution areas: rural, urban and suburban. The defined system configurations give the basis for the components count given in Sections 4, 5 and 6. Network configurations are discussed in Sections 4, 5 and 6 for each distribution area respectively.

There are two basic approaches to CATV distribution: the non-switched approach where all the video channels are available to the subscriber at the same time, and the switched approach where one or two selected channels are available to the subscriber at the same time. In the switched approach, a video switch is required at the distribution center and subscriber lines carry only one or two channels, rather than the total number of channels being transmitted over the system.

## 3.1 NON-SWITCHED VIDEO DISTRIBUTION SYSTEMS

This is the approach most commonly used in present CATV systems. It has the advantages that all channels are available to a subscriber simultaneously, and also that it requires a simple distribution center with no video switch. In a non-switched video distribution system, subscribers access a common bus carrying all the system channels, so that appropriate signal tapping schemes are required. These tapping schemes will directly affect the network shape.

Since all of the system channels are transmitted on every part of the transmission network, i.e. distribution trunk, feeders and drops, the signal multiplexing scheme is very important in non-switched video distribution systems. Furthermore, the subscriber interface unit will depend closely on the received signal format.

A non-switched distribution system, either coax or fiber optics, cannot grow easily unless future requirements are anticipated and the initial system is overbuilt and thus not optimized for present needs. Increasing the number of video channels transmitted or the length of a presently optimum non-switched system requires the replacement of most repeater amplifiers. This is a disadvantage of non-switched systems. However a fiber optic system could be upgraded without necessarily changing existing trunk lines, whereas this is not always possible with present coax systems.

### 3.1.1 Signal Tapping Schemes

The signal can be electrically tapped at points in the system where the conversion from optical to electrical is made. An example of this is shown in Fig. 3.1. This is the simplest method, however a separate transmitter is required for each subscriber and also the length of the drop depends on the distance between the subscriber and the point of conversion.

With optical tapping, feeders can be used in an arrangement analogous to present coaxial systems. Optical feeders both without amplifiers and with amplifiers are considered as illustrated in Fig. 3.2 and 3.3 respectively. The amplifiers correspond to line extenders in present coaxial systems.

Directional couplers are still in the laboratory development stage and practical taps rugged enough to be used in a CATV field environment will require further development. The directional couplers used in CATV systems should have a low insertion loss and their coupling ratio should preferably be adjustable, or else be available in many values with small increments between them. Also, they should perform well even when many of them are in series.

Light reflections in the optical feeder due to connectors may create echoes and affect the subscriber's viewing. The use of index matching fluid at the different connections will probably decrease the light reflections to a negligible power level, but this problem should still be considered in the system design.

### 3.1.2 Signal Frequencies

The signal frequency are important in the evaluation of the transmission performances and also in the design of the subscriber interface unit. In this interface unit a module converting the optical signal into an electrical signal is required, consisting essentially of a photodiode and an amplifier. An additional module may be needed to make the conversion module output compatible with the subscriber's TV set.

For the signal frequencies, there is a choice between the frequency allocation scheme used in the present CATV systems (54 - 300 MHz) and the lower frequencies of the electrical spectrum. The use of the present CATV system frequency allocation scheme would make it easier to interface a coaxial cable system with a fiber optic system. Also the signalling in systems having 12 channels or less would be compatible with the present TV sets, so that a frequency converter would not be required in the subscriber interface unit.

However, systems using high frequency signals would lose many advantages of fiber optics transmission. The high impedance front end amplifier approach is not as effective because the high signal frequencies do not permit a high input resistance, resulting in higher thermal noise and consequent smaller repeater spacings. Also the present CATV frequency allocation scheme does not use regions of the spectrum such as sub low-band or FM band which could efficiently be used by fiber optic system. Note that a fiber optics system is not subject to RF pickup or leakage like a coaxial cable system. Finally, the system length could become limited by the fiber frequency response.

The use of the VHF frequencies may raise problems with the light

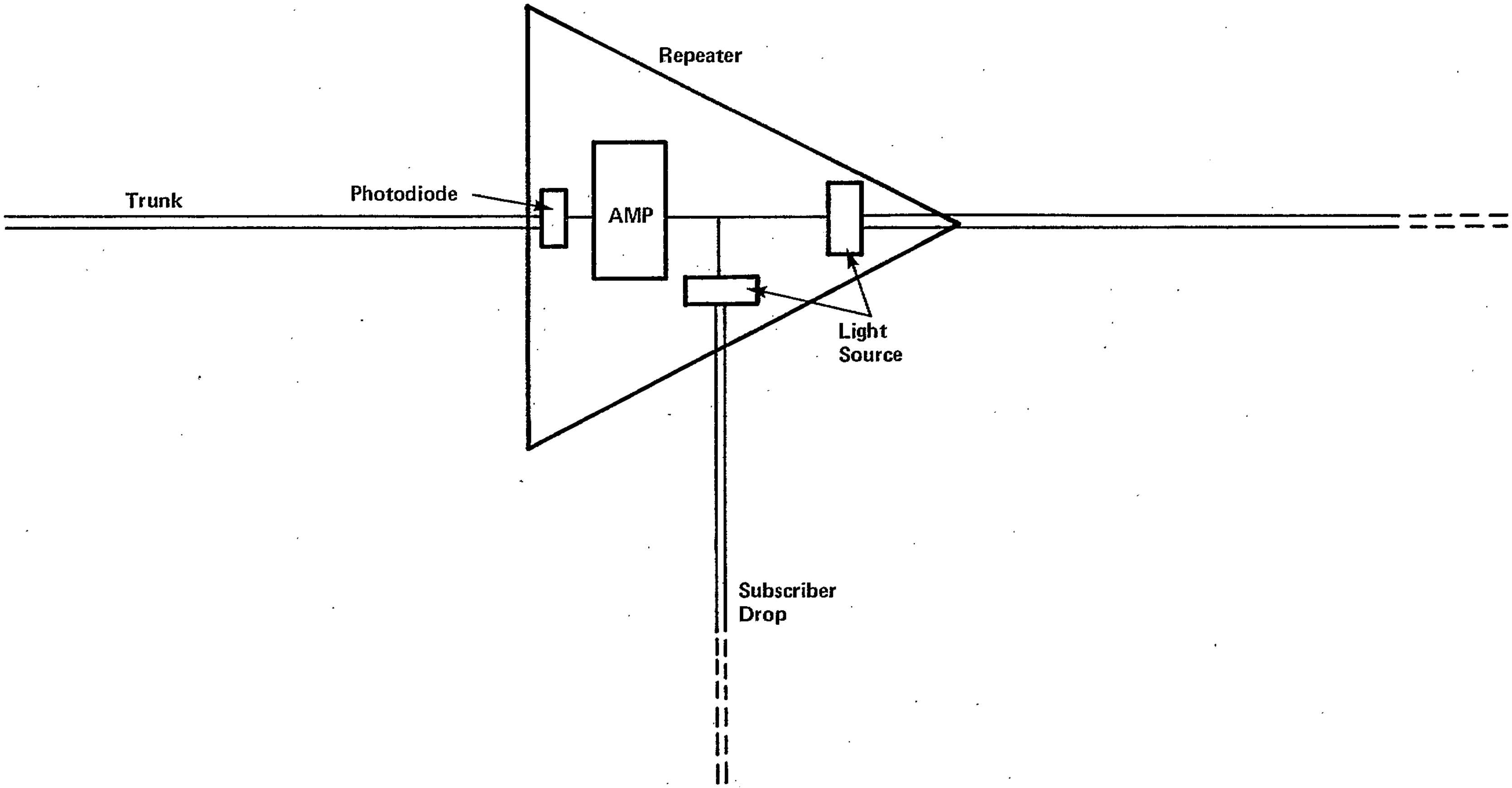



Figure 3.1  Electrical Tapping

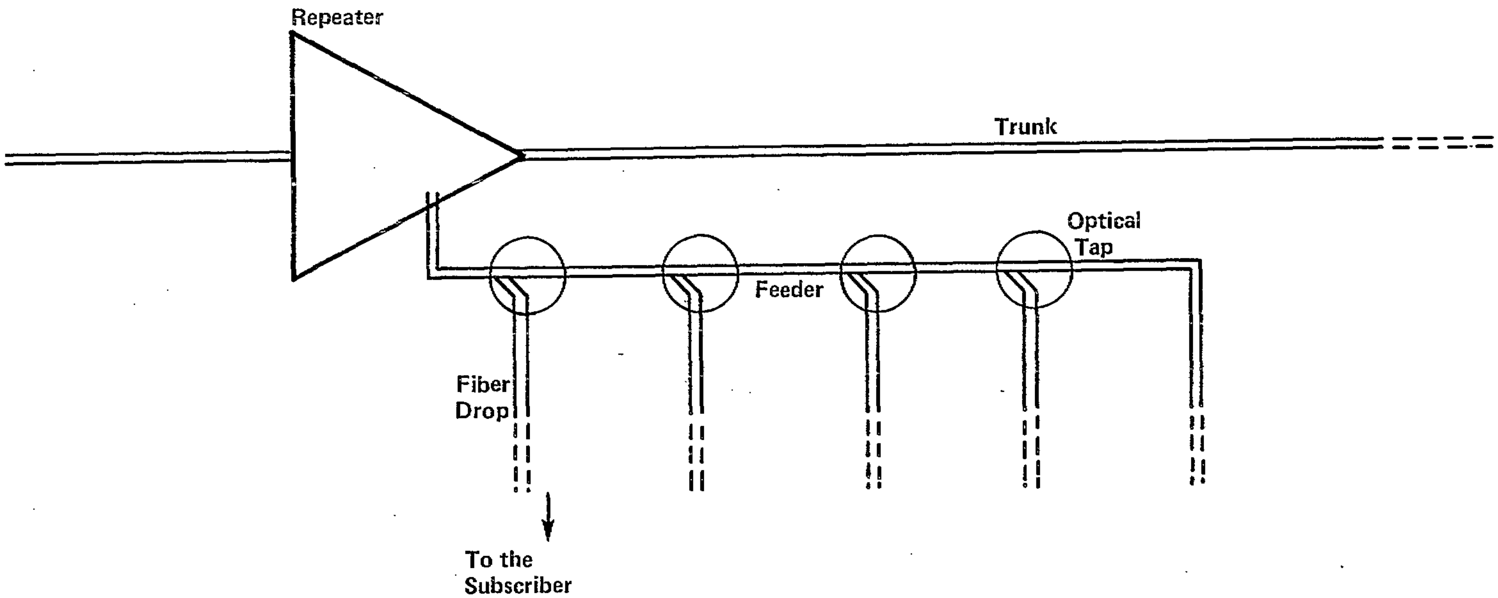



Figure 3.2 Optical Tapping
Optical Feeder

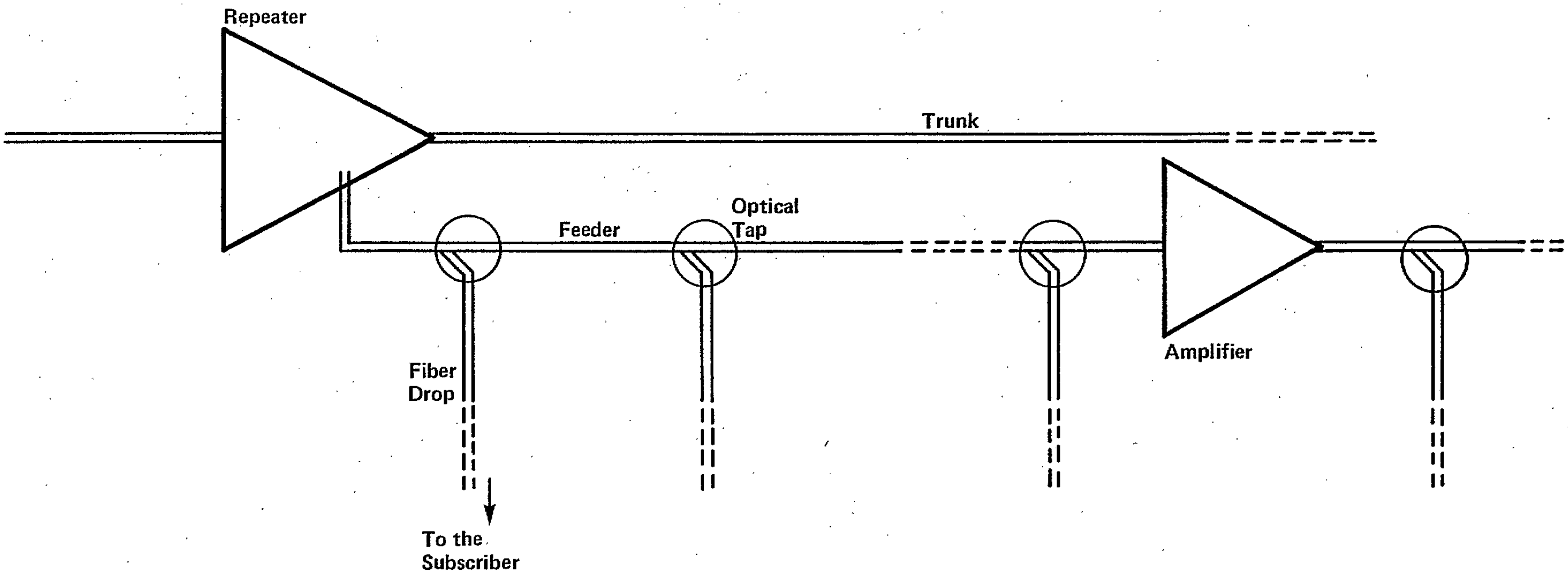



Figure 3.3 Optical Tapping
Optical Feeder With Amplifiers

sources. The quantum efficiency of LEDs decreases as the device bandwidth increases. Thus the use of high frequency signals will necessitate a wide-bandwidth, highly-doped LED which will result in a lower quantum efficiency and less power coupled into the fiber.

A strong resonance phenomenon occurs at a particular frequency in semiconductor lasers when they are modulated at high frequencies. This resonance frequency can be higher than 300 MHz in a new device, but occurs at a lower frequency with aging. This phenomenon could cause transmission problems. (Ref. 9).

It should also be mentioned that the transmission of lower frequency signals would relax the requirements on the electronic circuitry and, accordingly, would reduce electronics cost.

To summarize, there are two objections to low frequency signalling. Firstly, a frequency converter would be required for every subscriber in order to interface with present TV sets. However, an interface unit to convert from optical to electrical must be provided in any case. Therefore, it is only a question of how elaborate the interface unit is to be. Frequency converters for CATV subscribers are already on the market with proven technology and acceptable cost. Furthermore, it may be feasible to build frequency converters for fiber optics systems without the need for double conversion (VHF-UHF-VHF) as in most present CATV converters. This would further reduce the cost.

The second objection is that frequency converters would be required at the junction of coaxial and fiber optics CATV systems. This objection, however, is greatly outweighed by the advantages of low frequency signalling on a fiber optics system.

Note that the foregoing applies to the interface of a fiber optics CATV system with a presently available TV set. Future TV sets may be built with a baseband or a low carrier frequency input which would be highly desirable for a fiber optics CATV system.

### 3.1.3 Signal Multiplexing Schemes - Definitions

This study considers only baseband or AM-VSB transmission for the distribution part of the CATV system, because digital and FM video transmission would require expensive terminal equipment for every subscriber interface unit. Four multiplexing schemes are considered as follows:

- Frequency Division Multiplexing (FDM). Signals are multiplexed in the electrical domain as in present coaxial cable CATV systems, except that lower carrier frequencies are used.

- Space Division Multiplexing (SDM). One video channel is transmitted per fiber, either at baseband or on a low-frequency modulated carrier.

- Mixture of SDM and FDM (SDM-FDM). A small number of FDM video channels is transmitted over each fiber

- Wavelength Division Multiplexing(WDM). Video channels are multiplexed in the optical domain. Each channel is transmitted at a different optical wavelength and all video channels are transmitted through one fiber.

Other composite multiplexing schemes such as SDM-WDM and WDM-FDM could also have been considered, but since the possibilities and limitations of WDM are not known, it can be assumed that all of the system channels could be transmitted using pure WDM.

### 3.1.4 Configurations of Systems Using Frequency Division Multiplexing (FDM)

All of the system channels are transmitted through one fiber on modulated carriers. The major problem with this approach is the need for a very linear and efficient light source. The precise requirements are evaluated in Activity No. 5 as a function of the system length and the number of video channels. The frequency response of the fiber may be a significant factor in these systems. Unlike coaxial cable, the fiber frequency response is length dependent. Therefore, as the signal bandwidth increases, the maximum system length permitted by the fiber frequency response decreases, and the fiber response can thus become the limiting factor. However some equalization can be provided or a wider bandwidth and more expensive fiber can be used. Thus the fiber frequency response is less critical than the source linearity, but it must be considered.

A repeater for a FDM system will consist of one PIN photodiode, one amplifier and one light source, either laser or LED. It should be noted that the electronic circuitry in a FDM system must handle wide bandwidths (5-35 video channels), so it should be considered in making cost estimates.

The subscriber interface unit will consist of two modules: an optical-electrical conversion conversion module and a signal compatibility module. The conversion module will include a PIN photodiode with a low noise amplifier, while the compatibility module will be a frequency converter to make the received signal compatible with the VHF input of the subscriber's TV set.

If electrical signal tapping is used, one supplementary source per subscriber will be required at the tap. If optical tapping is used, subscribers will share the feeder facilities and the number of supplementary sources and directional couplers required for each subscriber cannot be specified here. These are specified in the different components counts. The system configuration with electrical tapping is schematically shown in Fig. 3.4.

### 3.1.5 Configuration of System Using Space Division Multiplexing (SDM)

One video channel is transmitted per fiber, either at baseband, or else on a low frequency modulated carrier so that transmission requirements are easier to meet. However, this scheme may cause serious outside plant problems, because for a system of N video channels, all trunk, feeder, and drop lines contain N fibers. Consequently N connectors or splices are required at each junction point.

Suitable connectors or splicing techniques will have to be developed, since the present uni-fiber connection technique is fairly time consuming, especially for lines with large numbers of fibers.

A repeater for a SDM system with N video channels will need N photodiodes and N sources. These could be built into integrated arrays for compactness. Each repeater will also require N amplifiers, however, these amplifiers need to handle only one video channel bandwidth each, so they could be less costly than the amplifiers used in the FDM approach.

The optical-electrical conversion module requires only one amplifier since only one TV program is viewed at a time. The program can be selected either by electrically switching N photodiodes to connect one photodiode to the amplifier or by switching N fibers to connect one fiber to a single photodiode.

The latter approach requires a mechanical switch with very tight tolerances in order to provide a good coupling efficiency between the fiber and the photodiode. Also, it would be difficult to avoid degradation of the fiber ends during use. Consequently the switch might need frequent servicing. For these reasons and also because a photodiode array would probably be cheaper than a mechanical switch, the use of a photodiode array with a photodiode selector is preferred.

A signal compatibility module containing a frequency converter is required if presently available TV sets have to be served, since signals should be transmitted on modulated carriers for these sets. Baseband transmission is not considered because a modulator would be required in the compatibility module. Modulators are very expensive on a per subscriber basis and experience so far in teleconferencing shows that they need frequent servicing.

In the case of future TV sets having a low carrier frequency input, signals could be input directly. If the future set has only a baseband input and a VHF input, a demodulator specially designed for this low frequency modulated carrier could feed the baseband input and give better performance than a frequency converter feeding the VHF input.

If only future sets with baseband inputs have to be served, baseband transmission could be preferred to modulated carriers because longer repeater spacings could be achieved.

If signal tapping is done electrically for a N video channel SDM system, N sources per subscriber would be needed. If tapping is done optically, up to N directional couplers per subscriber may be required if one subscriber is served by each tap. A SDM system configuration is illustrated in Fig. 3.5, with electrical tapping shown only.

### 3.1.6 Configuration of System Using Space Division Multiplexing and Frequency Division Multiplexing (SDM-FDM)

For a N video channel system, there are K fibers each carrying a small number of FDM video channels (N/K or rounded up to the nearest integer). With this composite multiplexing scheme, technical problems associated with each multiplexing scheme individually are less acute than with a SDM or FDM system for the same number of channels. Requirements on the source linearity and on

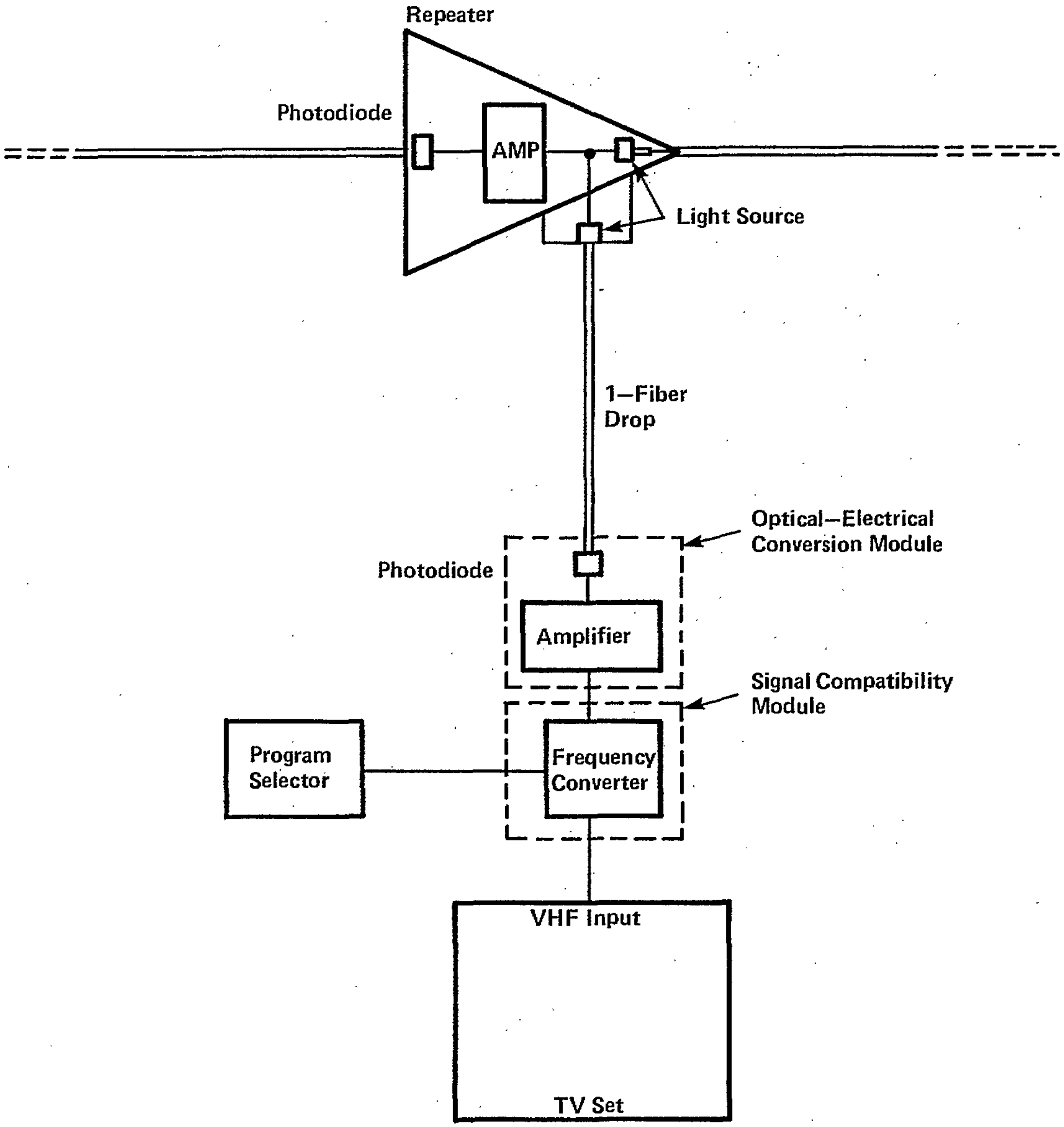



Figure 3.4 FDM Non—Switched System Configuration
Only One Subscriber and Electrical Tapping Shown

the connector technology are relaxed. However the respective advantages of each multiplexing approach are also less prominent.

A repeater for a system using K fibers requires K photodiodes, K amplifiers and K sources. Electronic circuitry has to accommodate a bandwidth at least equal to N/K video channel bandwidths.

The optical-electrical conversion module for the subscriber interface unit would use a K photodiode array with a photodiode selector preferred for the detection part, similarly to a system using only SDM.

For the signal compatibility module a frequency converter would probably be preferred for both present and future sets, similarly to a system using FDM. However, for future TV sets and a low number of FDM channels (N/K = 2 or 3), the use of separate demodulators feeding the baseband input could give better performance than a frequency converter. Furthermore, if only future sets have to be served, transmission of one channel at baseband and the others on modulated carriers may be considered in order to use the available TV inputs more effectively.

Electrical signal tapping for a K fiber system would require K sources. Optical tapping would require up to K directional couplers per subscriber. The preferred system configuration with electrical tapping is illustrated in Fig. 3.6.

### 3.1.7 Configuration of Systems Using Wavelength Division Multiplexing (WDM)

With this scheme, each transmitted optical wavelength carries one video channel, either at baseband or on a modulated carrier. Gallium arsenide sources are particularly suitable for this multiplexing scheme because they can be made to emit at any particular wavelength between 0.8 and 0.9 micron.

WDM is far from being a new concept, but technical problems still have to be solved before it becomes practical for fiber optics systems. Firstly, all the light beams coming from the different sources must be combined and efficiently coupled into a single fiber. Thus the need for an efficient source combiner. Secondly, at the receiving end the different wavelengths must be discriminated and the major part of their energy directed toward a single detector. This discrimination could be done, for example, by dichroic filters, prism, gratings, and Fabry-Perot. These techniques are commonly used in optics, but they would have to be adapted for fiber optics needs. However, it shows that WDM does not necessarily involve integrated optics. For the remaining part of the report, this discriminator will be referred to as a disperser.

A repeater would operate by demultiplexing the signals, amplifying each channel separately, and then multiplexing them again. Thus for a N video channel system, a repeater would need a disperser, a N photodiode array, N amplifiers, N light sources emitting at different wavelengths, and a source combiner. The electronic circuitry has to handle only one video channel bandwidth.

The optical-electrical conversion module for the subscriber interface unit is the same as for SDM, except that a disperser is required to interface

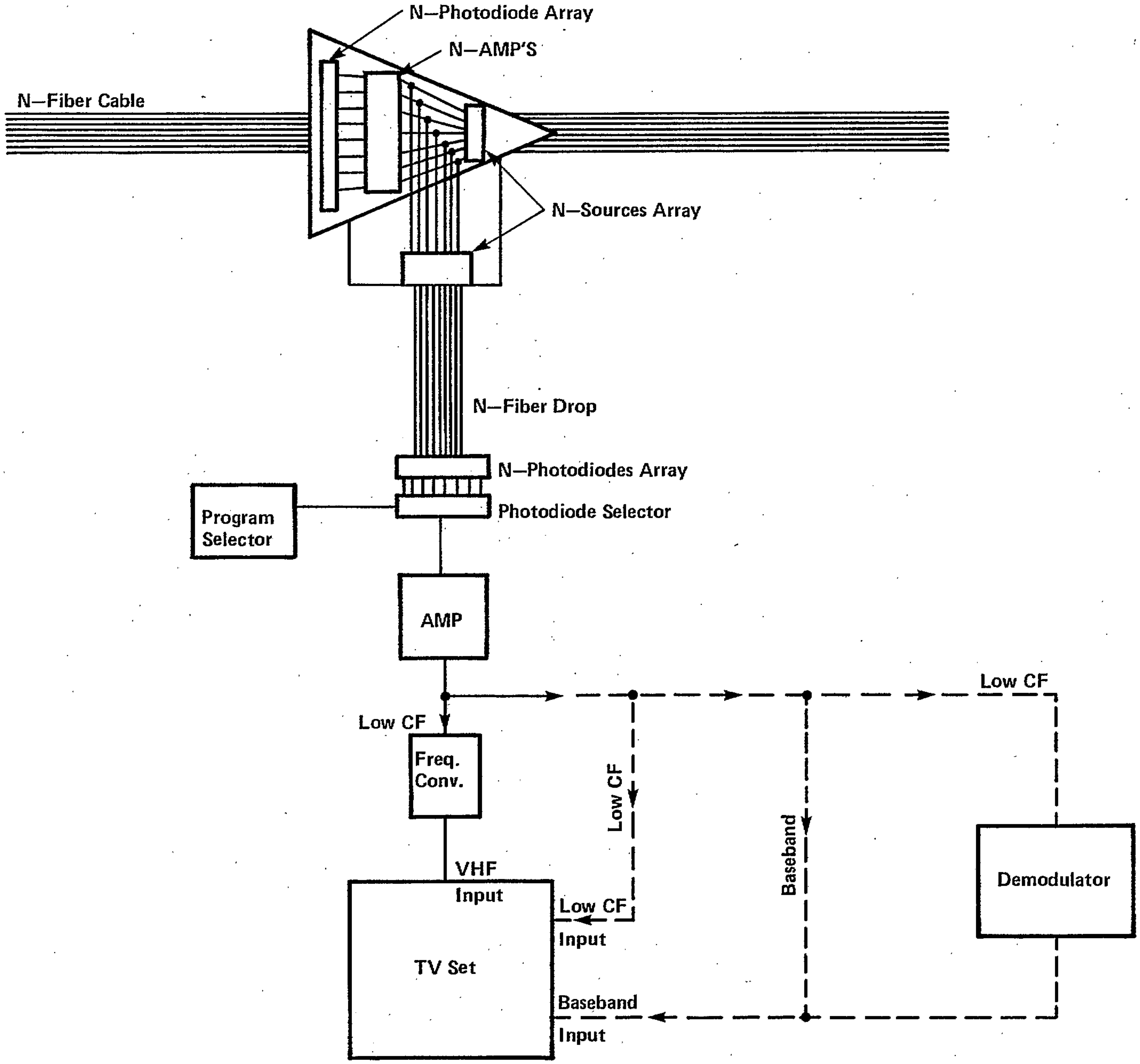



Figure 3.5 SDM Non–Switched System Configuration With Alternative TV Set Inputs. Only One Subscriber and Electrical Tapping Shown

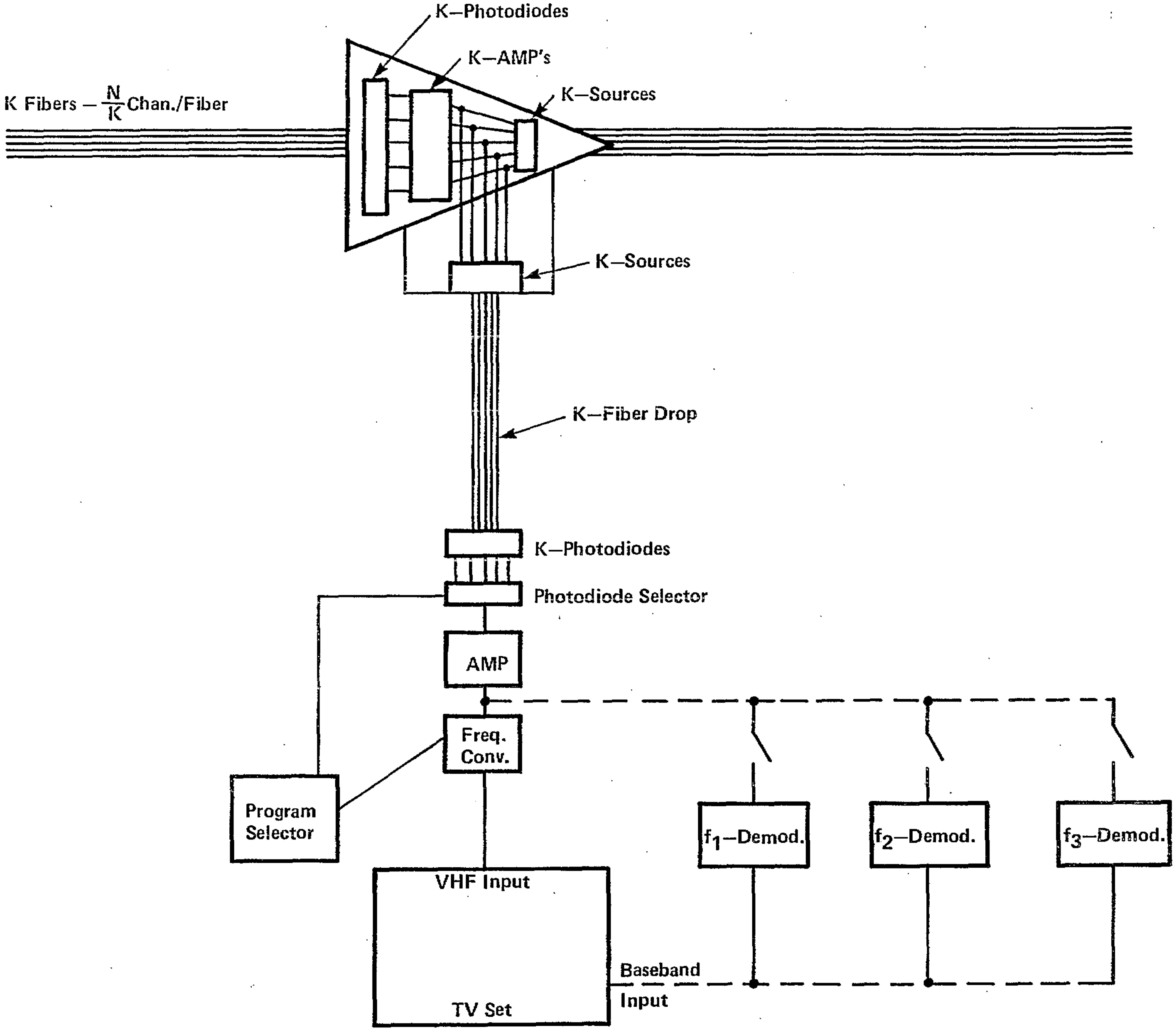



Figure 3.6 SDM–FDM Non–Switched System Configuration With Alternative TV Set Inputs
Only One Subscriber and Electrical Tapping Shown

between the fiber end and the N photodiode array. The signal compatibility module is exactly the same as for SDM. Refer to the discussion of the signal compatibility module in 3.1.5.

Electrical signal tapping for a N video channel system requires N sources and one source combiner per subscriber. If optical tapping is used, a maximum of one directional coupler per subscriber is required. The preferred system configuration is shown in Fig. 3.7 for an electrical tapping scheme.

## 3.2 SWITCHED VIDEO DISTRIBUTION SYSTEM

The switched video distribution system considered in this study uses spatial switching, where every subscriber has his own line going from his home to the video switch. The switched video distribution presents fewer transmission problems than the non-switched approach, because each subscriber line carries only one or two video channels.

Switched video distribution can accomodate a more flexible service growth than non-switched, because the number of available video channels can be increased without changing either the outside network or the subscriber terminals. Modifications have to be done only at the video switch. Switched video distribution is compatible with Pay-TV and similar services. Furthermore a switched CATV system could be upgraded into an interactive, integrated, broadband and narrowband system without having to change the outside network.

This report is concerned with how switched video influences the system and network configurations. Details such as how switching is performed, how program requests are handled, etc, are discussed in Activity No. 4.

### 3.2.1 Possible Return Paths for the Program Selection

The use of the present telephone pairs is not considered to be a feasible approach, because severe blocking could occur at peak hours. The implementation of techniques to avoid blocking would simply not be practical. This is discussed in detail in Activity No. 4.

A copper pair could be included in the subscriber line for the program selection as illustrated in Fig. 3.8. The copper pair could, in addition, add mechanical strength to the line. A supplementary light source for the program selection would not be required. However, the presence of a non-fiber return path would cancel certain advantages of the fiber optics system such as non-inductivity and electrical isolation between the subscriber and the video switch. This would render the system subject to surges due to lighting and thus reduce reliability, and also introduce the possibility of program selection being affect by crosstalk and RF induction and thus reduce the quality of service.

A separate fiber for the program selection could be used which would retain all of the advantages of fiber transmission as illustrated in Fig. 3.8. The fiber for the program selection could also be used later for upstream data or video transmission. With this approach, a supplementary light source is required. This could be an inexpensive light source if it is only used for the program selection. It could be upgraded later if upstream data or video transmission as desired.

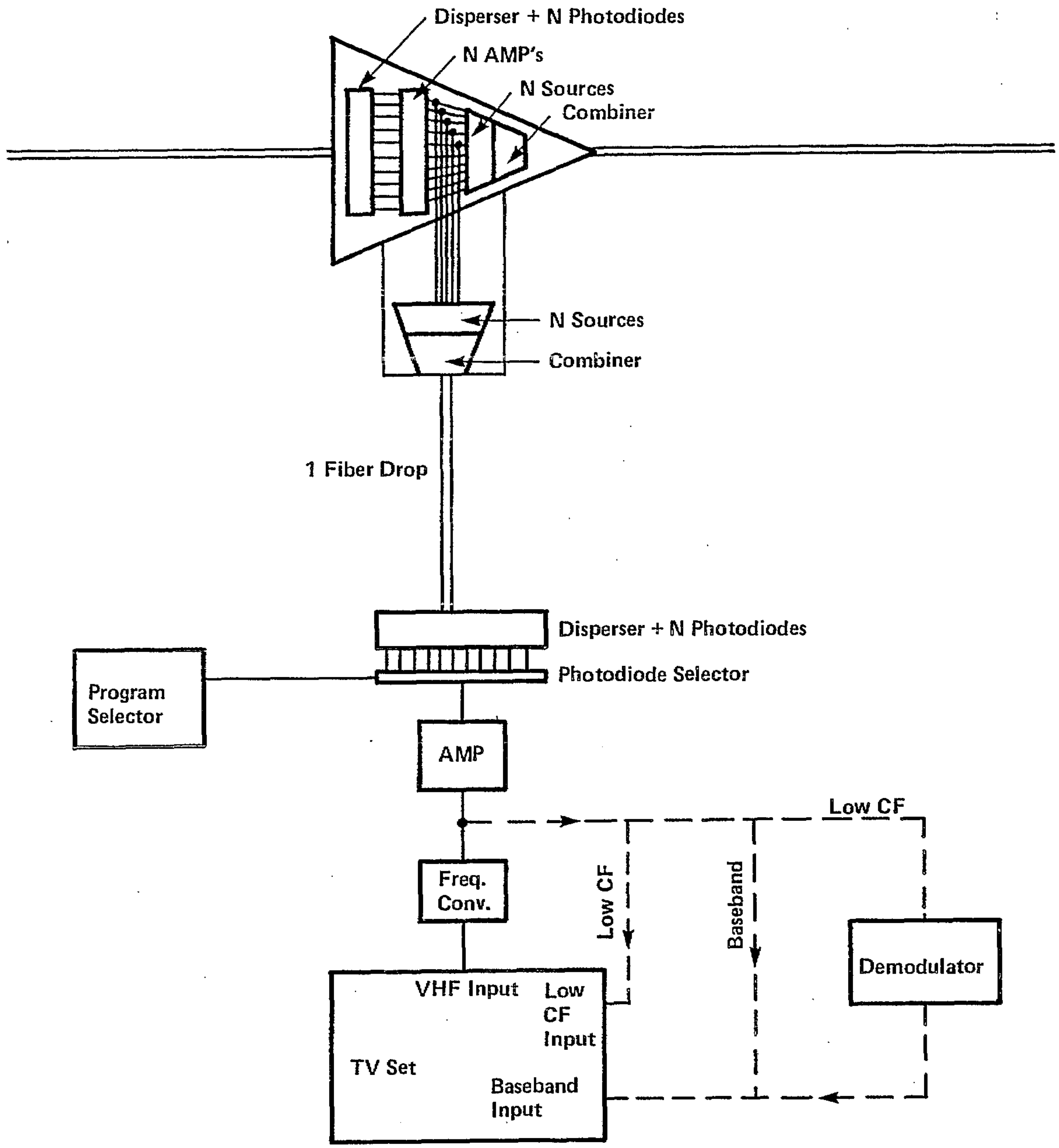



Figure 3.7 WDM Non–Switched System Configuration With Alternative TV Set Inputs
Only One Subscriber and Electrical Tapping Shown

Fiber can be a major cost factor in a CATV system, especially in rural areas. Thus the use of a supplementary fiber for the program selection could be very costly considering the low usage. Thus if the one fiber video facility could be used in the upstream direction as well for the program selection, it would result in major savings.

The bidirectional operation of a fiber could be achieved by placing directional couplers at both ends of the subscriber line as illustrated in Fig. 3.8. The required directional couplers are believed to be within the present state-of-the-art. The program selection might have to be done at a frequency outside the transmitted video channel bandwidths in order to avoid the interferences with the received program that could be caused by inadequate directivity of the directional couplers.

Bidirectional operation of the downstream fiber is the preferred return path for the program selection.

### 3.2.2 System Configuration

In a switched video distribution system there is a video switch placed at a central point and each subscriber is connected to it by a private line. Facilities for the downstream video and for the upstream program selection signalling must be provided in the subscriber line.

The downstream video signal on the subscriber line may have to transmit one or two video channels. If two channels are required at a time, they could easily be multiplexed on the same fiber, thus saving on the amount of fiber required. Two FDM video channels could be transmitted easily, so there would be no point in going for the extra complexity of WDM.

Signal frequency considerations of Section 3.1.2 apply for switched video distribution. The use of the low frequencies is also preferable for video switching because the required isolation between the video switch ports becomes more difficult and costly to meet as the signal frequencies increase.

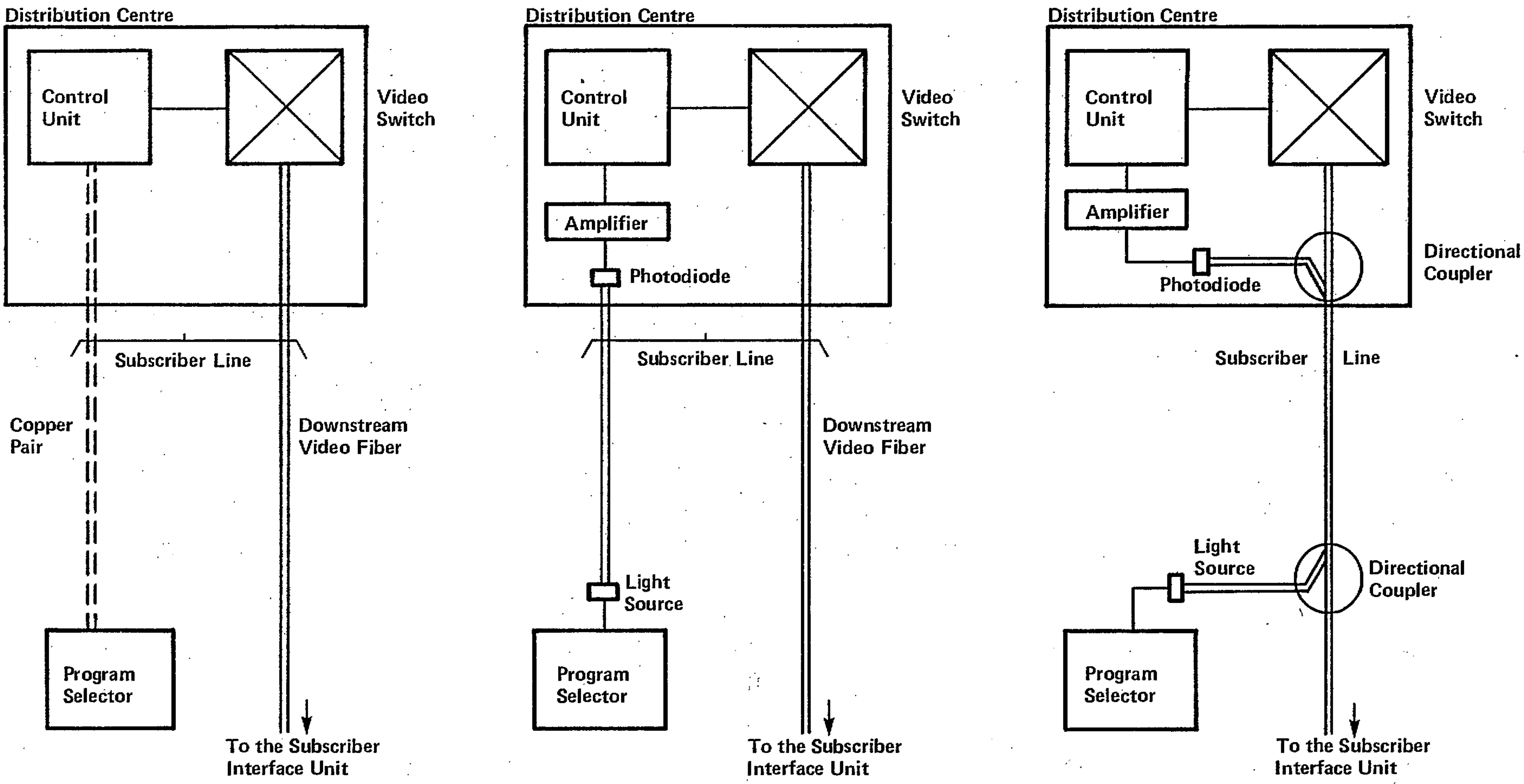
The preferred return path for program selection is the downstream video fiber operated in the upstream direction. The inclusion in the subscriber line of a separate copper pair or a supplementary fiber is less desirable.

The subscriber interface unit would require a light source for the transmission to the distribution center of the subscriber's request. This source could be of a lower quality than the ones used for the video transmission, so its cost should not be significant in the overall system cost.

To process the received video signal the subscriber interface unit would require an optical-electrical conversion module with one photodiode and one low-noise amplifier, and also a signal compatibility module.

If present TV sets have to be served, the transmission would have to be on modulated carriers, and frequency converters would be required. For future TV sets, the baseband or the low frequency carrier inputs could be used without the need of a compatibility module.

The preferred system configuration is shown in Fig. 3.9.




A) Copper Pair

B) Supplementary Fiber

C) Bi–directional Operation of a Fiber

Figure 3.8 Possible Return Paths For the Program Selection In Switched Video Distribution Systems

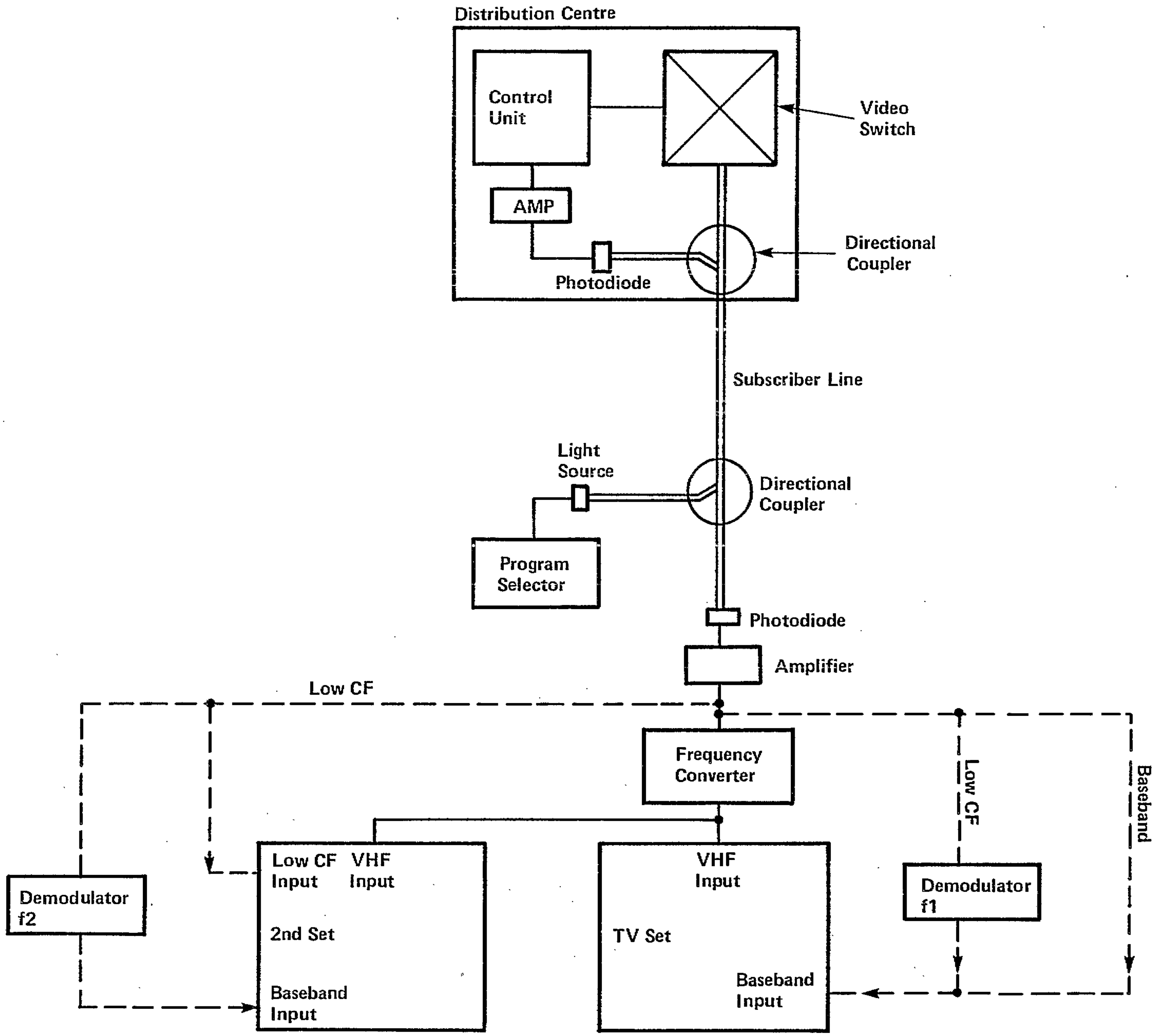



Figure 3.9 Switched Video System Configuration With Alternative TV Set Inputs
Only One Subscriber Shown

# 4. CATV DISTRIBUTION IN RURAL AREAS

## 4.1 CHARACTERIZATION OF THE RURAL DISTRIBUTION AREA

This study is based on models of the distribution areas reflecting typical population densities. For rural areas both uniform and non-uniform subscriber density models are considered. In both cases the distance from the distribution center to the subscriber was set at 40 km maximum.

For the uniform subscriber density model a density of 10 subscribers per square km is assumed. Each subscriber is placed at the center of a lot 320 meters square. 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. There are 50,000 subscribers in the 40 km radius distribution circle. This model is illustrated in Fig. 4.1.

In some rural areas the population is only located along the roads and the roads are widely spaced. Therefore, for the non-uniform subscriber density model, a linear distribution is assumed which places subscribers at 160 meter intervals along the roads and 160 meters from the roads. This model is equivalent to considering only two rows of subscribers in the uniform density model. This model is illustrated in Fig. 4.2.

## 4.2 POSSIBLE NETWORK CONFIGURATIONS

The network configuration will be influenced by the basic system approach, i.e. switched or non-switched. For the non-switched approach, it will depend also on the chosen signal tapping scheme, i.e. optical or electrical. The multiplexing scheme will affect the permitted repeater spacing and the amount of hardware required, but not the general shape of the network.

The network configuration also strongly depends on the population distribution model considered. Therefore two types of CATV distribution are considered: grid distribution and linear distribution. In grid distribution the distribution area is divided into smaller areas called distribution cells. In linear distribution the service is distributed along lines, rather then by area.

Linear distribution appears to be the only reasonable approach for the non-uniform subscriber density model. However, it can also apply to the uniform subscriber density model, and for some practical reasons may be preferred to the grid distribution approach.

For the network configurations considered here it is assumed that all light sources, amplifiers and detectors are similar, as far as their respective transmission performance is concerned. For example, the noise figure of a subscriber amplifier and the noise figure of a repeater amplifier are assumed to be the same. In addition, light sources for trunks, optical feeders and drops are assumed to couple the same maximum amount of optical power into the fiber. However even if their transmission performances are similar, it does not mean that they are of the same quality or that they cost the same. For example, a repeater amplifier and a subscriber amplifier

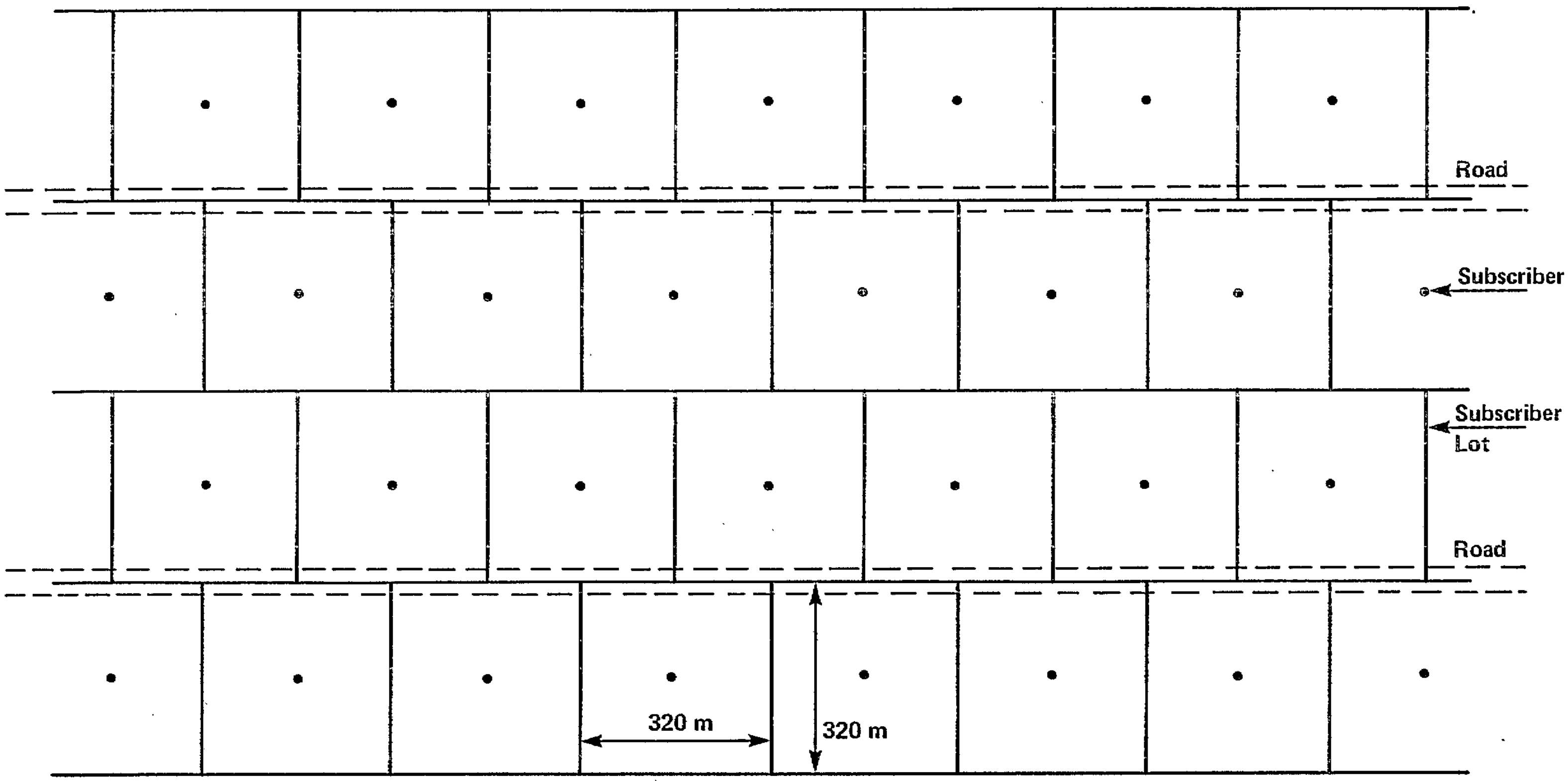



Figure 4.1 Rural Area — Uniform Subscriber Density Model

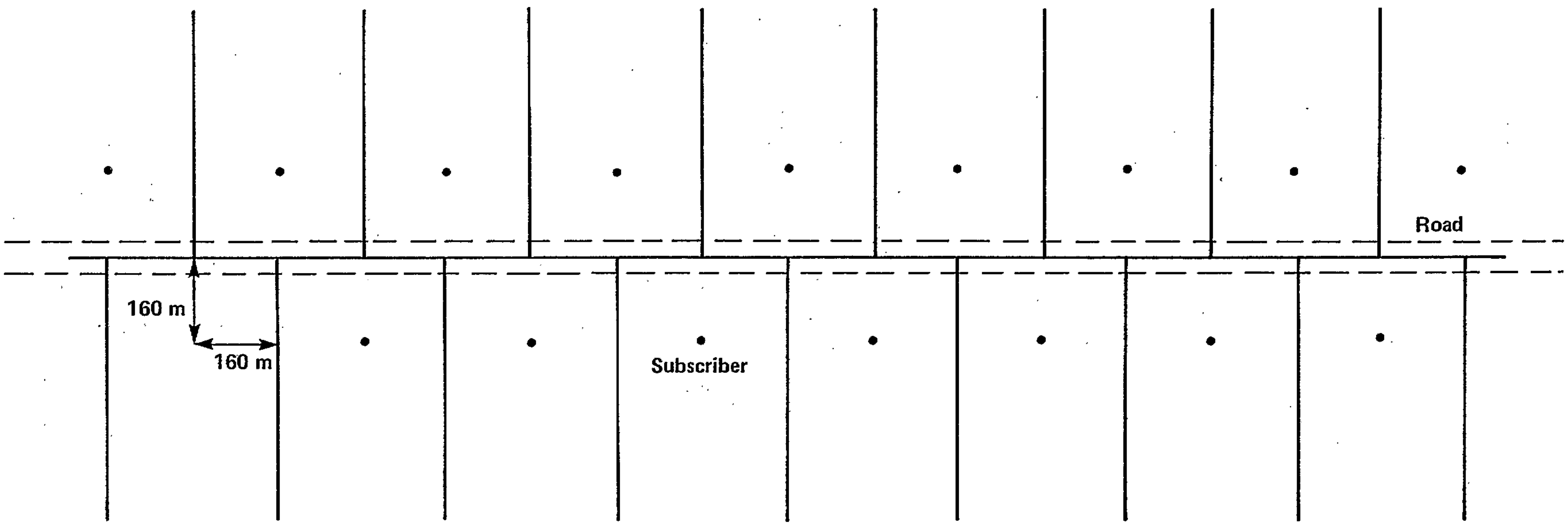



Figure 4.2 Rural Area – Non–Uniform Subscriber Density Model

do not have the same output power, therefore their costs will be different.

### 4.2.1 Non-Switched Grid Distribution

For rural areas the amount of electronics in the field must be minimized for system reliability and cost reasons. Because of the low population density of rural areas, the cost of a repeater would not be shared by many subscribers, therefore its cost would not be marginal on a per subscriber basis.

To achieve the minimam amount of electronics in the field, the maximum repeater spacing should be used and each repeater should serve the maximum area. The repeater spacing is fixed by the multiplexing scheme, the transmission performance requirements and the maximum length of a transmission line. The maximum size and the shape of a distribution cell covered by one repeater depends on the signal tapping scheme being used.

In the uniform distribution model it is assumed that distribution cables will follow streets or backlot boundaries. This means that cable paths are always parallel to the four main axes of the distribution area. It also means that the maximum length of transmission line required to serve a subscriber located on the 40 km radius circle, at 45 degrees from one main axis is equal to 40 x 1.414 km = 57 km approximately.

Having only four main axes of distribution may not be realistic. If there were eight main axes located 45 degrees apart and the distribution were made perpendicular to the main axes, then the longest transmission line would be approximately 52 km (40 cos 22.5 deg. + 40 sin 22.5 deg.). For the present purpose the difference is not significant and a network having four main axes of distribution will be considered.

With electrical tapping the maximum drop length is at least equal to the repeater spacing. Considering also that distribution cables must be parallel to the main axes and that a subscriber should be served by the closest repeater, an hexagonal distribution cell is obtained.

The network composed of the hexagonal distribution cells is schematically shown in Fig. 4.3. A detailed distribution cell is shown in Fig. 4.4. A main feeder is a cable containing all the subscriber individual drops going from the repeater to the subscriber's premises.

With optical tapping a feeder with no amplifier will be much shorter than the space between repeaters. However, for this to become a practical approach, a feeder should at least be able to serve a subscriber located at a distance equal to half of the repeater spacing. Otherwise, a supplementary distribution repeater must be placed between every two repeaters of the distribution trunk, thus violating the guideline of minimizing the electronics in the field.

Similarly, repeaters on the feeders would also violate this guideline. Calculations based on the Appendix B analysis show that one feeder repeater would be needed for every four subscribers in the case of 12 FDM channel transmission, and one repeater would be needed for every 10 subscribers in the case of one video channel transmission. Furthermore the number of trunk

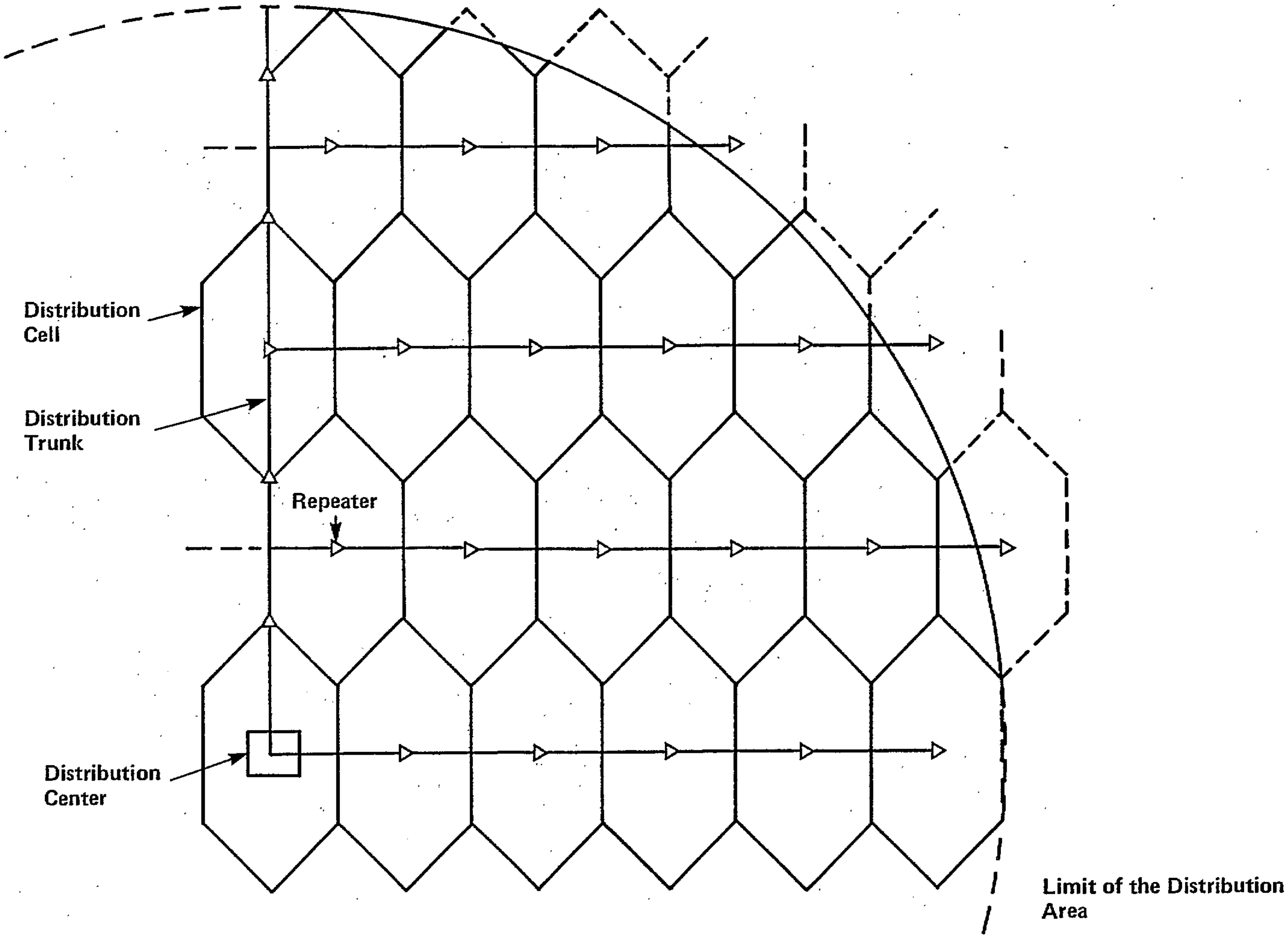



Figure 4.3 Grid Distribution – Non–Switched Approach – Electrical Tapping
One Quarter of the Distribution Area Shown Only

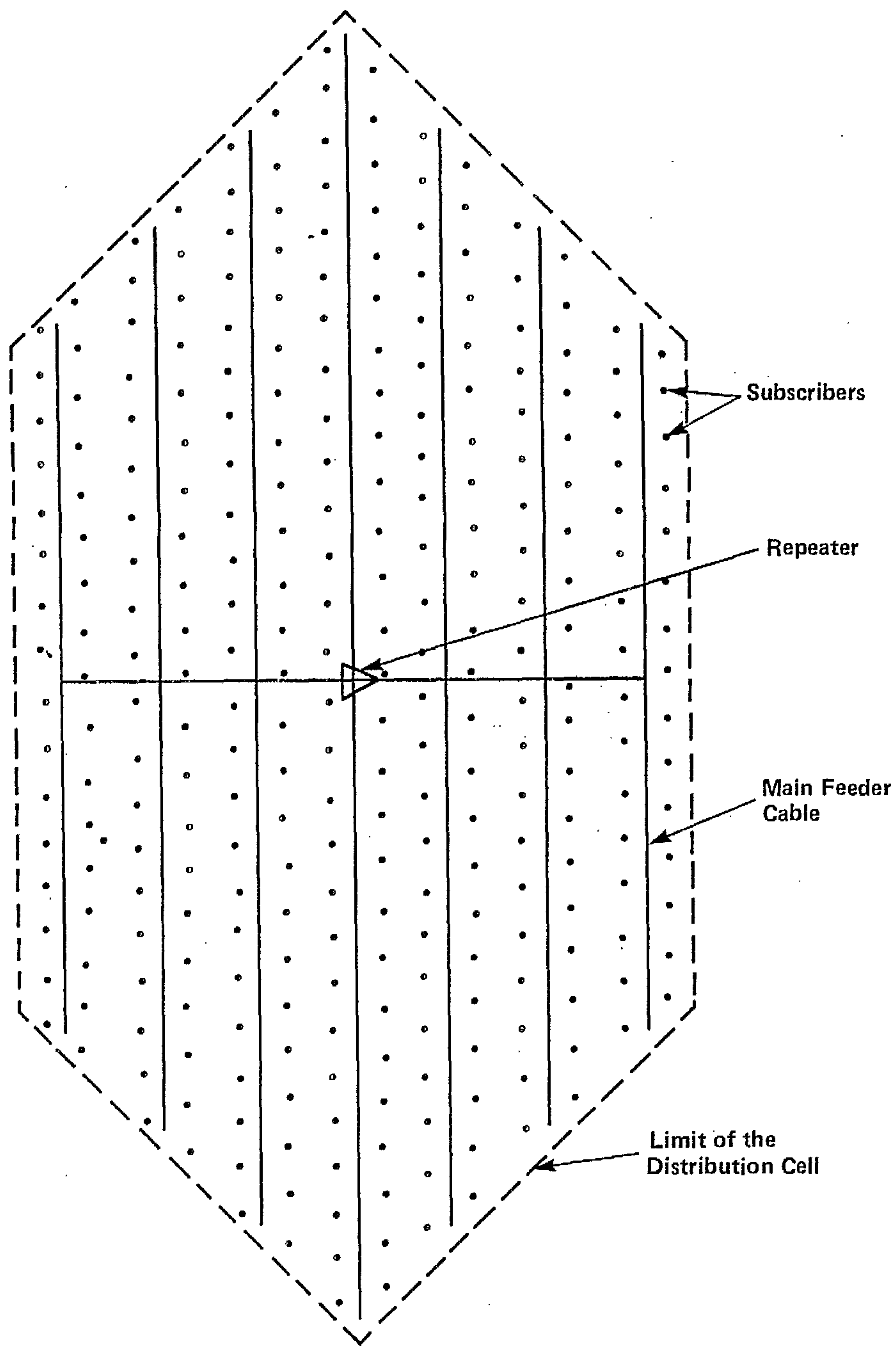



Figure 4.4 Grid Distribution — Non–Switched Approach
Electrical Tapping
Detailed Distribution Cell
Individual Drops Not Shown

repeaters must be added to the previous figures. Thus it becomes clear that having repeaters on the feeders is not a good approach for rural areas.

For the case where one feeder line with no amplifier cannot reach the half repeater spacing limit, the possibility of adding two more lines in the feeder cable is considered. A maximum of three lines is fixed arbitrarily. Up to three lines in a feeder cable is believed to be preferable to the introduction of a supplementary repeater. More than three lines would result in an intermediate approach between optical tapping and electrical tapping.

For a grid distribution using optical tapping, the distribution cell becomes a diamond with the diagonals equal to the repeater spacing. The distribution area and a distribution cell are illustrated in Fig. 4.5 and 4.6 respectively. For rural areas, one subscriber per tap is assumed, because subscribers do not face each other in the model, and also because in real rural areas, bringing the drop perpendicularly to the road could be the only practical way. Feeders are 640 meters apart which is equivalent to twice the length of the side of a subscriber lot.

### 4.2.2 Switched Grid Distribution

In the model for switched video distribution systems, there is no repeater on the subscriber line between the video switch and the subscriber premises. This implies that for rural areas remote video switches will be required. These are termed Remote Distribution Centers (RDC). Transportation trunks are shown to be capable of meeting signal-to-noise ratio requirements of 46 or 43 dB over distances as long as 57 km. The longest transmission length that could occur in the 4 main axis distribution model for rural areas is 57 km. With these transportation trunks, each RDC could be fed from a master distribution center located at the center of the distribution area.

A 43 dB SNR transportation trunk is chosen, therefore the transmission requirement for the RDC distribution section is 43 dB SNR in order to meet BP23 at the subscriber's set. A higher quality trunk could have been chosen, but the difference for the RDC distribution part is not significant. For a 46 dB SNR, or even a higher quality trunk, and for two video channels transmitted on the subscriber line, the difference in the allowed subscriber line optical loss is less than 2 dB, based on Appendix A analysis.

The maximum size of the distribution cell is fixed by the maximum length of subscriber line achievable. Also significant savings on the amount of fiber required can be made if the distribution cell is smaller. However the size of the cell, i.e. the number of subscribers being served by the RDC, should justify the cost of the video switch. Thus there is a tradeoff between the fiber cost and the video switch cost. This tradeoff will become more apparent in the components count.

The rural distribution area with the different distribution cells is illustrated in Fig. 4.7. The details of the distribution inside a distribution cell are shown in Fig. 4.8 Subscriber lines are regrouped in main feeder cables.

### 4.2.3 Non-Switched Linear Distribution

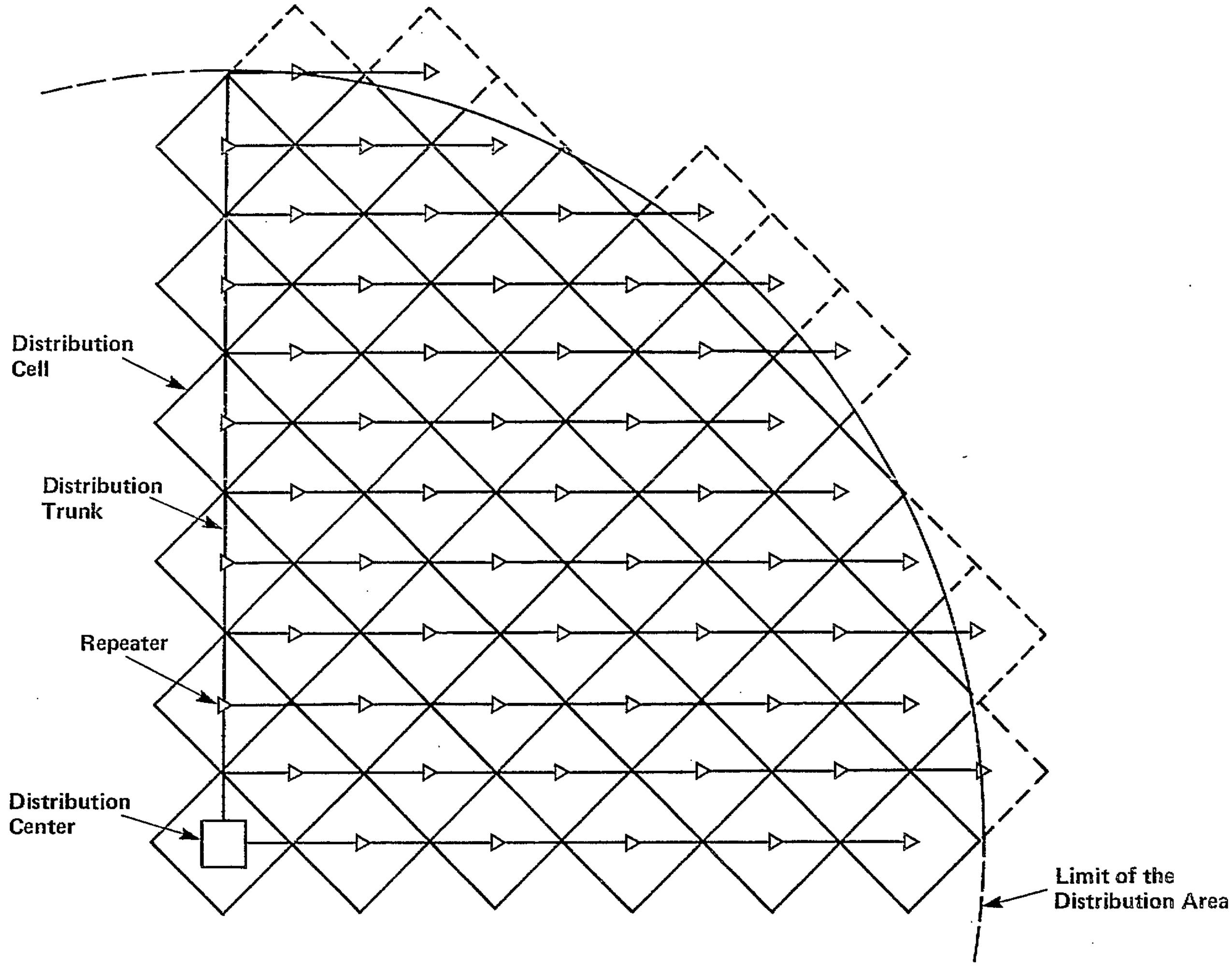



**Figure 4.5 Grid Distribution – Non–Switched Approach – Optical Tapping One Quarter of the Distribution Area Shown Only**

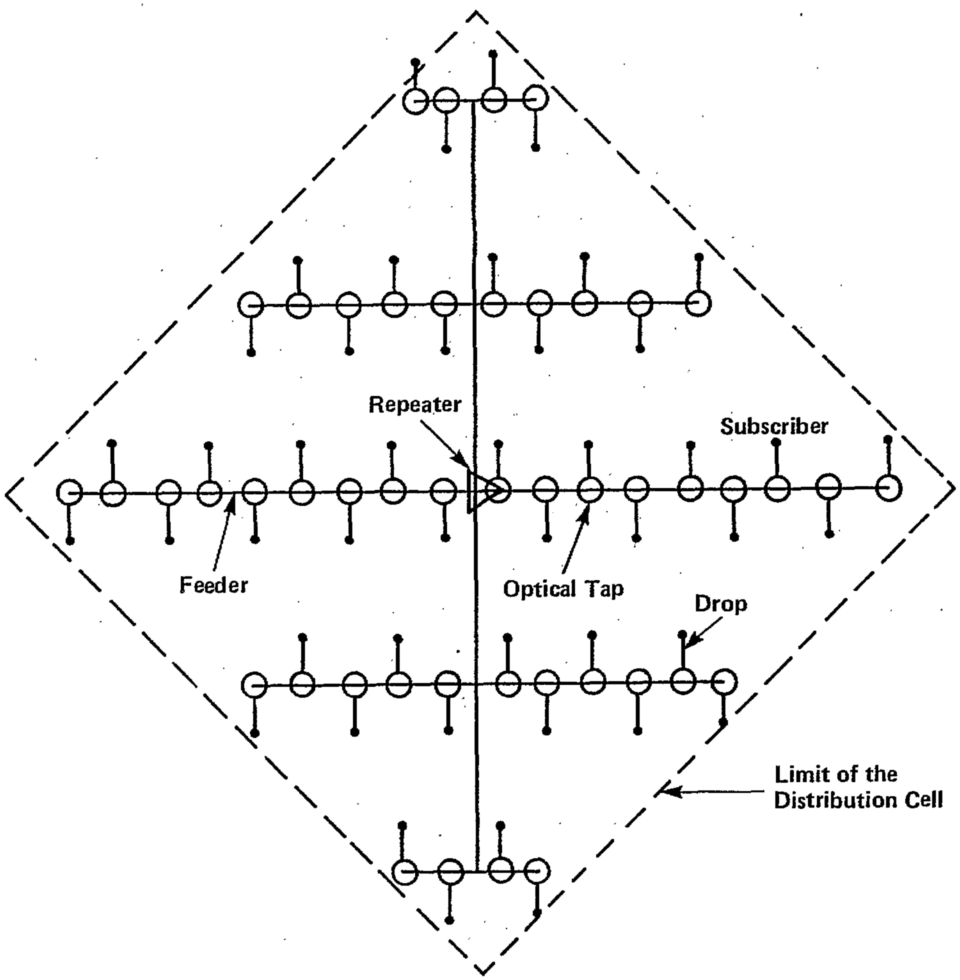



Figure 4.6 Grid Distribution – Non–Switched Approach – Optical Tapping
Detailed Distribution Cell

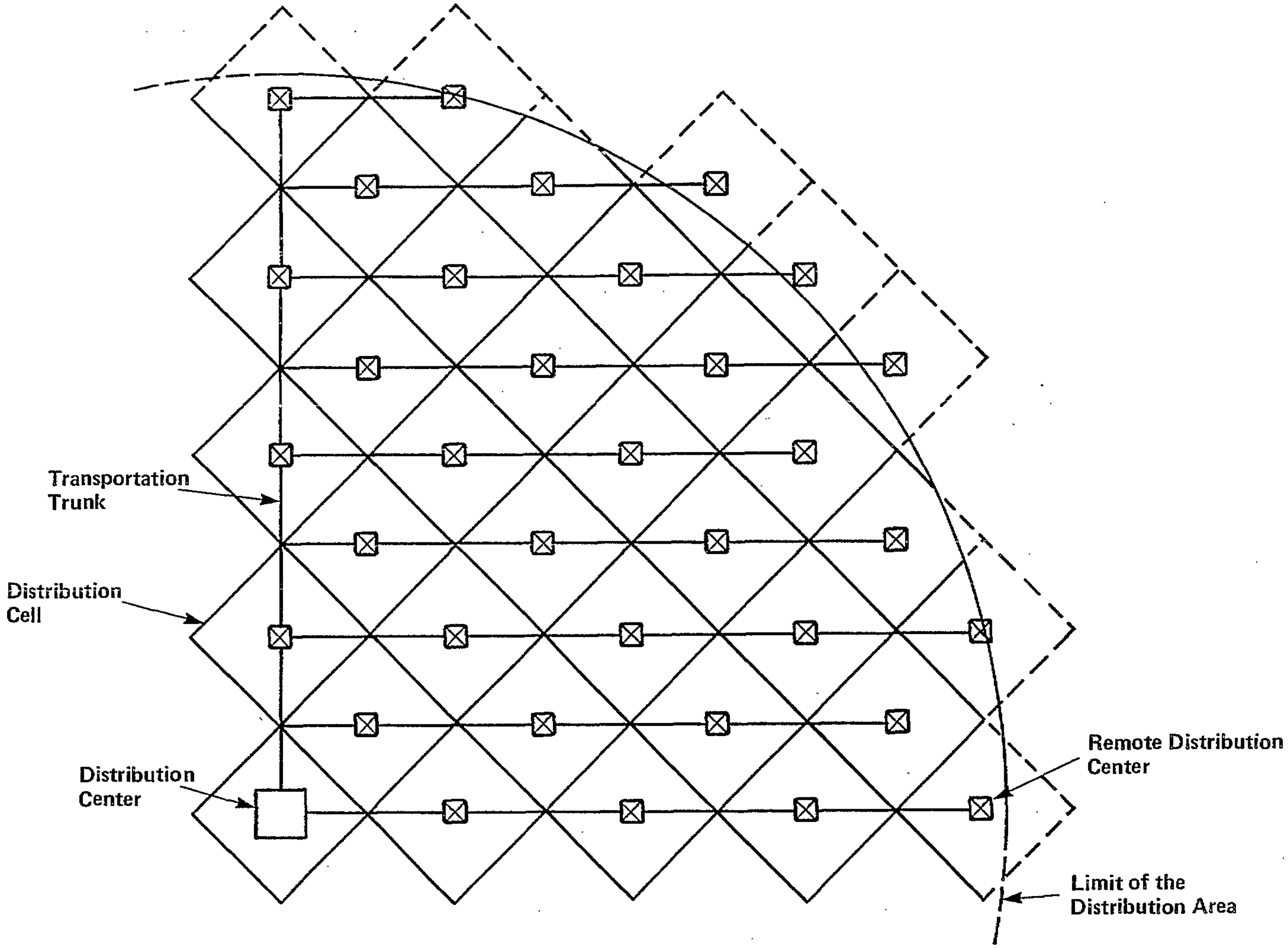



Figure 4.7 Grid Distribution — Switched Video Approach
One Quarter of the Distribution Area Shown Only

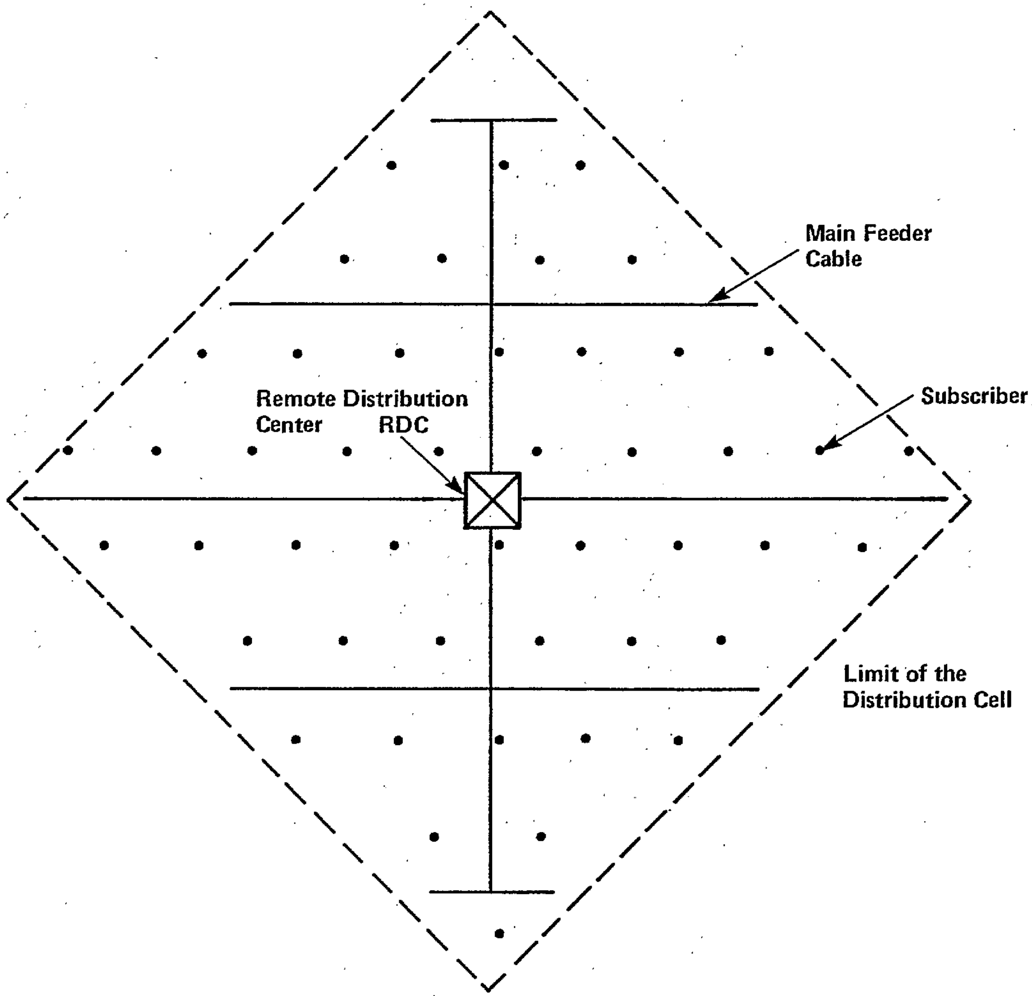



Figure 4.8 Grid Distribution — Switched Video Approach
Detailed Distribution Cell
Individual Subscriber Lines Not Represented

With electrical tapping, signals are distributed from a repeater to the subscribers living within a half repeater spacing as shown in Fig. 4.9. A distribution cable parallel to the distribution trunk contains the subscriber drops.

With optical tapping, video signals are distributed to subscribers living within a half repeater spacing. Subscribers tap the optical signals from a feeder laid parallel to the distribution trunk as illustrated in Fig. 4.10. Similarly to the grid distribution, feeders can contain up to three lines, each of which is tapped by a different group of subscribers.

Tapping the trunk is not recommended, because it reduces the maximum achievable length of the trunk. Tapping the trunk could be considered only for special cases, such as an isolated subscriber located between two repeaters where a special drop would be very costly and the tap would not affect line performance.

### 4.2.4 Switched Linear Distribution

In the case of linear distribution, a RDC serves a given length of the road. The maximum length or maximum number of subscribers is fixed by the longest non-repeatered subscriber line achievable. The network configuration is quite similar to the non-switched electrical tapping network configuration except that repeaters are replaced by video switches. This approach is illustrated in Fig. 4.11.

## 4.3 COMPONENTS COUNT

The amount of hardware required for different numbers of video channels is evaluated (N = 5, 12, 21, 35), based on the preceding system and network configurations. This will permit evaluation of the relative merits of each approach and identification of the approach best suited for CATV distribution in rural areas.

### 4.3.1 Assumptions and Evaluation Method

The system configurations discussed in Section 3 and the corresponding network configurations of Section 4.2 are considered. The following assumptions are made:

- BP23 must be met at the subscriber TV set
- Presently available TV sets (VHF-UHF input) must also be served. This implies that all video channels are transmitted on low frequency modulated carriers.
- For the switched video approach, two video channels are transmitted at a time to the subscriber.
- SDM is used for the 43 dB SNR transportation trunk required for the switched video approach.
- For the non-switched approach using SDM-FDM, up to three video channels are multiplexed on a fiber.

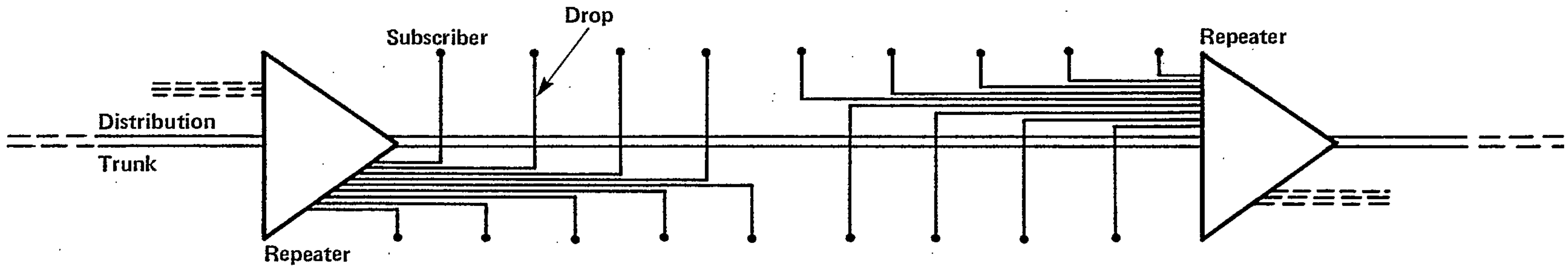



Figure 4.9 Linear Distribution — Non—Switched Approach
Electrical Tapping

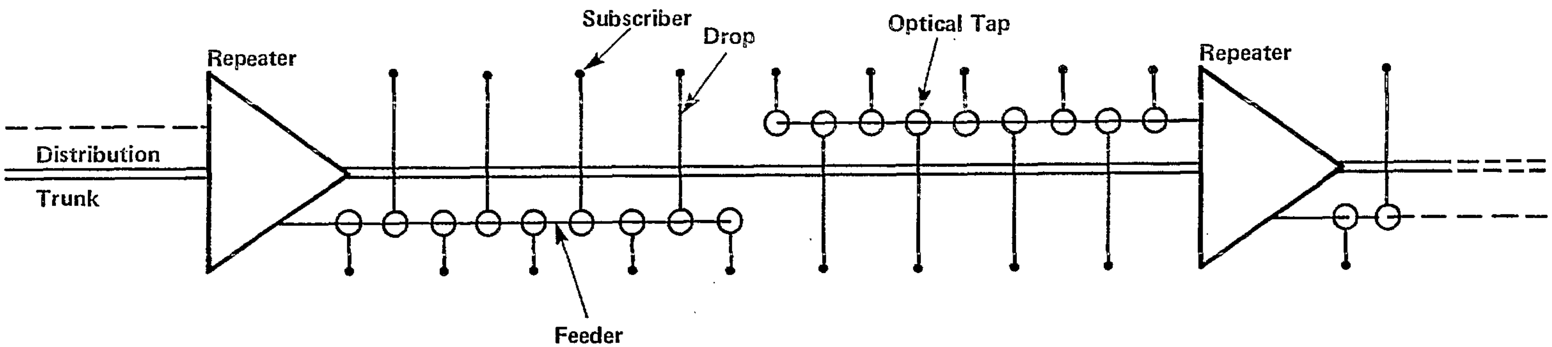



Figure 4.10 Linear Distribution – Non–Switched Approach
Optical Tapping

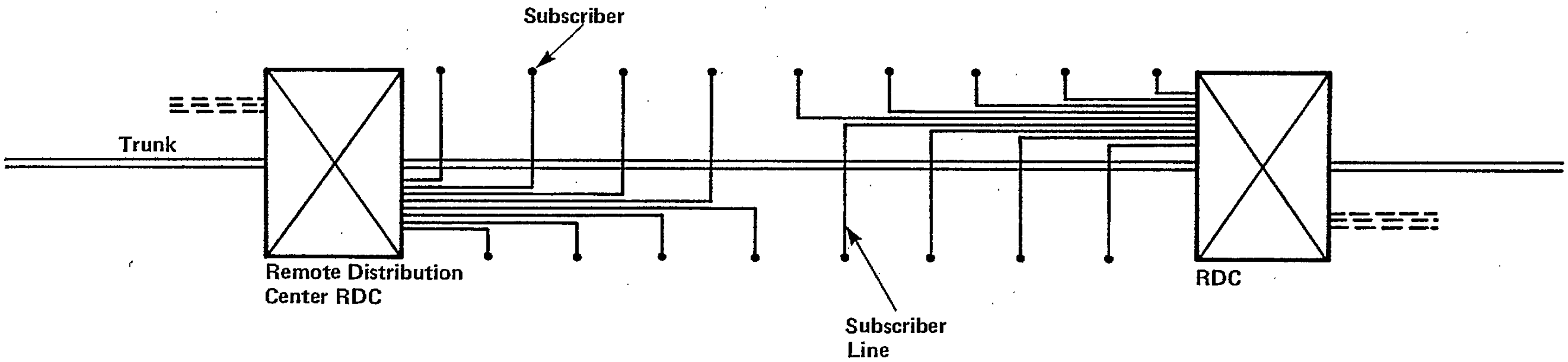



Figure 4.11 Linear Distribution — Switched Video Approach

- Transmission performance is limited only by noise. The source linearity is assumed sufficient for the moment. This is discussed in detail in 4.4.

- Longest transmission line occuring in the system is 57 km from the distribution center to the furthest subscriber.

- Optical signal power coupled into the fiber by each light source is 1 mW peak-to-peak, specifically 0.667 mW mean optical power with an optical modulation index of 0.75.

- Fiber attenuation is 5 dB/km, including connector and splice losses.

- Connector and splice losses equal 0.5 dB.

- Directional coupler intrinsic throughloss equals 0.5 dB.

- Coupling ratio of directional couplers can be finely adjusted for each subscriber's needs.

- Two connectors are required for each tap, so the tap throughloss equals 1.5 dB.

- Two connectors are required for each subscriber drop, so the drop loss equals 1.8 dB.

- Video switches and subscriber signal compatibility module do not introduce significant degradations to the signals.

The evaluation of the hardware required for the non-switched approach using electrical tapping and for the switched approach is straightforward if the system configurations, Fig. 3.4 - 3.9, and the respective network configurations, Fig. 4.3 - 4.11, are considered. Particularly for the switched approach, the transportation trunk must be properly allocated. Refer to appendix C for additional details.

For the non-switched approach using optical tapping, the required number of lines in the feeders, maximum three, and their respective lengths must be evaluated for each repeater of the 57 km trunk line, because they vary as a function of the repeater rank. Then the average length of fiber and the average number of sources per subscriber are evaluated. These averages must be representative of the total system, therefore they must be made taking into account the number of subscribers in the total system being served from a repeater of the particular rank considered. A computer program was written based on the preceding considerations and based on Appendix B analysis. Refer to Appendix C for details of this program.

For the non-switched approach the dimensions of the distribution cell, or length, depend on the repeater spacing. Repeater spacings are a function of the number of video channels transmitted and also of the distribution trunk length (57 km). The maximum repeater spacings for different transmission schemes are evaluated, based on the appendix A analysis. They are used in the components count and are given in Table 4.1.

TABLE 4.1 MAXIMUM REPEATER SPACINGS
NON-SWITCHED VIDEO DISTRIBUTION

| MULTIPLEXING SCHEME | NUMBER OF VIDEO CHANNELS | NUMBER OF REPEATERS TRUNK 57 km | REPEATER SPACING (km) |
|---|---|---|---|
| SDM, WDM | 1 | 12 | 4.76 |
| SDM-FDM | 3 | 16 | 3.58 |
| FDM | 5 | 18 | 3.1 |
| FDM | 12 | 29 | 1.96 |
| FDM | 21 | NOT POSSIBLE TO REACH THE 57 km LIMIT | |
| FDM | 35 | NOT POSSIBLE TO REACH THE 57 km LIMIT | |

For the switched approach, the maximum repeater spacing on the 57 km transportation trunk is 4.4 km and the maximum subscriber line length is 52 km, both for a SNR objective of 43 dB.

### 4.3.2 Components Count Results

The amount of hardware required in different CATV distribution systems for rural areas is evaluated. Results for each approach are given on a per subscriber basis, which shows the implications of providing CATV services following this approach. The required amount of hardware is evaluated in terms of repeaters, video switches, length of fiber, sources, photodiodes, amplifiers, directional couplers, photodiode selectors, and dispersers.

Components required in the signal compatibility module of the subscriber interface unit are not given because it depends on the type of TV set being served. However, if it is assumed that all the sets have only a VHF input, a frequency converter would be required for every subscriber.

Definitions of components are as follows:

- Repeater. This is a field unit and therefore needs an apparatus case, a power supply and a power amplifier. Equalization and some form of AGC may also be required.
- Video switch. This is the remote distribution center with all the supporting equipment.
- Fiber. This is the length of uncabled fiber required in total for distribution trunks, feeders, and drops, unless specified otherwise. Note that cabling cost could vary with each approach considered.
- Source. This is the light source, including the driving circuitry and the linearization circuitry if needed (FDM).
- Photodiode. This is the PIN photodiode with its biasing circuitry.
- Amplifier. This is the high impedance front end buffer amplifier placed between the photodiode and the following electronics which are required for further amplification, i.e. TV set for a subscriber interface unit and a power amplifier for the repeater.
- Directional coupler. This is the unit installed on a fiber to couple light from it. One is required per fiber, therefore one optical tap may consist of many directional couplers.
- Photodiode selector and dispersers are as defined in Section 3.

Results of the different components counts are given without extensive discussion. Readers should give special attention to the number of repeaters, video switches, kilometers of fiber, and sources required for the different approaches because it is believed that these items have the greatest effects on the system cost.

For the non-switched approach, results are given in Tables 4.2 to 4.9 for different numbers of video channels provided to the subscriber and for different types of distribution.

For the switched approach, three dimensions for the distribution cell are considered: 5.2 km, 4.4 km, and 2.2 km. The 5.2 km dimension corresponds to the maximum size for the distribution cell, but signals from the transportation trunk will have to be electrically tapped and brought from the nearest trunk repeater to the RDC. Supplementary transmission lines will be required.

If the longest subscriber line is 4.4 km, one of every two repeaters will be at a RDC, therefore no supplementary transmission line will be required. If the longest subscriber line is 2.2 km, every trunk repeater will be at a RDC and the average length of fiber required for the distribution will be less. A gain in system reliability can be achieved by having the trunk repeaters in the more controlled atmosphere of a RDC.

The amount of hardware required only for distribution inside the RDC distribution cell is independent of the number of channels available as shown in Table 4.10. However, for the trunk it strongly depends on the system number of channels, because SDM is used as shown in Table 4.11. Tables 4.10 and 4.11 are integrated to form Table 4.12 which represents the components count for the switched video grid distribution approach.

The components count for the linear distribution case is given in Table 4.13.

### 4.3.3 Components Count Conclusions

From Tables 4.2 - 4.13 the following conclusions can be drawn:

- Non-Switched Video Distribution

  - SDM should not be considered for CATV distribution in rural areas.

  - Optical tapping results in major savings in the number of sources and in the amount of fiber required, but it requires three times more repeaters in the field than electrical tapping. Although it should not have any significant effect on the system cost, fiber being the dominant cost factor, it could affect the system reliability. However, when electrical tapping is used, repeaters contain more active components, i.e. one light source per subscriber. This can affect also system reliability. Further study is needed before determining whether optical tapping results in a less reliable system.

  - FDM cannot be considered for systems having 21 or 35 channels.

  - WDM is the most attractive non-switched approach for systems having more than 12 channels, especially if optical tapping is used. If electrical tapping is used, the number of sources required could be annoying.

- For the uniform subscriber density model, linear distribution requires three to nine times more repeaters in the field. If electrical tapping is used, linear distribution requires significantly less fiber than grid distribution. If optical tapping is used, the difference between the two is marginal. Thus if optical tapping is used, grid distribution should be preferred for the uniform subscriber density model. If electrical tapping is used, a choice must be made depending on the tradeoff between the fiber cost and the system reliability with the repeater cost.

- Switched Grid Distribution

  - Optimum size of the distribution cell depends on the tradeoff between the distribution fiber cost and the cost of the video switch with the associated trunk.

  - The trunk cost per subscriber increases as the size of the distribution cell decreases. However there is a marginal difference in the required amounts of fiber and sources between the 5.2 and 4.4 km cases whereby the supplementary transmission line compensates for the decrease in the number of subscribers sharing the trunk cost. Thus a 4.4 km distribution cell should be preferred for system reliability reasons and system simplicity, i.e. no supplementary transmission line.

- Switched Linear Distribution

  - The cost of the trunk is important, but does not depend on the distribution length when supplementary transmission lines are not required. Thus the optimum size of the distribution length depends on the tradeoff between the fiber cost and the video switch cost.

- Switched vs Non-Switched

  - If electrical tapping is used for the non-switched approaches, the switched approach requires slightly more fiber than WDM or FDM, but less than SDM-FDM. However, WDM requires a large number of sources. Thus for systems having 21 or 35 channels, the switched approach should be preferred.

  - If optical tapping is used, WDM should be preferred for systems having 21 or 35 channels.

## 4.4 TECHNOLOGICAL CONSIDERATIONS

So far the availability of different approaches is assumed, without considering their technical feasibility in the near future. Here the likelihood of the realization of these different approaches and is assessed qualitatively and the required development work is outlined.

However experience with fiber optics applicable to CATV is limited and little effort is presently devoted to the development of fiber optics for analog broadband communication. Therefore this assessment is speculative to some degree.

4.4.1 Frequency Division Multiplexing (FDM)

The transmission of five FDM channels is considered feasible in the near term future, commercially within five years using linearized optical transmitters. A special frequency allocation scheme may be required in order to avoid the worst intermodulation beats. The transmission of 12 FDM channels is not considered impossible, but further improvements of the source intrinsic linearity and optical output power is required. Linearization techniques will also have to be used. It is believed that nothing could be gained by using a special carrier frequency allocation scheme for 12-channel systems. Thus it is doubtful that the transmission of 12 FDM video channels over long, repeatered lines will be feasible in the near term future unless major efforts are devoted to it.

The transmission of 21 or 35 FDM channels over long, repeatered lines is not considered possible with directly modulated semiconductor light sources. However, in Activity No. 5, the linearity requirements will be evaluated more precisely.

4.4.2 Wavelength Division Multiplexing (WDM)

The fabrication of light sources emitting at different wavelengths is well mastered. However, practical realizations of an efficient source combiner and of an efficient disperser have to be made. Integrated optics surely will bring answers to these problems, but it is believed that WDM could become practical without integrated optics. Since practically no effort is devoted presently to WDM for uni-fiber broadband communication, its feasibility for future CATV applications cannot be assessed. However it has a great potential for rural areas and the idea should be studied in more depth.

4.4.3 Video Switch

Video switches with the proper performance can already be built. However the development of a solid state video switch specially designed for large scale CATV application would be highly desirable. Furthermore, it would be desirable if its cost per subscriber did not depend on the total number of subscribers being served from the switch. Then its cost would not have to be justified by a minimum number of subscribers and it could be used in rural areas with low population densities.

4.4.4 Optical Tapping

A practical optical tap that could be installed in the field has yet to be developed. It seems that the intrinsic throughloss of the directional coupler could be very low, so the tap throughloss would consist mainly of the insertion loss of the two required connectors. Thus optical tapping is really limited by the connector technology.

## 4.5 CONCLUSIONS

For a given system number of channels (5, 12, 21, or 35), in order to choose the best systems approach, technically feasible approaches must be identified. This depends on the available technology, which is a function of the time frame considered and also how much development effort has been devoted to it. Once a set of possible approaches is compiled, they can be compared by using the results of the components count. However a weighting factor must be assigned to each component, e.g. the component cost, in order to adequately compare the different approaches.

Presently only the switched approach and the non-switched approach using SDM-FDM with electrical tapping are feasible. Based on the components count of Section 4.3, the switched approach would be the best one for CATV systems having 5, 12, 21 or 35 video channels and for a uniform subscriber density model. For a non-uniform subscriber density model, SDM-FDM could be preferred for systems having 5 or 12 channels, depending on the cost of a video switch.

In the near term future optical tapping and frequency division multiplexing of five channels may also become feasible. Thus, based on the components count, FDM with optical tapping should be preferred for a 5-channel system. The choice is not clear between SDM-FDM with optical tapping and switched with a 2.2 km distribution cell for 12 channel systems. For systems having 21 or 35 channels, the switched approach would be the best one.

At such time as WDM becomes feasible it could be preferred for system having 12, 21, or 35 video channels.

TABLE 4.2 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - GRID DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 5

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | .0070 | 2.14 | 1.007 | 1.007 | 1.007 | - | |
| FDM-O | .0197 | .63 | .3 | 1.020 | 1.020 | 1 | |
| WDM-E | .0030 | 3.15 | 5.0150 | 5.0150 | 1.015 | - | 1.003 DISP<br>1 P.S. |
| WDM-O | .0088 | .6 | 1.0 | 5.044 | 1.044 | 1 | 1.009 DISP<br>1 P.S. |
| SDM-E | .0030 | 15.75 | 5.0150 | 5.015 | 1.015 | - | 1 P.S. |
| SDM-O | .0088 | 3.0 | 1.0 | 5.044 | 1.044 | 5 | 1 P.S. |
| SDM-FDM-E | .0053 | 4.86 | 2.0106 | 2.0106 | 1.0106 | - | 1 P.S. |
| SDM-FDM-O | .0156 | 1.14 | .46 | 2.0312 | 1.0312 | 2 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.3 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - GRID DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 12

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | .017 | 1.44 | 1.017 | 1.017 | 1.017 | - | |
| FDM-O | .051 | .63 | .447 | 1.051 | 1.051 | 1 | |
| WDM-E | .003 | 3.15 | 12.036 | 12.036 | 1.036 | - | 1.003 DISP<br>1 P.S. |
| WDM-O | .0088 | .6 | 2.4 | 12.1056 | 1.1056 | 1 | 1.009 DISP<br>1 P.S. |
| SDM-E | .003 | 37.8 | 12.036 | 12.036 | 1.036 | - | 1 P.S. |
| SDM-O | .0088 | 7.2 | 2.4 | 12.1056 | 1.1056 | 12 | 1 P.S. |
| SDM-FDM-E | .0053 | 9.72 | 4.0212 | 4.0212 | 1.0212 | - | 1 P.S. |
| SDM-FDM-O | .0156 | 2.28 | .92 | 4.0624 | 1.0624 | 4 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.4 RURAL AREA – COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED – GRID DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 21

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | (not possible to reach the 57 km limit) | | | | | | |
| FDM-O | | | | | | | |
| WDM-E | .003 | 3.15 | 21.063 | 21.063 | 1.063 | – | 1.003 DISP<br>1 P.S. |
| WDM-O | .0088 | .60 | 4.2 | 21.185 | 1.185 | 1 | 1.009 DISP<br>1 P.S. |
| SDM-E | .003 | 66.15 | 21.063 | 21.063 | 1.063 | | 1 P.S. |
| SDM-O | .0081 | 12.6 | 4.2 | 21.185 | 1.185 | 21 | 1 P.S. |
| SDM-FDM-E | .0053 | 17.01 | 7.0371 | 7.0371 | 1.0371 | – | 1 P.S. |
| SDM-FDM-O | .0156 | 4.0 | 1.61 | 7.1092 | 1.1092 | 7 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.5 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - GRID DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 35

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | | | | | | | |
| | NOT POSSIBLE TO REACH 57 km LIMIT | | | | | | |
| FDM-O | | | | | | | |
| WDM-E | .003 | 3.15 | 35.105 | 35.105 | 1.105 | - | 1.003 DISP<br>1.0 P.S. |
| WDM-O | .0088 | .6 | 7.0 | 35.308 | 1.308 | 1 | 1.009 DISP<br>1.0 P.S. |
| SDM-E | .003 | 110.25 | 35.105 | 35.105 | 1.105 | - | 1 P.S. |
| SDM-O | .0088 | 21. | 7.0 | 35.308 | 1.308 | 35 | 1 P.S. |
| SDM-FDM-E | .0053 | 29.16 | 12.0636 | 12.0636 | 1.0636 | - | 1 P.S. |
| SDM-FDM-O | .016 | 6.84 | 2.76 | 12.1872 | 1.1872 | 12 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.6 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - LINEAR DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 5

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | .0516 | 1.17 | 1.0516 | 1.0516 | 1.0516 | - | - |
| FDM-O | .0516 | .5 | .198 | 1.0516 | 1.0516 | 1 | |
| WDM-E | .0337 | 1.59 | 5.1685 | 5.1685 | 1.1685 | - | 1.0337 DISP<br>1 P.S. |
| WDM-O | .0337 | .48 | .503 | 5.1685 | 1.1685 | 1 | 1.0337 DISP<br>1 P.S. |
| SDM-E | .0337 | 7.95 | 5.1685 | 5.1685 | 1.1685 | - | 1 P.S. |
| SDM-O | .0337 | 2.4 | .503 | 5.1685 | 1.1685 | 5 | 1 P.S. |
| SDM-FDM-E | .0447 | 2.58 | 2.0894 | 2.0894 | 1.0894 | - | 1 P.S. |
| SDM-FDM-O | .0447 | 1.0 | .323 | 2.0894 | 1.0894 | 2 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.7 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - LINEAR DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 12

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | .0816 | .89 | 1.0816 | 1.0816 | 1.0816 | - | - |
| FDM-O | .0816 | .53 | .3846 | 1.0816 | 1.0816 | 1 | |
| WDM-E | .0337 | 1.59 | 12.4044 | 12.4044 | 1.4044 | - | 1.0337 DISP<br>1 P.S. |
| WDM-O | .0337 | .48 | 1.208 | 12.4044 | 1.4044 | 1 | 1.0337 DISP<br>1 P.S. |
| SDM-E | .0337 | 19.08 | 12.4044 | 12.4044 | 1.4044 | - | 1 P.S. |
| SDM-O | .0337 | 5.76 | 1.208 | 12.4044 | 1.4044 | 12 | 1 P.S. |
| SDM-FDM-E | .0447 | 5.16 | 4.1788 | 4.1788 | 1.1788 | - | 1 P.S. |
| SDM-FDM-O | .0447 | 2.0 | .648 | 4.1788 | 1.1788 | 4 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.8 RURAL AREA - COMPONENT COUNT (PER SUBSCRIBER)
NON-SWITCHED - LINEAR DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 21

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | NOT POSSIBLE TO REACH THE 57 km LIMIT | | | | | | |
| FDM-O | | | | | | | |
| WDM-E | .0337 | 1.59 | 21.7077 | 21.7077 | 1.7077 | - | 1.0337 DISP<br>1 P.S. |
| WDM-O | .0337 | .48 | 2.115 | 21.7077 | 1.7077 | 1 | 1.0337 DISP<br>1 P.S. |
| SDM-E | .0337 | 33.39 | 21.7077 | 21.7077 | 1.7077 | - | 1 P.S. |
| SDM-O | .0337 | 10.08 | 2.115 | 21.7077 | 1.7077 | 21 | 1 P.S. |
| SDM-FDM-E | .0447 | 9.03 | 7.3129 | 7.3129 | 1.3129 | - | 1 P.S. |
| SDM-FDM-O | .0447 | 3.5 | 1.134 | 7.3129 | 1.3129 | 7 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.9 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
NON-SWITCHED - LINEAR DISTRIBUTION
NUMBER OF VIDEO CHANNELS: N = 35

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM-E | NOT POSSIBLE TO REACH THE 57 km LIMIT | | | | | | |
| FDM-O | | | | | | | |
| WDM-E | .0337 | 1.59 | 36.1795 | 36.1795 | 2.1795 | - | 1.0337 DISP<br>1 P.S. |
| WDM-O | .0337 | .48 | 3.525 | 36.1795 | 2.1795 | 1 | 1.0337 DISP<br>1 P.S. |
| SDM-E | .0337 | 55.65 | 36.1795 | 36.1795 | 2.1795 | - | 1 P.S. |
| SDM-O | .0337 | 16.8 | 3.525 | 36.1795 | 2.1795 | 35 | 1 P.S. |
| SDM-FDM-E | .0447 | 15.48 | 12.5364 | 12.5364 | .5364 | - | 1 P.S. |
| SDM-FDM-O | .0447 | 6.0 | 1.944 | 12.5364 | .5364 | 12 | 1 P.S. |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: OPTICAL DISPERSER

TABLE 4.10 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
SWITCHED - GRID DISTRIBUTION
DISTRIBUTION ONLY

| SUBSCRIBER LINE MAXIMUM LENGTH (km) | VIDEO SWITCH | FIBER (km) | SOURCE | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLERS |
|---|---|---|---|---|---|---|
| 5.2 | .00185 | 3.69 | 2 | 2 | 2 | 2 |
| 4.4 | .00258 | 3.16 | 2 | 2 | 2 | 2 |
| 2.2 | .01033 | 1.69 | 2 | 2 | 2 | 2 |

TABLE 4.11 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)
SWITCHED - GRID DISTRIBUTION
TRANSPORTATION TRUNK ONLY

| SUBSCRIBER LINE MAXIMUM LENGTH (km) | REPEATERS | NUMBER OF VIDEO CHANNELS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS |
|---|---|---|---|---|---|---|
| 5.2 | .00437 | 5 | .107 | .031 | .031 | .031 |
| | | 12 | .257 | .075 | .075 | .075 |
| | | 21 | .450 | .131 | .131 | .131 |
| | | 35 | .750 | .218 | .218 | .218 |
| 4.4 | .00517 | 5 | .114 | .026 | .026 | .026 |
| | | 12 | .272 | .062 | .062 | .062 |
| | | 21 | .477 | .109 | .109 | .109 |
| | | 35 | .795 | .181 | .181 | .181 |
| 2.2 | .01037 | 5 | .227 | .052 | .052 | .052 |
| | | 12 | .545 | .124 | .124 | .124 |
| | | 21 | .955 | .217 | .217 | .217 |
| | | 35 | 1.590 | .362 | .362 | .362 |

TABLE 4.12 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)

SWITCHED - GRID DISTRIBUTION

| SUBSCRIBER LINE MAXIMUM LENGTH (km) | VIDEO SWITCH | REPEATERS | NUMBER OF VIDEO CHANNELS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLERS |
|---|---|---|---|---|---|---|---|---|
| 5.2 | .00185 | .00437 | 5 | 3.80 | 2.031 | 2.031 | 2.031 | 2 |
| | | | 12 | 3.95 | 2.075 | 2.075 | 2.075 | 2 |
| | | | 21 | 4.14 | 2.131 | 2.131 | 2.131 | 2 |
| | | | 35 | 4.44 | 2.218 | 2.218 | 2.218 | 2 |
| 4.4 | .00258 | .00517 | 5 | 3.27 | 2.026 | 2.026 | 2.026 | 2 |
| | | | 12 | 3.43 | 2.062 | 2.062 | 2.062 | 2 |
| | | | 21 | 3.64 | 2.109 | 2.109 | 2.109 | 2 |
| | | | 35 | 3.96 | 2.181 | 2.181 | 2.181 | 2 |
| 2.2 | .0103 | .0103 | 5 | 1.92 | 2.052 | 2.052 | 2.052 | 2 |
| | | | 12 | 2.24 | 2.124 | 2.124 | 2.124 | 2 |
| | | | 21 | 2.65 | 2.217 | 2.217 | 2.217 | 2 |
| | | | 35 | 3.28 | 2.362 | 2.362 | 2.362 | 2 |

TABLE 4.13 RURAL AREA - COMPONENTS COUNT (PER SUBSCRIBER)

SWITCHED - LINEAR DISTRIBUTION

| SUBSCRIBER LINE MAXIMUM LENGTH (km) | VIDEO SWITCH | REPEATERS | NUMBER OF VIDEO CHANNELS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLERS |
|---|---|---|---|---|---|---|---|---|
| 5.2 | .0154 | .0364 | 5 | 3.73 | 2.259 | 2.259 | 2.259 | 2 |
| | | | 12 | 4.98 | 2.622 | 2.622 | 2.622 | 2 |
| | | | 21 | 6.59 | 3.089 | 3.089 | 3.089 | 2 |
| | | | 35 | 9.09 | 3.813 | 3.813 | 3.813 | 2 |
| 4.4 | .0182 | .0364 | 5 | 3.24 | 2.182 | 2.182 | 2.182 | 2 |
| | | | 12 | 4.36 | 2.437 | 2.437 | 2.437 | 2 |
| | | | 21 | 5.80 | 2.764 | 2.764 | 2.764 | 2 |
| | | | 35 | 8.04 | 3.274 | 3.274 | 3.274 | 2 |
| 2.2 | .0364 | .0364 | 5 | 2.23 | 2.182 | 2.182 | 2.182 | 2 |
| | | | 12 | 3.64 | 2.437 | 2.437 | 2.437 | 2 |
| | | | 21 | 5.09 | 2.764 | 2.764 | 2.764 | 2 |
| | | | 35 | 7.59 | 3.274 | 3.274 | 3.274 | 2 |

# 5. CATV DISTRIBUTION IN SUBURBAN AREAS

## 5.1 CHARACTERIZATION OF THE SUBURBAN DISTRIBUTION AREA

For suburban areas, a uniform subscriber density model is used. A subscriber density of 300 subscribers per km square is assumed typical. Each subscriber is placed at the center of a 58 meters square lot. Subscribers living on each side of a street face each other, as opposed to the rural areas model where they were not allowed to face each other. This model is illustrated in Fig. 5.1. A total of 50,000 subscribers are included in a circle of 7.3 km radius, which justifies the installation of a CATV distribution system.

In the event that suburban areas extend over distances longer than 14.6 km, then a high quality transportation trunk can be used to take the signals to a distribution center placed at the center of another 7.3 km radius distribution area. Section 2 shows that high quality fiber optics transportation trunks could be as long as 57 km, and that their cost, once shared by 50,000 subscribers, should not be significant.

## 5.2 POSSIBLE NETWORK CONFIGURATIONS

Unlike rural areas, it is not necessary to maximize the repeater spacings and the size of the distribution cells, because the subscriber density can justify more electronics per unit of area on a cost and reliability basis. Also, because transmission performance requirements are relaxed, transmission line maximum length is only 10.3 km instead of 57 km.

Two approaches to CATV distribution in suburban areas are considered that should permit reduction of the amount of fiber required per subscriber. These are the use of small distribution cells with a distribution hub placed at the center, and the use of optical feeders with amplifiers.

### 5.2.1 Distribution Hub Approach

The expression 'distribution hub' for the central point of the suburban distribution cell is preferred because, as opposed to rural areas, the distribution cells will not always be centered on a distribution trunk repeater.

CATV signals will be brought to the distribution hub from the nearest distribution trunk repeater. The maximum length for a non repeatered transmission line going from a repeater to a distribution hub is at least equal to the repeater spacing on the distribution trunk. Thus each distribution trunk repeater covers an area fixed by the repeater spacing. This distribution area is divided into smaller parts, each of which is covered by a distribution hub as illustrated in Fig. 5.2.

The SNR of signals brought to the distribution hub is set at 43 dB minimum. Therefore the distribution trunk should be designed to meet a SNR objective of 43 dB over a length of 10.3 km plus one repeater spacing, which corresponds to the worst case situation. The SNR transmission objective within a distribution cell must also be 43 dB in order to give an overall SNR

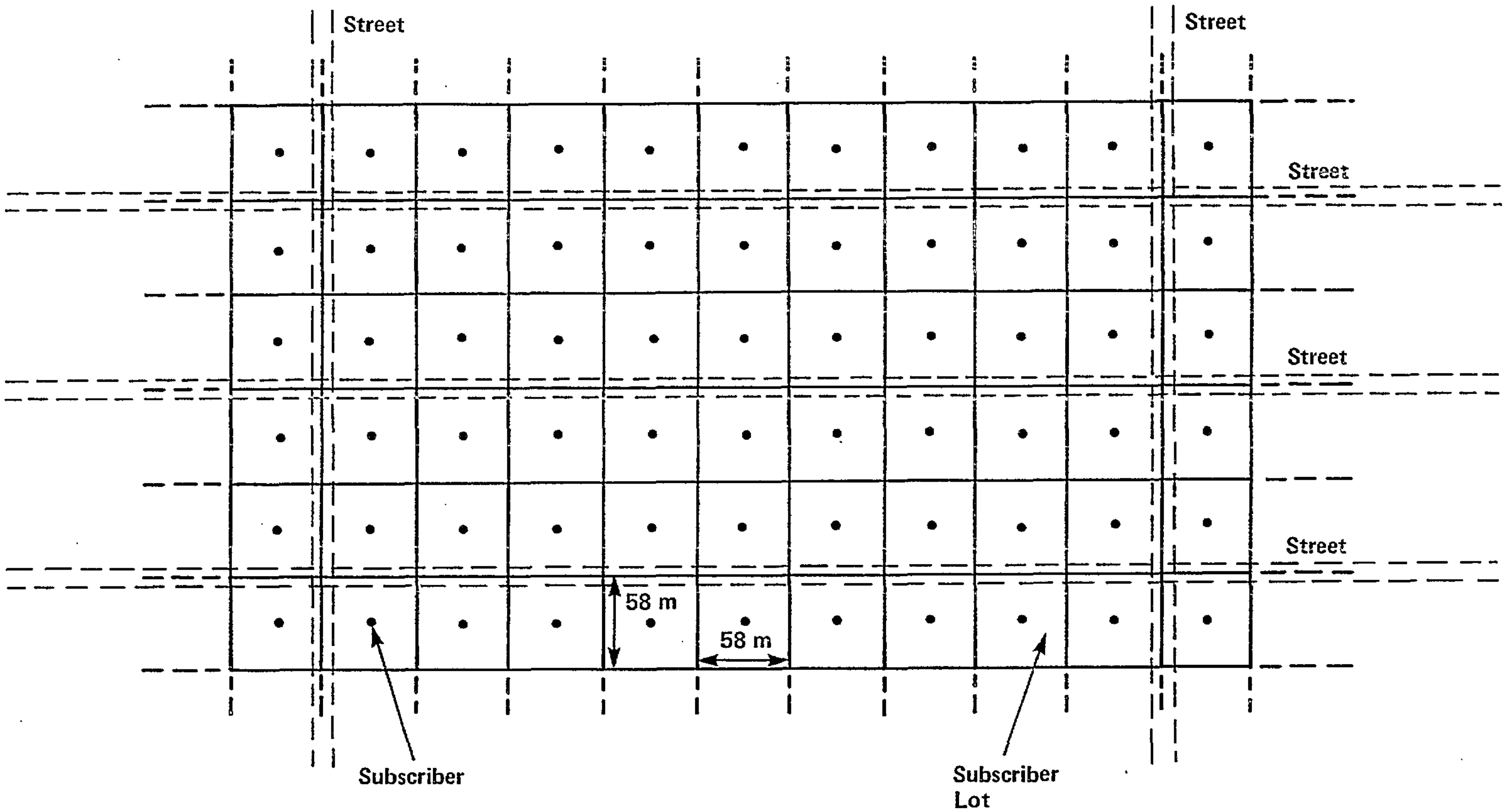



**Figure 5.1 Suburban Area Model**

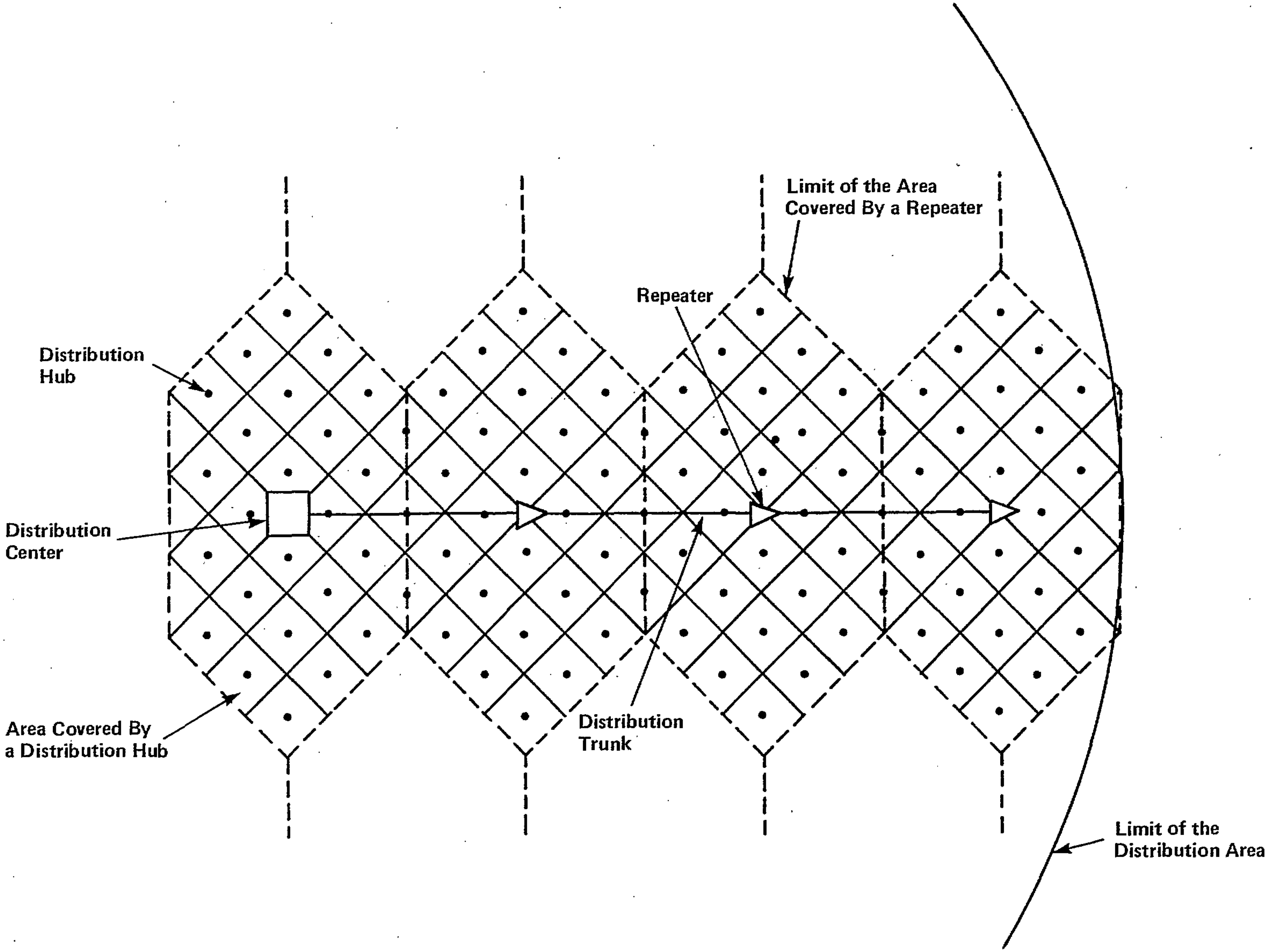



Figure 5.2 Distribution Hub Approach

of 40 dB at the subscriber set.

Signals can be brought from a distribution trunk repeater to a distribution hub either by a special transmission line joining only the two, or by a transmission line joining a series of distribution hubs, with a repeater at each hub. This latter approach does not result in a signal with a SNR of less than 43 dB at the last distribution hub. Because the distance between distribution hubs is much less than the repeater spacing on the distribution trunk, this transmission line is of very high quality, and does not significantly degrade the signal for lengths of less than one repeater spacing.

Since a power amplifier is required in either case for redistributing signals to the subscribers, there is no difference between the two approaches in the number of sources, photodiodes, and amplifiers required. Thus the approach consisting of joining the distribution hubs in series should be preferred because it requires less fiber.

The distribution within the distribution cell can be done using either the switched or the non-switched approaches. For the non-switched approaches, optical tapping or electrical tapping can be used.

### 5.2.2 Optical Feeder with Amplifiers

In suburban areas the optical loss between optical taps will be smaller than in rural areas. Furthermore, in suburban areas subscribers can share an optical tap - sharing also its throughloss - without increasing significantly the optical loss of their drop. Thus the use of feeders with amplifiers as defined in section 3.1 could become attractive.

If the distribution follows the four main axes of the circle, the maximum length of transmission line required to reach a subscriber at 7.3 km from the distribution center is 10.3 km. In this network approach the distribution trunks follow the four main axes of the distribution circle and the longest feeder tapped length is 5.15 km, as illustrated in Fig. 5.3.

Note that this network configuration applies only to non-switched video distribution systems.

## 5.3 COMPONENTS COUNT

The amounts of hardware required for systems having 12, 21 and 35 video channels are evaluated. Components counts are made for the network approaches considered in this section and for the different network configurations and system approaches considered in Section 3.

### 5.3.1 Assumptions and Evaluation Methods

The following assumptions are made:

- BP23 must be met at the subscriber's TV set.
- Presently available TV sets (VHF-UHF input) must also be served. This implies that all video channels are transmitted on low

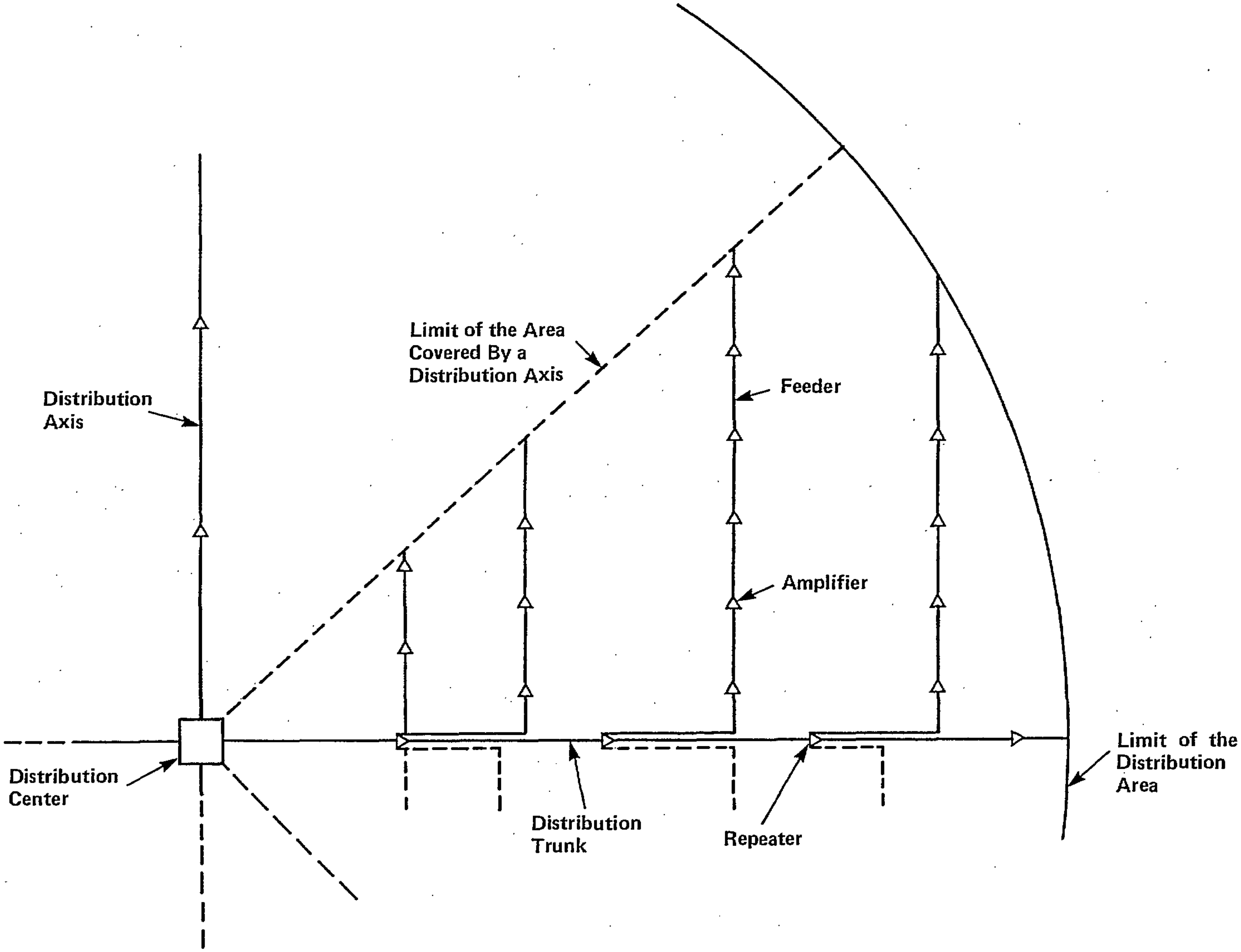



Figure 5.3 Optical Feeder With Amplifiers Approach

frequency modulated carriers.

- For the video switched approach, two video channels are transmitted at a time to the subscriber.

- For the switched video approach a SDM line is used for bringing the signals to the distribution hub.

- For the non-switched approach using SDM-FDM, up to three video channels are multiplexed on a fiber.

- Transmission performances are limited only by noise. The source linearity is assumed sufficient for the moment. This is discussed in detail in 5.4.

- Longest transmission line occuring in the system is 10.3 km from the distribution center to the furthest subscriber.

- If optical tapping is used, each tap serves four subscribers and the drops are 41 m long.

- Optical signal power coupled into the fiber by each light source is 1 mW peak-to-peak, more specifically, 0.667 mW mean optical power with an optical modulation index of 0.75.

- Fiber attenuation is 5 dB/km, including connectors and splice losses.

- Fiber attenuation is 5 dB/km, including connectors and splice losses.

- Connector and splice losses are 0.5 dB.

- Directional coupler intrinsic throughloss is 0.5 dB.

- Coupling ratio of directional couplers can be finely adjusted for each subscriber's needs.

- Two connectors are required for each tap, so the tap throughloss is 1.5 dB.

- Two connectors are also required for each subscriber drop, so the drop loss is 1.2 dB.

- Video switches and subscriber signal compatibility module do not introduce significant degradations to the signals.

For the distribution hub approach, the distribution trunk is considered separately and its components are proportionnally allocated to every subscriber in the distribution area. The components count for the distribution inside a distribution cell is done similarly to the method used for rural areas as given in section 4.3.1, except that the distribution cell is a diamond, even for electrical tapping.

For the optical feeder with amplifiers approach, the calculations are based on Appendix B analysis. Refer to Appendix D for complete details.

5.3.2 Components Count Results

For the distribution hub approach, different sizes of distribution cell are considered to show the influence of size on the amount of hardware required. Four different sizes are considered: 8 square km - 2400 subscribers, 2 square km - 600 subscribers, 0.5 square km - 150 subscribers, 0.125 square km - 38 subscribers. The subscriber line maximum lengths are 2, 1, 0.5, and 0.25 km respectively.

The distribution trunk is shared by all of the 50,000 subscribers and does not depend on the size of the distribution cell. Therefore the components count for the distribution trunk is given separately for the different system numbers of video channels in Tables 5.1 - 5.3. The total system components counts per subscriber, including the distribution trunk, for each distribution cell size are given in Tables 5.4 - 5.6.

For the optical feeder with amplifiers approach, the results are given in Tables 5.7 - 5.9. Since with this approach the required number of trunk repeaters is largely dominated by the number of feeder repeaters, the components count of the distribution trunk will not influence the total system components count on a per subscriber basis.

5.3.3 Components Count Conclusions

The following conclusions are made regarding the distribution hub approach.

- Distribution trunk is not significant.

- SDM should not be considered for CATV distribution in suburban areas.

- FDM has limited transmission capability, especially when optical tapping is used. This limits the size of the distribution cell and results in a higher cost per subscriber of the distribution hub.

- When electrical tapping is used, decreasing the size of the distribution cell also decreases the amount of fiber required. However, electrical tapping requires many sources, especially for WDM and SDM. Therefore sources could become a major cost factor in a system using electrical tapping.

- Optical tapping requires less fiber and fewer sources than electrical tapping, but puts more stringent requirements on the system transmission capability. Based on the components count, e.g. FDM, a 600 subscriber distribution cell is optimum for suburban areas if the cost of the distribution hub per subscriber is negligible relative to the fiber cost.

- Based on the components count, optical tapping should be preferred for CATV ditribution in suburban areas.

The following conclusions are made regarding an approach based on optical feeders with amplifiers:

- FDM and WDM require less fiber.

- WDM and SDM require fewer repeaters.

- FDM requires the least number of photodiodes and sources.

- FDM or WDM should be chosen, depending on the relative costs of repeaters, sources, and photodiodes.

NOTE: When comparing sources costs, it may happen that the cost of a linearized FDM transmitter will be about the same as the cost of a WDM transmitter with its N sources. Thus if the differences in source costs are negligible, WDM should be preferred.

The following conclusions are made regarding a comparison of distribution hub vs optical feeder with amplifiers.

- The difference in fiber required between the distribution hub approach using optical tapping and the optical feeder with amplifiers is marginal.

- The cost of a distribution hub should be comparable to the cost of repeaters. Thus the distribution hub approach should be preferred to the optical-feeder-with-amplifiers approach since the hubs/subscriber ratio is much smaller than the repeaters/subscriber ratio.

## 5.4 TECHNOLOGICAL CONSIDERATIONS

These are basically the same as for the rural area case, Section 4.4, except that requirements on the source linearity for FDM transmission are somewhat relaxed because transmission lines are shorter. Shorter transmission lines imply less repeaters in tandem, so the cumulative effect of repeater non-linearities is less important than in rural areas. Thus the end-to-end transmission objectives can be met with less linear devices. Source linearity requirements are evaluated more precisely in Activity No. 5. Also, for FDM transmission, the optical power coupled into the fiber will need to be increased if optical tapping is used.

## 5.5 CONCLUSIONS

For suburban areas, two network configurations can be considered: the distribution-hub approach and the optical-feeder-with-amplifiers approach. The distribution-hub approach should be preferred because it is believed that distribution hubs will be cheaper than repeaters on a per subscriber basis. This statement should be verified in a more extensive system cost analysis. Also the distribution hub approach should result in a more reliable system because the network has fewer active points.

Before deciding between the switched and the different non-switched approaches, the ones that are technically feasible must be identified. Then they can be compared using the components count results with the proper component weighting factors,

In the identification of suitable system approaches, factors other than the technical feasibility could be considered, such as compatibility with expected future changes in the service provided to the subscribers. The technical feasibility depends on the time frame of the system implementation and also on how much development work is devoted to the different approaches.

Presently, switched video distribution would be the best approach for providing CATV services in suburban areas. Also, due to the higher population density, the cost of the distribution hub with the video switch would be more easy to justify for suburban areas than for rural areas. In future, if the potential of FDM, WDM and optical tapping are developed, the non-switched approach should reveal itself to be more economical for providing CATV service as defined in Section 1.1.

TABLE 5.1 SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 12

DISTRIBUTION TRUNK ONLY

| APPROACH | REPEATERS | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | OTHER |
|---|---|---|---|---|---|---|
| FDM | .00033 | .00086 | .00033 | .00033 | .00033 | |
| WDM | .00008 | .00043 | .00100 | .00100 | .00100 | .0008 DISP. |
| SDM SWITCHED | .00008 | .00516 | .00100 | .00100 | .00100 | |
| SDM-FDM | .00013 | .00216 | .00052 | .00052 | .00052 | |

DISP: DISPERSER

TABLE 5.2 SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)

DISTIRBUTION HUB - N = 21

DISTRIBUTION TRUNK ONLY

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | OTHER |
|---|---|---|---|---|---|---|
| FDM | .00069 | .00124 | .00069 | .00069 | .00069 | |
| WDM | .00008 | .00043 | .00174 | .00174 | .00174 | .0008 DISP. |
| SDM SWITCHED | .00008 | .00903 | .00174 | .00174 | .00174 | |
| SDM-FDM | .00013 | .00378 | .00093 | .00093 | .00093 | |

DISP: DISPERSER

TABLE 5.3 SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)

DISTIRBUTION HUB - N = 35

DISTRIBUTION TRUNK ONLY

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | OTHER |
|---|---|---|---|---|---|---|
| FDM | .00155 | .00186 | .00155 | .00155 | .00155 | |
| WDM | .00008 | .00043 | .00291 | .00291 | .00291 | .00008 DISP. |
| SDM SWITCHED | .00008 | .01505 | .00291 | .00291 | .00291 | |
| SDM-FMD | .00013 | .00648 | .00160 | .00160 | .00160 | |

DISP: DISPERSER

TABLE 5.4 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 12

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| FDM-E | 2.0 | .00042 | .00033 | 1.38 | 1.001 | 1.001 | 1.001 | - | |
| | 1.0 | .00168 | | 0.71 | 1.002 | 1.002 | 1.002 | | |
| | 0.5 | .00667 | | 0.38 | 1.007 | 1.007 | 1.007 | | |
| | 0.25 | .02667 | | .21 | 1.027 | 1.027 | 1.027 | | |
| FDM-O | 2.0 | .00042 | .00033 | - | - | - | - | | |
| | 1.0 | .00168 | | - | - | - | - | | |
| | 0.5 | .00667 | | .10 | .110 | 1.007 | 1.007 | .25 | |
| | 0.25 | .02667 | | .10 | .214 | 1.027 | 1.027 | .25 | |
| WDM-E | 2.0 | .00042 | .00008 | 1.38 | 12.006 | 12.006 | 1.006 | | 1 P.S. + 1.001 DISP |
| | 1.0 | .00168 | | .71 | 12.021 | 12.021 | 1.021 | | 1.002 DISP |
| | 0.5 | .00667 | | .38 | 12.081 | 12.081 | 1.081 | | 1.007 DISP |
| | 0.25 | .02667 | | .21 | 12.320 | 12.320 | 1.320 | | 1.027 DISP |
| WDM-O | 2.0 | .00042 | .00008 | .17 | .857 | 12.006 | 1.006 | .25 | 1 P.S. + 1.001 DISP |
| | 1.0 | .00168 | | .10 | .645 | 12.021 | 1.021 | | 1.002 DISP |
| | .5 | .00667 | | .10 | 1.389 | 12.081 | 1.081 | | 1.007 DISP |
| | .25 | .02667 | | .10 | 2.564 | 12.320 | 1.320 | | 1.027 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP: DISPERSER

TABLE 5.4 SUBURBAN AREA _ COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N - 12

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| SDM-E | 2. | .00042 | .00008 | 16.56 | 12.006 | 12.006 | 1.006 | - | 1 P.S. |
| | 1. | .00168 | | 8.52 | 12.021 | 12.021 | 1.021 | | |
| | .5 | .00667 | | 4.56 | 12.081 | 12.081 | 1.081 | | |
| | .25 | .02667 | | 2.52 | 12.320 | 12.320 | 1.320 | | |
| SDM-O | 2.0 | .00042 | .00008 | 2.04 | .857 | 12.006 | 1.006 | 3.0 | 1 P.S. |
| | 1.0 | .00168 | | 1.20 | .645 | 12.021 | 1.021 | | |
| | 0.5 | .00667 | | 1.20 | 1.389 | 12.081 | 1.081 | | |
| | 0.25 | .02667 | | 1.20 | 2.564 | 12.320 | 1.320 | | |
| SDM-FDM-E | 2.0 | .00042 | .00013 | 5.52 | 4.002 | 4.002 | 1.002 | | 1 P.S. |
| | 1.0 | .00168 | | 2.84 | 4.007 | 4.007 | 1.007 | | |
| | 0.5 | .00667 | | 1.51 | 4.027 | 4.027 | 1.027 | | |
| | 0.25 | .02667 | | .80 | 4.106 | 4.106 | 1.106 | | |
| SDM-FDM-O | 2.0 | .00042 | .00013 | - | - | - | - | 1.0 | 1 P.S. |
| | 1.0 | .00168 | | .46 | .368 | 4.007 | 1.007 | | |
| | 0.5 | .00667 | | .48 | .388 | 4.027 | 1.027 | | |
| | 0.25 | .02667 | | .50 | .464 | 4.106 | 1.106 | | |
| SWITCHED VIDEO | 2.0 | .00042 | .00008 | 1.40 | 2.006 | 2.006 | 2.006 | 2. | |
| | 1.0 | .00168 | | .75 | 2.021 | 2.021 | 2.021 | 2. | |
| | 0.5 | .00667 | | .45 | 2.081 | 2.081 | 2.081 | 2. | |
| | 0.25 | .02667 | | .36 | 2.320 | 2.320 | 2.320 | 2. | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.5 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 21

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| FDM-E | 2.0 | .00042 | - | - | - | - | - | | |
| | 1.0 | .00168 | .0069 | .71 | 1.003 | 1.003 | 1.003 | | |
| | .5 | .00667 | | .38 | 1.008 | 1.008 | 1.008 | | |
| | .25 | .02667 | | .21 | 1.028 | 1.028 | 1.028 | | |
| FDM-O | 2.0 | .00042 | .00069 | - | - | - | - | | |
| | 1.0 | .00168 | | - | - | - | - | | |
| | 0.5 | .00667 | | .11 | .164 | 1.008 | 1.008 | .25 | |
| | 0.25 | .02667 | | .10 | .214 | 1.028 | 1.028 | .25 | |
| WDM-E | 2.0 | .00042 | .00008 | 1.38 | 21.010 | 21.010 | 1.010 | | 1 P.S.+ 1.001 DISP |
| | 1.0 | .00168 | | .71 | 21.037 | 21.037 | 1.037 | | 1.002 DISP |
| | 0.5 | .00667 | | .38 | 21.142 | 21.142 | 1.142 | | 1.007 DISP |
| | 0.25 | .02667 | | .21 | 21.560 | 21.560 | 1.560 | | 1.027 DISP |
| WDM-O | 2.0 | .00042 | .00008 | .17 | 1.500 | 21.010 | 1.010 | | 1 P.S.+ 1.001 DISP |
| | 1.0 | .00168 | | .10 | 1.129 | 21.037 | 1.037 | | 1.002 DISP |
| | .5 | .00667 | | .10 | 2.431 | 21.142 | 1.142 | | 1.007 DISP |
| | .25 | .02667 | | .10 | 4.487 | 21.560 | 1.560 | | 1.027 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.5 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 21

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| SDM-E | 2.0 | .00042 | .00008 | 29.98 | 21.010 | 21.010 | 1.010 | | 1 P.S. |
| | 1.0 | .00168 | | 14.91 | 21.037 | 21.037 | 1.037 | | |
| | 0.5 | .00667 | | 7.98 | 21.142 | 21.142 | 1.142 | | |
| | .25 | .02667 | | 4.41 | 21.560 | 21.560 | 1.560 | | |
| SDM-O | 2.0 | .00042 | .00008 | 3.57 | 1.500 | 21.010 | 1.010 | 5.25 | 1 P.S |
| | 1.0 | .00168 | | 2.10 | 1.129 | 21.037 | 1.037 | | |
| | 0.5 | .00667 | | 2.10 | 2.431 | 21.142 | 1.142 | | |
| | .25 | .02667 | | 2.10 | 4.487 | 21.560 | 1.560 | | |
| SDM-FDM-E | 2.0 | .00042 | .00013 | 9.66 | 7.004 | 7.004 | 1.004 | | 1 P.S. |
| | 1.0 | .00168 | | 4.97 | 7.012 | 7.012 | 1.012 | | |
| | 0.5 | .00667 | | 2.64 | 7.047 | 7.047 | 1.047 | | |
| | .25 | .02667 | | 1.4 | 7.186 | 7.186 | 1.186 | | |
| SDM-FDM-O | 2.0 | .00042 | .00013 | - | - | - | - | | |
| | 1.0 | .00168 | | .80 | .644 | 7.012 | 1.012 | 1.75 | 1 P.S. |
| | 0.5 | .00667 | | .84 | .679 | 7.047 | 1.047 | | |
| | .25 | .02667 | | .87 | .812 | 7.186 | 1.186 | | |
| SWITCHED VIDEO | 2.0 | .00042 | .00008 | 1.42 | 2.010 | 2.010 | 2.010 | 2.0 | |
| | 1.0 | .00168 | | .78 | 2.037 | 2.037 | 2.037 | 2.0 | |
| | 0.5 | .00667 | | .51 | 2.142 | 2.142 | 2.142 | 2.0 | |
| | .25 | .02667 | | .48 | 2.560 | 2.560 | 2.560 | 2.0 | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.6 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 35

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| FDM-E | 2.0 | .00042 | .00155 | - | - | - | - | - | |
| | 1.0 | .00168 | | .71 | 1.003 | 1.003 | 1.003 | | |
| | .5 | .00667 | | .38 | 1.008 | 1.008 | 1.008 | | |
| | .25 | .02667 | | .21 | 1.028 | 1.028 | 1.028 | | |
| FDM-O | 2.0 | .00042 | .00155 | - | - | - | - | - | |
| | 1.0 | .00168 | | - | - | - | - | - | |
| | .5 | .00667 | | .15 | .241 | 1.008 | 1.008 | .25 | |
| | .25 | .02-67 | | .11 | .215 | 1.028 | 1.028 | .25 | |
| WDM-E | 2.0 | .00042 | .00008 | 1.38 | 35.017 | 35.017 | 1.017 | | 1 P.S. + 1.001 DISP |
| | 1.0 | .00168 | | .71 | 35.062 | 35.062 | 1.062 | | 1.002 DISP |
| | 0.5 | .00667 | | .38 | 35.237 | 35.237 | 1.237 | | 1.007 DISP |
| | 0.25 | .02667 | | .21 | 35.933 | 35.933 | 1.933 | | 1.027 DISP |
| WDM-O | 2.0 | .00042 | .00008 | .17 | 2.500 | 35.017 | 1.017 | .25 | 1 P.S. + 1.001 DISP |
| | 1.0 | .00168 | | .10 | 1.882 | 35.062 | 1.062 | | 1.002 DISP |
| | 0.5 | .00667 | | .10 | 4.052 | 35.237 | 1.237 | | 1.007 DISP |
| | 0.25 | .02667 | | .10 | 7.478 | 35.933 | 1.933 | | 1.027 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.6 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 35

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | TRUNK REPEATERS | FIBER (km) | SOURCE | PHOTODIODE | AMPLIFIER | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|---|
| SDM-E | 2.0 | .00042 | .00008 | 48.30 | 35.017 | 35.017 | 1.017 | | 1 P.S. |
| | 1.0 | .00168 | | 24.85 | 35.062 | 35.062 | 1.062 | | |
| | .5 | .00667 | | 13.3 | 35.237 | 35.237 | 1.237 | | |
| | .25 | .02667 | | 7.35 | 35.933 | 35.933 | 1.933 | | |
| SDM-0 | 2.0 | .00042 | .00008 | 5.95 | 2.500 | 35.017 | 1.017 | 8.75 | 1 P.S. |
| | 1.0 | .00168 | | 3.50 | 1.882 | 35.062 | 1.062 | | |
| | .5 | .00667 | | 3.50 | 4.052 | 35.237 | 1.237 | | |
| | .25 | .02667 | | 3.50 | 7.478 | 35.933 | 1.933 | | |
| SDM-FDM-E | 2.0 | .00042 | .00013 | 16.56 | 12.007 | 12.007 | 1.007 | | 1 P.S. |
| | 1.0 | .00168 | | 8.52 | 12.021 | 12.021 | 1.021 | | |
| | 0.5 | .00667 | | 4.53 | 12.081 | 12.081 | 1.081 | | |
| | 0.25 | .02667 | | 2.40 | 12.319 | 12.319 | 1.319 | | |
| SDM-FDM-0 | 2.0 | .00042 | .00013 | - | - | - | - | | |
| | 1.0 | .00168 | | 1.37 | 1.104 | 12.021 | 1.021 | 3.0 | 1 P.S. |
| | 0.5 | .00667 | | 1.44 | 1.164 | 12.081 | 1.081 | | |
| | 0.25 | .02667 | | 1.49 | 1.392 | 12.319 | 1.319 | | |
| SWITCHED VIDEO | 7.0 | .00042 | .00008 | 1.43 | 2.017 | 2.017 | 2.017 | 2.0 | |
| | 1.0 | .00168 | | .72 | 2.062 | 2.062 | 2.062 | 2.0 | |
| | 0.5 | .00667 | | .60 | 2.237 | 2.237 | 2.237 | 2.0 | |
| | 0.25 | .02667 | | .66 | 2.933 | 2.933 | 2.933 | 2.0 | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.7 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 12

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .036 | .070 | .036 | 1.036 | 1.036 | .25 | |
| WDM | .019 | .070 | .228 | 12.228 | 1.228 | .25 | 1.019 DISP<br>1 P.S. |
| SDM | .019 | .840 | .228 | 12.228 | 1.228 | 3.0 | 1 P.S. |
| SDM-FDM | .023 | .280 | .092 | 4.092 | 1.092 | 1.0 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.8 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 21

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .036 | .070 | .036 | 1.036 | 1.036 | .25 | |
| WDM | .019 | .070 | .399 | 21.399 | 1.399 | .25 | 1.019 DISP<br>1 P.S. |
| SDM | .019 | 1.47 | .399 | 21.399 | 1.399 | 5.25 | 1 P.S. |
| SDM-FDM | .023 | .490 | .161 | 7.161 | 1.161 | 1.75 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 5.9 SUBURBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 35

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .036 | .070 | .036 | 1.036 | 1.036 | .25 | |
| WDM | .019 | .070 | .665 | 35.665 | 1.665 | .25 | 1.019 DISP<br>1 P.S. |
| SDM | .019 | 2.45 | .665 | 35.665 | 1.665 | 8.75 | 1 P.S. |
| SDM-FDM | .023 | .84 | .276 | 12.276 | 1.276 | 3.0 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

# 6. CATV DISTRIBUTION IN URBAN AREAS

## 6.1 CHARACTERIZATION OF THE URBAN DISTRIBUTION AREA

For the urban distribution area, a uniform subscriber density model is used. A density of 5000 subscribers per square km is assumed. Four subscribers share a 28 m square lot and each subscriber is placed at the center of the lot. This lot model simulates a typical urban apartment building.

A 1.8 km radius distribution area with 50,000 subscribers is considered. Urban areas can extend over distances greater than 3.6 km, in which case a high quality transportation trunk could feed the different distribution centers required to cover the total urban area.

## 6.2 POSSIBLE NETWORK CONFIGURATIONS

The same basic network configurations that were used for suburban areas are considered here. These are the distribution-hub approach and the optical-feeder-with-amplifiers approach described in Section 5.2. Unlike suburban areas, a distribution trunk is not required for either network configuration. The maximum tapped feeder length becomes 2.5 km, if the optical feeder approach is used.

## 6.3 COMPONENTS COUNT

CATV systems providing 12, 21, and 35 video channels are considered. Components counts are made for the two network configurations and for the different system approaches considered in Section 3.

### 6.3.1. Assumptions and Evaluation Methods

The assumptions are the same as for suburban areas, except that, in the case of optical tapping, 16 subscribers are served by each tap and the drops are 20 m long. This results in a drop loss of 1.1 dB, including the two connector losses. The same evaluation methods are used as for suburban areas, Section 5.3.1, except that the part concerning the distribution trunk does not apply here. Refer to appendix E for details of evaluation method.

### 6.3.2 Components Count Results

For the distribution hub approach, the components counts are made for four different sizes of distribution cell. The four cells considered contain, respectively 10,000, 2500, 625, and 156 subscribers. Their corresponding line maximum lengths are respectively, 1.0, 0.5, 0.25, and 0.125 km. Results are given as a function of the system number of video channels in Tables 6.1 - 6.3. For the optical feeder with amplifiers approach, the results are given in Tables 6.4 - 6.6.

### 6.3.3 Components Count Conclusions

The following conclusions are made regarding the distribution hub approach:

- Optical tapping requires far fewer sources and much less fiber than electrical tapping. Therefore it should be preferred.

- When optical tapping is used, the expected fiber cost becomes marginal. Thus the system cost is dominated by the cost of sources and by the cost of the electronics in general.

- FDM is limited to 12 channels and to small distribution cells when optical tapping is used.

- There is an optimum distribution cell size as far as the number of sources and the amount of fiber required are concerned.

For a system using optical feeders with amplifiers, based on the components count, FDM and WDM are the best approaches. The choice between the two depends on the relative cost of the repeaters, sources, photodiodes, and associated electronics.

A comparison between distribution-hub vs optical-feeder-with-amplifiers approaches show the following:

- The difference in the amounts of fiber required is marginal.

- The optical feeder approach requires more repeaters than the distribution hub approach requires hubs, once optimized. However the distribution hub requires more sources and sources could cost more than repeaters on a per subscriber basis. Thus it is not possible at this point to prefer one network approach over the other.

## 6.4 TECHNOLOGICAL CONSIDERATIONS

The technological considerations for CATV distribution in urban areas are basically the same as for suburban areas and nothing specific to urban areas can be added.

## 6.5 CONCLUSIONS

The choice between the two possible network configurations for non-switched systems would require an evaluation of their respective costs. However, reliability considerations would favor the distribution hub approach because it requires fewer active points in the network.

The components count for urban areas indicates that fiber cost may no longer be the dominant system cost factor. Moreover, installation costs in urban areas could dominate the hardware cost and will not be necessarily a function of the amount of hardware required. Thus, especially for urban areas, factors other than the amount of hardware required should be considered before deciding on the system approach.

Again the feasibility of the different system approaches will depend on the time frame considered. Presently the switched video distribution system is the most feasible approach.

The high subscriber density makes it easy to justify the cost of the video switch. Also the cost of the subscriber line should not be excessive. For a 10,000 subscriber system, an average fiber length of 0.68 km is required per subscriber. Furthermore, a single video switch placed at the distribution center could serve the whole distribution area, using only presently available LED sources.

In future, if FDM, WDM and optical tapping are developed, they could be used in CATV distribution systems. They possibly could provide the CATV service, as defined in Section 1, more economically than the switched approach.

TABLE 6.1 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 12

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| FDM-E | 1.0 | .0001 | .69 | 1.0001 | 1.0001 | 1.0001 | | |
| | .5 | .0004 | .35 | 1.0004 | 1.0004 | 1.0004 | | |
| | .25 | .0016 | .19 | 1.0016 | 1.0016 | 1.0016 | | |
| | .125 | .0064 | .10 | 1.0064 | 1.0064 | 1.0064 | | |
| FDM-O | 1.0 | .0001 | - | - | - | - | | |
| | .5 | .0004 | - | - | - | - | | |
| | .25 | .0016 | .03 | .060 | 1.0016 | 1.0016 | .0625 | |
| | .125 | .0064 | .03 | .053 | 1.0064 | 1.0064 | | |
| WDM-E | 1.0 | .0001 | .69 | 12.0012 | 12.0012 | 1.0012 | | 1 P.S. + 1.001 DISP |
| | .5 | .0004 | .35 | 12.0048 | 12.0048 | 1.0048 | | 1.004 DISP |
| | .25 | .0016 | .19 | 12.0192 | 12.0192 | 1.0192 | | 1.0016 DISP |
| | .125 | .0064 | .10 | 12.0768 | 12.0768 | 1.0768 | | 1.0064 DISP |
| WDM-O | 1.0 | .0001 | .04 | .200 | 12.0012 | 1.0012 | .0625 | 1 P.S.+ 1.0001 DISP |
| | .5 | .0004 | .03 | .161 | 12.0048 | 1.0048 | | 1.0004 DISP |
| | .25 | .0016 | .03 | .348 | 12.0192 | 1.0192 | | 1.0016 DISP |
| | .125 | .0064 | .03 | .636 | 12.0768 | 1.0768 | | 1.0064 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.1 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 12

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| SDM-E | 1.0 | .0001 | 10.992 | 12.0012 | 12.0012 | 1.0012 | | 1 P.S. |
| | .5 | .0004 | 4.236 | 12.0048 | 12.0048 | 1.0048 | | |
| | .25 | .0016 | 2.256 | 12.0192 | 12.0192 | 1.0192 | | |
| | .125 | .0064 | 1.248 | 12.0768 | 12.0768 | 1.0768 | | |
| SDM-O | 1.0 | .0001 | .48 | .200 | 12.0012 | 1.0012 | .75 | 1 P.S. |
| | .5 | .0004 | .36 | .161 | 12.0048 | 1.0048 | | |
| | .25 | .0016 | .36 | .348 | 12.0192 | 1.0192 | | |
| | .125 | .0064 | .36 | .636 | 12.0768 | 1.0768 | | |
| SDM-FDM-E | 1.0 | .0001 | 2.749 | 4.0004 | 4.0004 | 1.0004 | | 1 P.S. |
| | .5 | .0004 | 1.412 | 4.0016 | 4.0016 | 1.0016 | | |
| | .25 | .0016 | .752 | 4.0064 | 4.0064 | 1.0064 | | |
| | .125 | .0064 | .416 | 4.0256 | 4.0256 | 1.0256 | | |
| SDM-FDM-O | 1.0 | .0001 | – | – | – | – | | 1 P.S. |
| | .5 | .0004 | .12 | .100 | 4.0016 | 1.0016 | .25 | |
| | .25 | .0016 | .11 | .116 | 4.0064 | 1.0064 | | |
| | .125 | .0064 | .11 | .212 | 4.0256 | 1.0256 | | |
| SWITCHED | 1.0 | .0001 | .68 | 2.0012 | 2.0012 | 2.0012 | 2.0 | |
| | .5 | .0004 | .35 | 2.0048 | 2.0048 | 2.0048 | | |
| | .25 | .0016 | .20 | 2.0192 | 2.0192 | 2.0192 | | |
| | .125 | .0064 | .12 | 2.0768 | 2.0768 | 2.0768 | | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.2 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 21

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| FDM-E | 1.0 | .0001 | .69 | 1.0001 | 1.0001 | 1.0001 | | |
| | .5 | .0004 | .35 | 1.0004 | 1.0004 | 1.0004 | | |
| | .25 | .0016 | .19 | 1.0016 | 1.0016 | 1.0016 | | |
| | .125 | .0064 | .10 | 1.0064 | 1.0064 | 1.0064 | | |
| FDM-O | 1.0 | .0001 | - | - | - | - | - | |
| | 0.5 | .0004 | - | - | - | - | - | |
| | 0.25 | .0016 | - | - | - | - | - | |
| | .125 | .0064 | - | - | - | - | - | |
| WDM-E | 1.0 | .0001 | .69 | 21.0021 | 21.0021 | 1.0021 | | 1 P.S. + 1.0001 DISP |
| | .5 | .0004 | .35 | 21.0084 | 21.0084 | 1.0084 | | 1.0004 DISP |
| | .25 | .0016 | .19 | 21.0336 | 21.0336 | 1.0336 | | 1.0016 DISP |
| | .125 | .0064 | .10 | 21.1344 | 21.1344 | 1.1344 | | 1.0064 DISP |
| WDM-O | 1.0 | .0001 | .04 | .353 | 21.0021 | 1.0021 | .0625 | 1 P.S. + 1.0001 DISP |
| | .5 | .0004 | .03 | .282 | 21.0084 | 1.0084 | | 1.0004 DISP |
| | .25 | .0016 | .03 | .609 | 21.0336 | 1.0336 | | 1.0016 DISP |
| | .125 | .0064 | .03 | 1.113 | 21.1344 | 1.1344 | | 1.0064 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.2 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 21

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| SDM-E | 1.0 | .0001 | 19.236 | 21.0021 | 21.0021 | 1.0021 | | 1 P.S. |
| | .5 | .0004 | 7.413 | 21.0084 | 21.0084 | 1.0084 | | |
| | .25 | .0016 | 3.948 | 21.0332 | 21.0332 | 1.0332 | | |
| | .125 | .0064 | 2.184 | 21.1344 | 21.1344 | 1.1344 | | |
| SDM-O | 1.0 | .0001 | .84 | .353 | 21.0021 | 1.0021 | 1.31 | 1 P.S. |
| | .5 | .0004 | .63 | .282 | 21.0084 | 1.0084 | | |
| | .25 | .0016 | .63 | .609 | 21.0332 | 1.0332 | | |
| | .125 | .0064 | .63 | 1.113 | 21.1344 | 1.1344 | | |
| SDM-FDM-E | 1.0 | .0001 | 4.809 | 7.0007 | 7.0007 | 1.0007 | | 1 P.S. |
| | .5 | .0004 | 2.471 | 7.0028 | 7.0028 | 1.0028 | | |
| | .25 | .0016 | 1.316 | 7.0112 | 7.0112 | 1.0112 | | |
| | .125 | .0064 | .728 | 7.0448 | 7.0448 | 1.0448 | | |
| SDM-FDM-O | 1.0 | .0001 | - | - | - | - | | |
| | .5 | .0004 | .21 | .175 | 7.0028 | 1.0028 | .44 | 1 P.S. |
| | .25 | .0016 | .19 | .203 | 7.0112 | 1.0112 | | |
| | .125 | .0064 | .19 | .371 | 7.0448 | 1.0448 | | |
| SWITCHED | 1.0 | .0001 | .68 | 2.0021 | 2.0021 | 1.0021 | 2.0 | |
| | .5 | .0004 | .36 | 2.0084 | 2.0084 | 1.0084 | | |
| | .25 | .0016 | .21 | 2.0332 | 2.0332 | 1.0332 | | |
| | .125 | .0064 | .13 | 2.1344 | 2.1344 | 1.1344 | | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.3 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 35

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| FDM-E | 1.0 | .0001 | .69 | 1.0001 | 1.0001 | 1.0001 | | |
| | .5 | .0004 | .35 | 1.0004 | 1.0004 | 1.0004 | | |
| | .25 | .0016 | .19 | 1.0016 | 1.0016 | 1.0016 | | |
| | .125 | .0064 | .10 | 1.0064 | 1.0064 | 1.0064 | | |
| FDM-O | 1.0 | .0001 | - | - | - | - | | |
| | .5 | .0004 | - | - | - | - | | |
| | .25 | .0016 | - | - | - | - | | |
| | .125 | .0064 | - | - | - | - | | |
| WDM-E | 1.0 | .0001 | .69 | 35.0035 | 35.0035 | 1.0035 | | 1 P.S. + 1.0001 DISP |
| | .5 | .0004 | .35 | 35.0140 | 35.0140 | 1.0140 | | 1.0004 DISP |
| | .25 | .0016 | .19 | 35.0560 | 35.0560 | 1.0560 | | 1.0016 DISP |
| | .125 | .0064 | .10 | 35.2240 | 35.2240 | 1.2240 | | 1.0064 DISP |
| WDM-O | 1.0 | .0001 | .04 | .588 | 35.0035 | 1.0035 | .0625 | 1 P.S. + 1.0001 DISP |
| | .5 | .0004 | .03 | .469 | 35.0140 | 1.0140 | | 1.0004 DISP |
| | .25 | .0016 | .03 | 1.015 | 35.0560 | 1.0560 | | 1.0016 DISP |
| | .125 | .0064 | .03 | 1.855 | 35.2240 | 1.2240 | | 1.0064 DISP |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.3 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

DISTRIBUTION HUB - N = 35

| APPROACH | SUBSCRIBER LINE MAXIMUM LENGTH (km) | DISTRIBUTION HUB | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|---|
| SDM-E | 1.0 | .0001 | 32.06 | 35.0035 | 35.0035 | 1.0035 | | 1 P.S. |
| | .5 | .0004 | 12.36 | 35.0140 | 35.0140 | 1.0140 | | |
| | .25 | .0016 | 6.58 | 35.0560 | 35.0560 | 1.0560 | | |
| | .125 | .0064 | 3.64 | 35.2240 | 35.2240 | 1.2240 | | |
| SDM-O | 1.0 | .0001 | 1.24 | .588 | 35.0035 | 1.0035 | 2.19 | 1 P.S. |
| | .5 | .0004 | .94 | .469 | 35.0140 | 1.0140 | | |
| | .25 | .0016 | .98 | 1.015 | 35.0560 | 1.0560 | | |
| | .125 | .0064 | .94 | 1.855 | 35.2240 | 1.2240 | | |
| SDM-FDM-E | 1.0 | .0001 | 8.244 | 12.0012 | 12.0012 | 1.0012 | | 1 P.S. |
| | .5 | .0004 | 4.236 | 12.0048 | 12.0048 | 1.0048 | | |
| | .25 | .0016 | 2.256 | 12.0192 | 12.0192 | 1.0192 | | |
| | .125 | .0064 | 1.248 | 12.0768 | 12.0768 | 1.0768 | | |
| SDM-FDM-O | 1.0 | .0001 | - | - | - | - | | |
| | .5 | .0004 | .36 | .300 | 12.0048 | 1.0048 | .75 | 1 P.S. |
| | .25 | .0016 | .33 | .348 | 12.0192 | 1.0192 | | |
| | .125 | .0064 | .33 | .636 | 12.0768 | 1.0768 | | |
| SWITCHED | 1.0 | .0001 | .68 | 2.0035 | 2.0035 | 2.0035 | 2.0 | |
| | .5 | .0004 | .36 | 2.0140 | 2.0140 | 2.0140 | | |
| | .25 | .0016 | .22 | 2.0560 | 2.0560 | 2.0560 | | |
| | .125 | .0064 | .16 | 2.2240 | 2.2240 | 2.2240 | | |

E: ELECTRICAL TAPPING

O: OPTICAL TAPPING

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.4 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 12

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .0069 | .023 | .0069 | 1.0069 | 1.0069 | .0625 | |
| WDM | .0039 | .023 | .0468 | 12.0468 | 1.0468 | .0625 | 1 P.S.<br>1.0039 DISP. |
| SDM | .0039 | .282 | .0468 | 12.0468 | 1.0468 | .75 | 1 P.S. |
| SDM-FDM | .0052 | .094 | .0208 | 4.0208 | 1.0208 | .25 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.5 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 21

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .0069 | .023 | .0069 | 1.0069 | 1.0069 | .0625 | |
| WDM | .0039 | .023 | .0819 | 21.0819 | 1.0819 | .0625 | 1 P.S.<br>1.0039 DISP. |
| SDM | .0039 | .483 | .0819 | 21.0819 | 1.0819 | 1.31 | 1 P.S. |
| SDM-FDM | .0052 | .161 | .0364 | 7.0364 | 1.0364 | .44 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

TABLE 6.6 URBAN AREA - COMPONENTS COUNT (PER SUBSCRIBER)

OPTICAL FEEDERS WITH AMPLIFIERS - N = 35

| APPROACH | REPEATER | FIBER (km) | SOURCES | PHOTODIODES | AMPLIFIERS | DIRECTIONAL COUPLER | OTHER |
|---|---|---|---|---|---|---|---|
| FDM | .0069 | .023 | .0069 | 1.0069 | 1.0069 | .0625 | |
| WDM | .0039 | .023 | .1365 | 35.1365 | 1.1365 | .0625 | 1 P.S.<br>1.0039 DISP |
| SDM | .0039 | .805 | .1365 | 35.1365 | 1.1365 | 2.19 | 1 P.S. |
| SDM-FDM | .0052 | .276 | .0624 | 12.0624 | 1.0624 | .75 | 1 P.S. |

P.S.: PHOTODIODE SELECTOR

DISP.: DISPERSER

## 7. IMPLICATIONS OF PROVIDING FM RADIO BROADCAST CHANNELS

Some of the present coaxial cable CATV systems also provide FM radio broadcast channels to subscribers. It is a supplementary service which is easy and cheap to provide in these systems, because the FM band is included in the standard 12 VHF channel frequency scheme. Thus no extra signal bandwidth is involved.

For a fiber optics CATV system a low frequency signalling scheme is optimum for video transmission. Thus the provision of FM radio channels would require supplementary signal bandwidth and special considerations in the design of the signal frequency scheme and of the subscriber interface unit.

### 7.1 SIGNALLING SCHEME

Since video channels would be transmitted adequately, the transmission of FM radio signals should not be a problem as far as meeting the transmission performance requirements is concerned. The FM signals received at the distribution center must be processed, unless the FM band (88-108 MHz) is included in or adjacent to the band occupied by the video channels on the system. This is the case for a 12, 21 or 35 channel FDM system. Otherwise, FM channels would be transmitted at lower frequencies in order to minimize the effect of increasing the signal bandwidth on the video transmission performance.

The signals could also be processed further to compress the FM band. If all FM channels were at the same power level, 600 kHz separation between carrier frequencies would not be required. Thus the present service in the broadcast FM band could be accommodated by a 3-5 MHz compressed FM band. However, there is a cost associated with this compression and it should be compared with the resultant cost of transmitting the full FM band.

The precise FM frequency allocation scheme depends on the system approach and on the subscriber interface unit. However, some general considerations in determining the frequency scheme are as follows:

- If many sources are used for the video transmission (SDM, WDM and SDM-FDM), they should share the FM band, especially if the full FM band is used.

- If supplementary bandwidth has to be used, FM channels should be transmitted above the video channels so that if there is a system frequency rolloff, the video channels will not be affected. Also frequency block conversion of the video and FM channels will be possible.

### 7.2 SUBSCRIBER INTERFACE UNIT

The subscriber interface unit will need special attention if the CATV system provides FM radio broadcast channels. If the FM signals are not transmitted at frequencies inside the standard FM broadcast band, then frequency converters will be required.

If a frequency converter already exists for video, it should preferably be used for FM too. This frequency converter would have to be designed in such a way that FM channels transmitted above the video channels fall inside the broadcast FM band. Unfortunately this could cause a number of very awkward problems. For example, if the FM band is converted up to 88-108MHz, then the video channel immediately below will be converted up to channel 6. This would be undersirable in areas with a strong channel 6 broadcast signal, and thus would neccessitate leaving a 6 MHz band blank immediately below the FM band. The consequent wider bandwidth requirement would, of course, lead to lower amplifier input resistance and smaller repeater spacing. Thus in some cases, the use of a separate frequency converter for FM might be preferable. If a special converter is used for FM, it might be possible to use the non-occupied bandwidth at the lower end of the spectrum (0-5 MHz) where a compressed FM band is used or where the standard FM band is shared by at least four sources.

## 7.3 CONCLUSIONS

Fiber optics CATV systems can accommodate the supplementary service of providing FM radio broadcast channels, but it would be done at the expense of the system video transmission capability or of the system complexity. Signal processing at the distribution center and a special frequency converter in the subscriber interface unit may be required. Therefore providing FM service would result in a more expensive CATV system. Thus the demand for this supplementary service should be assessed before deciding to provide it.

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## APPENDIX A

## FIBER OPTICS ANALOG VIDEO TRANSMISSION CAPABILITIES BASED ON SIGNAL-TO-NOISE RATIO CONSIDERATIONS

For video channels transmitted on modulated carriers, the BP 23 (NCTA) definition of SNR is used. This gives the following expression for fiber optics systems, considering only thermal and quantum noises.

$$SNR_{NCTA} = \frac{\left(\frac{\eta eG}{h\nu}\right)^2 \frac{m_I^{\ 2}\ P_{DC}^{\ 2}}{2K}}{N\ 4kTb\left(\frac{Ft}{R_{eq}} + \frac{2e^2}{h\nu}\ \eta G^2\ F_D b\ P_{DC}\right)} \qquad \text{(A1)}$$

where

G = detector gain

$\eta$ = detector quantum efficiency

$h\nu$ = photon energy

e = charge of an electron

$m_I$ = optical modulation index

$P_{DC}$ = average optical power received at the detector

K = number of video channels transmitted

N = number of repeaters

k = Boltzmann constant

T = absolute temperature

b = video signal bandwidth

$F_t$ = amplifier noise figure

$R_{eq}$ = amplifier input resistance

$F_D$ = avalanche gain excess noise factor

For baseband video transmission, the unweighted Bell Telephone Laboratories SNR definition is used. Assuming worst case situation for the quantum noise, this gives

$$SNR_{BTL} = \frac{\left(\frac{\eta e G}{h\nu}\right)^2 4 \, P_{DC}^{\,2} \, m_I^{\,2}}{N\left(4kTb \frac{F_t}{R_{eq}} + \frac{2e^2}{h\nu} \eta G^2 \, F_D b \, (1 + m_I) P_{DC}\right)} \qquad \text{(A2)}$$

These two SNR definitions are related as follows*

$$SNR_{NCTA} = SNR_{BTL} + 4.0 \text{ dB} \qquad \text{(A3)}$$

This means that a baseband signal having a $SNR_{BTL}$ of 36 dB gives the same picture quality as a modulated carrier meeting BP 23 SNR requirement would give.

From the SNR expression, the minimum optical power ($P_{DC}$) that must be received at the detector to meet a given SNR can be derived for different numbers of repeaters. Then, knowing this minimum power, the power coupled into the fiber attenuation (dB/km), the repeater spacing can be evaluated.

$$\text{Repeater spacing} = \frac{10 \log \frac{PIN}{P_{DC}}}{\alpha} \qquad \text{(A4)}$$

where PIN = average power coupled in the fiber

$P_{DC}$ = Minimum optical power required at the detector

$\alpha$ = fiber attenuation (dB/km)

In the calculations made in this report, parameters were held constant except for the number of channels transmitted, K, the number of repeaters, N, and the equivalent input resistance, $R_{eq}$. For a given signal bandwidth, the value of this equivalent resistance is limited by the effective input capacitance of the amplifier. The capacitance and the resistance at the amplifier input act as a low pass filter.

The effective input capacitance can be reduced by using bootstrapping techniques. However, the practical efficiency of bootstrapping decreases as the signal bandwidth increases. Thus the effective capacitance increases also. This effect was considered when setting the different values of equivalent input resistance as a function of the signal transmitted as shown in the following table.

---

* T.M. Straus, "The Relationship Between the NCTA, EIA, and CCIR Definition of Signal-to-Noise Ratio," IEEE Transaction on Broadcasting, Vol. BC-20, No. 3, September 1974.

| Signal transmitted | Equivalent input resistance (kilohms) |
|---|---|
| 1 baseband | 80 |
| 1 modulated carrier | 40 |
| 2 modulated carriers | 24 |
| 3 modulated carriers | 11 |
| 5 modulated carriers | 7 |
| 12 modulated carriers | 2 |
| 21 modulated carriers | 0.8 |
| 35 modulated carriers | 0.5 |

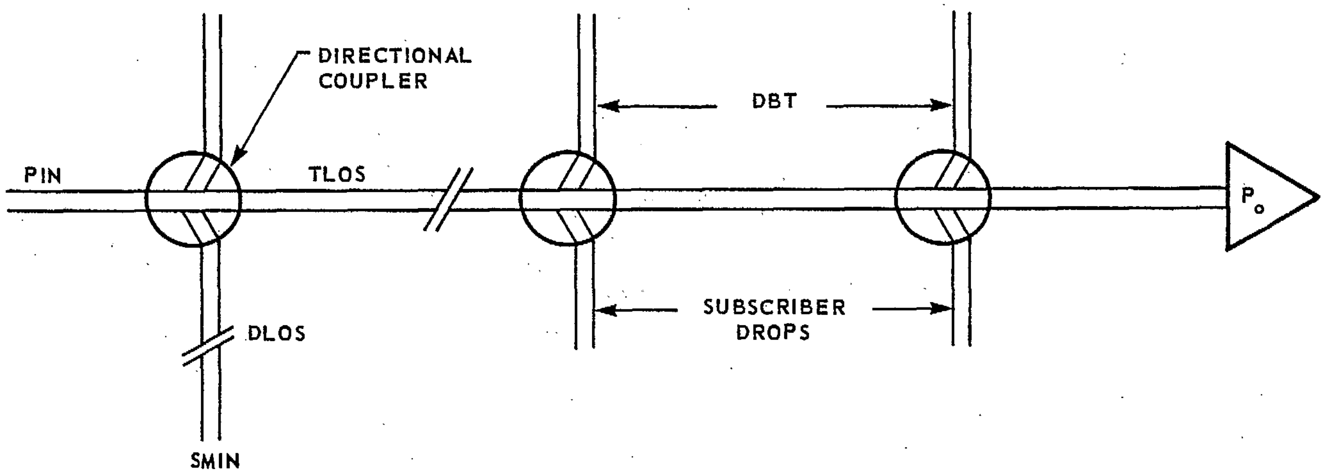
The following values were assumed for the other parameters.

| Symbol | Parameter | Value | Units |
|---|---|---|---|
| PIN | average power coupled in the fiber | 0.667 | mW |
| $m_I$ | optical modulation index | 0.75 | --- |
| --- | peak-to-peak signal power | 1.0 | mW |
| $\alpha$ | fiber attenuation | 5.0 | dB/km |
| $\eta$ | detector quantum efficiency | 0.85 | --- |
| G | detector gain | 1 | --- |
| $F_D$ | excess noise factor | 1 | --- |
| $F_t$ | amplifier noise figure | 2 | --- |
| b | video signal bandwidth | $4 \times 10^6$ | Hz |
| $h\nu$ | photon energy | $2.24 \times 10^{-19}$ | J |
| T | absolute temperature | 300 | K |
| k | Boltzmann constant | $1.381 \times 10^{-23}$ | J/degK |
| e | electron charge | $1.602 \times 10^{-19}$ | C |

## APPENDIX B

## CALCULATION OF MAXIMUM NUMBER OF TAPS ON AN OPTICAL FEEDER

The arrangement of taps on an optical feeder using directional couplers is shown in the following figure.




For optical feeders with no amplifier, $P_o = 0$. It is assumed that the coupling ratio of each directional coupler can be finely adjusted so that only the minimum power required to meet the transmission objectives at the subscriber set is tapped. Therefore the power needed at the input for a given subscriber equals the power required at his detector plus the power loss along the transmission path.

For the $i$th tap the power required at the input

$$P_i = 10 \text{ EXP } \left\{ [i \text{ DBT } \alpha + (i-1) \text{ TLOS} + \text{SMIN} + \text{DLOS} + \text{LNSPT}]/10 \right\} \qquad \text{(B1)}$$

where

$i$ = rank of tap

$P_i$ = input power required for $i$th tap (W)

DBT = distance between successive taps (km)

= fiber attenuation (dB/km)

TLOS = tap throughloss (dB)

and the term TLOS is given by

$$\text{TLOS} = 10 \log \frac{\text{Pout}}{\text{Pin} - \text{Pc}} \qquad \text{(B2)}$$

and

SMIN = minimum optical power required (dBW).
This is the minimum power required at the subscriber detector in order to meet the transmission performance objectives. SMIN is a function of the number of cascaded amplifiers. It can be evaluated from the analysis of Appendix A where it corresponds to $P_{DC}$.

Pout = optical power coming out from the tap

Pin = optical power entering in the tap

Pc = total optical power coupled in the subscriber's drop

DLOS = subscriber drop attenuation (dB)

LNSPT = factor taking into account the number of subscribers per tap (dB)

= 10 log number of subscriber tap

Thus the total power required at the input for a N tap feeder is given by

$$PIN = \sum_{i=1}^{N} P_i \tag{B3}$$

Usually PIN is fixed and equation (B3) yields the maximum number of taps, N. Equation (B3) can be evaluated for different values of N to find the value of N for which the summation is $\geqslant$ PIN. This is only practical, of course, with a computer.

However, the equation can be written in non-dB form and becomes

$$P_i = AB^i C^{i-1} \tag{B4}$$

where

$i$ = rank of tap

A = power required per tap

= 10 EXP [(SMIN + DLOS + LNSPT)/10]

B = attenuation due fiber length equal to the distance between successive taps

= 10 EXP [DBT $\alpha$/10]

C = tap throughloss

= 10 EXP [TLOS/10]

$= \dfrac{\text{Pin} - \text{Pc}}{\text{Pout}}$

Making the following aproximation

$$C^{i-1} \approx C^{i} \quad \text{(B5)}$$

and

$$P_i' = AB^{i}C^{i} > P_i \quad \text{(B6)}$$

$$PIN' = \sum_{i=1}^{N} A(BC)^{i} \quad \text{(B7)}$$

$$= \frac{(ABC)^{n+1} - ABC}{BC - 1}$$

then the approximated maximum number of taps is given by

$$N \simeq \frac{\log\left(PIN + \frac{ABC}{BC - 1}\right) - \log A + \log (BC - 1)}{\log BC} - 1 \quad \text{(B8)}$$

This approximate number is always lower than the real number. Therefore it is a conservative estimate of the allowed number of taps on a feeder with no amplifier.

For feeders with amplifiers the power required at the input is equal to the power required by the subscribers plus the power needed by the following amplifier. Therefore

$$PIN = \sum_{i=1}^{N} P_i + P_o \; 10 \; EXP[N \; DBT \; \alpha/10] \quad \text{(B9)}$$

where

$P_o$ = power required at the repeater input (W)

The term $P_o$ is a function of the total number of cascaded amplifiers on the line and can be evaluated from the analysis of Appendix A.

The right hand side of equation (B9) has to be evaluated for different numbers of taps (N), and then compared with the available power at the input (PIN), until the right number is found.

# APPENDIX C

## DETAILED METHODS FOR EVALUATING COMPONENT COUNTS - RURAL AREAS

Repeater spacings are found using the analysis of Appendix A. The repeater spacing depends on SNR to be achieved, number of channels transmitted per light source, power coupled into the fiber, fiber attenuation, characteristics of the detector and amplifier, and length of the longest transmission line occurring in the distribution area. In the analysis of Appendix A, the number of repeaters required to achieve the longest transmission line is found by iteration. For the non-switched approaches, the corresponding repeater spacings are given in Table 4.1.

LINEAR DISTRIBUTION, NON-SWITCHED, ELECTRICAL TAPPING (Tables 4.6 - 4.9)

In this case the methods used are more easily shown, and also the methods used in the grid distribution case are just extensions of the linear case methods.

The components count is based on one repeater section. The number of subscribers served from one repeater is given by

$$NS = \frac{2\ REPS}{a}$$

where

REPS = repeater spacing

a = dimension of a subscriber lot (length of the frontage)

Drops go from the repeater to the subscriber and do not all have the same length. The average drop length is given by

$$ADL = \frac{\Sigma\ drops}{NS}$$

$$= \frac{2\left(\frac{NS}{2} + 1\right)\left(\frac{NS}{2}\right)\frac{a}{4}}{NS} + \frac{a}{2}$$

$$= a\left(\frac{NS}{8} + \frac{3}{4}\right)$$

Then the components count becomes straightforward by referring to the non-switched system configurations shown in Fig. 3.4 - 3.7.

The details of the components count are given in Table C-1, where

N = number of video channels distributed by the system (N = 5, 12, 21, 35)

NS = number of subscribers served from a repeater (depends on the repeater spacing)

REPS = repeater spacing

ADL = average drop length

K = number of fibers used in the SDM-FDM approach (For N = 5, 12, 21, 35, K = 2, 4, 7, 12, respectively)

TABLE C-1

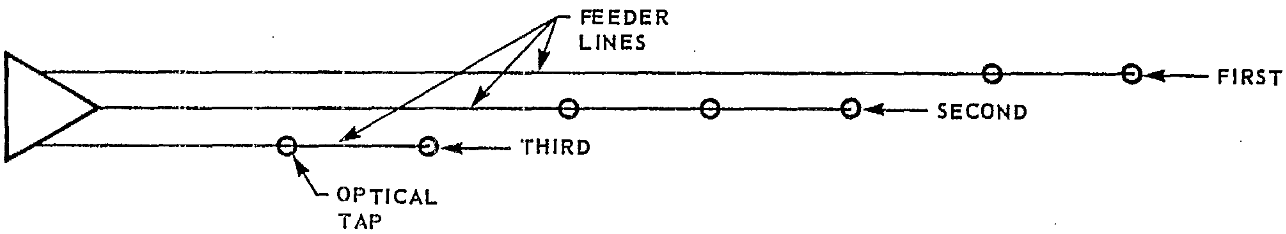
RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
LINEAR DISTRIBUTION - NON-SWITCHED-ELECTRICAL TAPPING

| APPROACH | REPEATER | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | DISPERSER | PHOTODIODE SELECTOR |
|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + ADL$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | - | - |
| SDM | $\frac{1}{NS}$ | $\left(\frac{REPS}{NS} + ADL\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | - | 1 |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(\frac{REPS}{NS} + ADL\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | - | 1 |
| WDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + ADL$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | $1 + \frac{1}{NS}$ | 1 |

LINEAR DISTRIBUTION, NON-SWITCHED, OPTICAL TAPPING (Tables 4.6 - 4.9)

The optical feeder is half a repeater spacing long. If a single feeder line cannot supply all the subscribers, up to two supplementary feeder lines could be added. In the case where three feeder lines would not suffice, the approach is considered not feasible. The method used for evaluating the maximum number of taps is shown in Appendix B.

If a single feeder line cannot serve all the subscribers, a second feeder line is added. The first line will serve the maximum possible number of subscribers which are farther from the repeater. The second feeder line will start by serving the farthest subscribers which are not already served by the first feeder line. Then, if two feeder lines are not sufficient, a third one could serve the remaining subscribers. This scheme is illustrated below.



The different numbers of taps are evaluated using the analysis of Appendix B, where PIN is the power coupled into the fiber at the repeater, less the loss encountered through the untapped portion of the feeder line.

The determination of the number of feeder lines and their length is necessary for the evaluation of the number of sources and of the amount of fiber required.

The evaluation of the average number of sources and the average amount of fiber required per subscriber for the feeders is based on the total length of the longest transmission line occurring in the distribution area. These averages must be taken over the whole transmission line because the repeater sections near the distribution center require fewer feeder lines than the repeater sections farther from the distribution center. The distant repeater sections require more feeder lines because more power must be coupled into the subscriber's drop to meet the required SNR. More power is needed for the same SNR due to the compounding of noise at each repeater.

The details of the components count are given in Table C-2, where

N = number of video channels distributed by the system

REPS = repeater spacing

a = dimension of a subscriber lot (length of frontage)

NS = number of subscribers served from a repeater

$$= \frac{2REPS}{a}$$

K = number of fibers used in the SDM-FDM approach

IF = number of repeaters required for the longest distribution trunk

AFS = average number of feeder sources required per subscriber

$$= \frac{\sum_{i=0}^{i=IF} \text{number of feeder sources required at repeater}}{IF \times NS}$$

AFL = average feeder length required per subscriber

$$= \frac{\sum_{i=0}^{i=IF} \text{sum of the lengths of the feeder lines going out from repeater } i}{IF \times NS}$$

TABLE C-2

RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
LINEAR DISTRIBUTION - NON-SWITCHED-OPTICAL TAPPING

| APPROACH | REPEATER | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | DISPER-SER | PHOTODIODE SELECTOR | DIRECTIONAL COUPLER |
|---|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} \div AFL \div \frac{a}{2}$ | $\frac{1}{NS} \div AFS$ | $1 \div \frac{1}{NS}$ | $1 \div \frac{1}{NS}$ | - | - | 1 |
| SDM | $\frac{1}{NS}$ | $N\left(\frac{REPS}{NS} + AFL + \frac{a}{2}\right)$ | $N\left(\frac{1}{NS} + AFS\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | - | 1 | N |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(\frac{REPS}{NS} + AFL + \frac{a}{2}\right)$ | $K\left(\frac{1}{NS} + AFS\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | - | 1 | K |
| WDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + AFL + \frac{a}{2}$ | $N\left(\frac{1}{NS} + AFS\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | $1 + \frac{N}{NS}$ | 1 | 1 |

LINEAR DISTRIBUTION, SWITCHED (Table 4.13)

The components required for the transportation trunk are evaluated separately from the distribution part of the network.

The components count per subscriber for a SDM transportation trunk is given by

repeater $\frac{a}{2\ \text{REPS}}$

fiber $N\frac{a}{2} + \frac{N\ \Sigma\ \text{lengths of the supplementary transmission lines if required}}{\text{Total number of subscribers served by the trunk line}}$

sources, photodiodes, amplifiers $\frac{N\ a}{2\ \text{REPS}} + \frac{N \times \text{number of supplementary transmission lines}}{\text{Total number of subscribers served by the trunk line}}$

Given the maximum length for a subscriber line, the hardware required for the distribution can be evaluated, based on one video switch section.

The components count, including the transportation trunk and the distribution, is given in Table C-3, where

N = number of video channels provided by the system

a = dimension of a subscriber lot (length of frontage)

MSL = subscriber line maximum length

REPS = repeater spacing on the transportation trunk (from Appendix A for a SNR of 43 dB)

TL = length of the trunk line

TABLE C-3

RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
LINEAR DISTRIBUTION - SWITCHED

| | |
|---|---|
| Repeater | $\frac{a}{2\ \text{REPS}}$ |
| Video Switch | $\frac{a}{4\ \text{MSL}}$ |
| Fiber | $(N+1)\frac{a}{2} + \left(\frac{2\ \text{MSL}}{a} + 1\right)\frac{a}{4} + \frac{N\ \Sigma\ \text{lengths of the supplementary transmission lines}}{2\left(\frac{\text{TL} + \text{MSL}}{a}\right)}$ |
| Sources<br>Photodiodes<br>Amplifiers | $2 + \frac{N\ a}{2\ \text{REPS}} + \frac{N\ (\text{Number of supplementary transmission lines})}{2\left(\frac{\text{TL} + \text{MSL}}{a}\right)}$ |
| Directional Couplers | 2 |

GRID DISTRIBUTION, NON-SWITCHED ELECTRICAL TAPPING (Table 4.2 - 4.5)

The network configuration is shown in Fig. 4.3 and 4.4. The procedure is similar to the linear distribution case, except that there are many main feeder cables.

The components count is based on one distribution cell. The size of the distribution cell depends on the repeater spacing which is the same as for the linear distribution case (Table 4.1).

The details of the components count are given in Table C-4, where

N = number of channels provided by the system

NS = number of subscribers in a distribution cell
$\frac{3}{2}(REPS)^2$ x subscriber density

REPS = repeater spacing

K = number of fibers used in the SDM-FDM approach (K = 2, 4, 7, 12)

ADL = average drop length. This value has been evaluated using the program shown in Fig. C-1.

Note that Table C-4 is similar to Table C-1. However the functions ADL and NS do not take the same values.

TABLE C-4

RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
GRID DISTRIBUTION - NON-SWITCHED-ELECTRICAL TAPPING

| APPROACH | REPEATER | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | DISPERSER | PHOTODIODE SELECTOR |
|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} \div ADL$ | $1 \div \frac{1}{NS}$ | $1 \div \frac{1}{NS}$ | $1 \div \frac{1}{NS}$ | - | - |
| SDM | $\frac{1}{NS}$ | $N\left(\frac{REPS}{NS} + ADL\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | - | 1 |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(\frac{REPS}{NS} + ADL\right)$ | $K\left(1 \div \frac{1}{NS}\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | - | 1 |
| WDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + ADL$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | $1 + \frac{1}{NS}$ | 1 |

```
C
C
C
C
C
C      PROGRAM FOR EVALUATING THE AVERAGE DROP LENGTH (ADL)
       RURAL AREAS - GRID DISTRIBUTION - NON-SWITCHED
       ELECTRICAL TAPPING
       GIVEN:
             REPS - REPEATER SPACING (KM)
                A - DIMENSION OF A SUBSCRIBER LOT (KM)
       PROGRAM STOPS WHEN REPS GIVEN IS LESS THAN .1
C
C
C
5      READ(5,*) REPS,A
       IF(REPS.LT.0.1) STOP
       FAC=1
       I=0
       TOFI=0
       TONU=0
10     FL=REPS-(2*I*A)
       SNUM=2*FL/A
       EXT=((SNUM+1)*SNUM*A/4)+(SNUM*A/2)+(SNUM*(REPS-FL))
       IF(I.EQ.0) EXT=EXT/2
       IF(I.EQ.0) SNUM=SNUM/2
       IF(FL.LT.(REPS/2)+A) FAC=1-ABS((FL-((REACH/2)+A))/(2*A))
       TOFI=TOFI+(FAC*EXT)
       TONU=TONU+(SNUM*FAC)
       IF(FL.LE.(REPS/2)+A) GO TO 200
       I=I+1
       GO TO 10
200    FITOT=4*TOFI
       SNUTOT=4*TONU
       ADL=FITOT/SNUTOT
       WRITE(6,*) ADL
       GO TO 5
       END
```

Fig. C-1 (1 of 2)

program listing

program input:

```
- - - - - - - - - -
   REPS,A
      .
      .
      .
     x,y
- - - - - - - - - -
```

program output:

```
- - - - - - - - - -
   ADL
    .
    .
    .
- - - - - - - - - -
```

where

REPS : repeater spacing (km)
A : dimension of a subscriber lot (km)
x,y : numbers to indicate program termination
x: less than .1
y: any value
ADL : average drop length (km)

Fig. C-1 (2 of 2)

GRID DISTRIBUTION, NON-SWITCHED, OPTICAL TAPPING (Tables 4.2 - 4.5)

The network configuration is represented in Fig. 4.5 and 4.6. For the components count, the same procedure as for the linear distribution case is followed. However the average feeder length (AFL) and average number of sources (AFS) per subscriber are evaluated based on the total distribution area.

The details of the components count are given in Table C-5, where

N = number of channels provided by the system

REPS = repeater spacing

NS = number of subscribers in a distribution cell

$$= \frac{(REPS)^2}{2} \times \text{subscriber density}$$

K = number of fibers used in the SDM-FDM approach (K = 2, 4, 7, 12)

a = dimension of subscriber lot

GFISUB = average feeder length per subscriber + length of subscriber's drop

$$= AFL + \frac{a}{2}$$

GSOSUB = average number of sources per subscriber required for the feeders

Both GFISUB and GSOSUB are evaluated using the computer program given in Figure C-2.

TABLE C-5

RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
GRID DISTRIBUTION - NON-SWITCHED-OPTICAL TAPPING

| APPROACH | REPEATER | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | DISPER-SER | PHOTODIODE SELECTOR | DIRECTIONAL COUPLERS |
|---|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + GFISUB$ | $\frac{1}{NS} + GSOSUB$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | – | – | 1 |
| SDM | $\frac{1}{NS}$ | $N\left(\frac{REPS}{NS} + GFISUB\right)$ | $N\left(\frac{1}{NS} + GSOSUB\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | – | 1 | N |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(\frac{REPS}{NS} + GFISUB\right)$ | $K\left(\frac{1}{NS} + GSOSUB\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | – | 1 | K |
| WDM | $\frac{1}{NS}$ | $\frac{REPS}{NS} + GFISUB$ | $N\left(\frac{1}{NS} + GSOSUB\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | $1 + \frac{N}{NS}$ | $1 + \frac{N}{NS}$ | 1 |

```
C
C
      PROGRAM FOR EVALUATING THE AVERAGE FEEDER LENGTH + DROP LENGTH
      (AFL + A/2) AND THE AVERAGE NUMBER OF FEEDER SOURCES (AFS)
      RURAL AREAS - GRID DISTRIBUTION - NON-SWITCHED
      OPTICAL TAPPING
C
C
C
C
      READ(5,*) DLOS,TLOS,ALPHA,A,REPS,NSPT,SMIN
      DBT=A*NSPT/2
       N=0
      GFITOT=0
      GSOTOT=0
      GNUTOT=0
      FIAVE=0
      AREA1=0
1       IFEE=0
       FITOT=0
       SOTOT=0
       NUTOT=0
10     NMAX=0
       N2AX=0
        N3AX=0
      NTAP=IFIX(.5+(REPS-4*IFEE*A)/(2*DBT))
      IF(NTAP.LT.1) GO TO 3000
      I=1
      PINIT1=.667*10**(-2*IFEE*A*ALPHA/10)
      POTOT=0
100   B=(SMIN+DLOS+(I-1)*TLOS+(I*ALPHA*(2*IFEE-1)*DBT)/2)/10
      BEXP=NSPT*10**B
      POTOT=POTOT+BEXP
      IF(POTOT.GT.PINIT1) GO TO 300
      IF(I.EQ.NTAP) GO TO 1200
      I=I+1
      GO TO 100
300   NMAX=I-1
      I2=0
      POTOT2=0
350   B2=(SMIN+DLOS+I2*TLOS+(I2*ALPHA*DBT))/10
      BEXP2=NSPT*10**B2
      POTOT2=POTOT2+BEXP2
      F2LOS=-(((NTAP-(I2-.5))*ALPHA*DBT)+(2*IFEE*A*ALPHA))/10
      PINIT2=(.667)*10**F2LOS
      IF(PINIT2.LT.POTOT2) GO TO 400
      I2=I2+1
      GO TO 350
400   IF(I2.EQ.0)GO TO 900
      IF(I2+NMAX.LT.NTAP) GO TO 600
      N2AX=I2
      GO TO 1300
600   POTOT3=0
```

Fig. C-2 (1 of 4)

```
      N2AX=I2
      I3=0
650   B3=(SMIN+DLOS+(I3*TLOS)+I3*ALPHA*DBT)/10
      BEXP3=NSPT*10**B3
      POTOT3=POTOT3+BEXP3
      F3LOS=-(((NTAP-(N2AX+(I3-.5)))*ALPHA*DBT)+(2*IFEE*A*ALPHA))/10
      PINIT3=(.667)*10**F3LOS
      IF(PINIT3.LT.POTOT3) GO TO 800
      I3=I3+1
      GO TO 650
800   IF(I3+N2AX+NMAX.LT.NTAP) GO TO 900
      N3AX=I3
        GO TO 1400
900   WRITE(6,901)
901    FORMAT('  NOT POSSIBLE TO REACH THE LIMIT')
       STOP
1200   FL=REPS
       IF(NSPT.LE.2) FIT=REPS+NSPT*NTAP*A
       IF(NSPT.GT.2) FIT=FL+1.4142*NSPT*NTAP*A
       NU=2*NTAP*NSPT
       NSO=2
       GO TO 2000
1300   FL=(2*NTAP-N2AX)*DBT+4*IFEE*A
        IF(NSPT.LE.2) FIT=2*FL+NSPT*NTAP*A
        IF(NSPT.GT.2) FIT=2*FL+1.4142*NSPT*NTAP*A
        NU=2*NTAP*NSPT
        NSO=4
        GO TO 2000
1400    FL=((3*NTAP)-(2*N2AX-N3AX))*DBT+6*IFEE*A
        IF(NSPT.LE.2) FIT=2*FL+NSPT*NTAP*A
        IF(NSPT.GT.2) FIT=2*FL+1.4142*NSPT*NTAP*A
        NU=2*NTAP*NSPT
        NSO=6
        GO TO 2000
2000  IF(IFEE.EQ.0) FIT=FIT/2
      FITOT=FITOT+2*FIT
      IF(IFEE.EQ.0) NSO=NSO/2
      SOTOT=SOTOT+NSO*2
       IF(IFEE.EQ.0) NU=NU/2
       NUTOT=NUTOT+2*NU
       IFEE=IFEE+1
       GO TO 10
3000    FISUB=FITOT/NUTOT
        SOSUB=SOTOT/NUTOT
       N=N+1
       AREA2=SURF(REPS,N)
      GFITOT=GFITOT+FITOT
      GNUTOT=GNUTOT+NUTOT
       GSOTOT=GSOTOT+SOTOT
      FIAVE=FIAVE+((AREA2-AREA1)*FISUB)
       AREA1=AREA2
3500    READ(5,*) SMIN
        IF(SMIN.GT.0) GO TO4000
         GO TO 1
4000  GFISUB=FIAVE/AREA1
```

Fig. C-2 (2 of 4)

```
      GSOSUB=(GSOTOT*GFISUB)/GFITOT
       WRITE(6,*) GFISUB,GSOSUB
       STOP
        END
       FUNCTION SURF(R,NA)
C   WEIGHTING FACTOR FOR A 40 KM RADIUS DISTRIBUTION AREA
       IF(NA*R.GT.40) GO TO 10
       SURF=2*((R*(NA-.5))**2)
       RETURN
10     TETA=ARSIN((NA*R-40)/40)
       S1=TETA*(40**2)
       S2=((40**2)/2)*SIN(1.571-2*TETA)
       SURF=4*(S1+S2)
       RETURN
       END
```

Fig. C-2 (3 of 4)

program listing

program input:

```
DLOS, TLOS, ALPHA, A, REPS, NSPT, SMIN(1)
SMIN(2)
SMIN(3)
  .
  .
  .
SMIN(NA)
x+
```

program output:

```
GFISUB, GSOSUB
```

where

- DLOS: drop loss (dB)
- TLOS: directional coupler throughloss (dB)
- ALPHA: fiber attenuation (dB/km)
- A: dimension of a subscriber lot (km)
- REPS: repeater spacing (km)
- NSPT: number of subscribers per tap
- SMIN(i): mean optical power required on the detector to achieve a SNR of 40 dB when the signals pass by i amplifiers (dBm0)
  $SMIN = 10 \log P_{DC} \quad (P_{DC}:mW)$
- NA: maximum number of cascaded amplifiers
  NA = maximum number of repeaters required to reach the limit of the distribution area + 1
- x+: any number greater than 0 (program termination)
- GFISUB: average feeder length per subscriber + drop length (km)
  $GFISUB = AFL + \frac{a}{2}$
- GSOSUB: average number of feeder sources per subscriber

The program assumes 0.667 mW for the average power coupled into the fiber and a 40 km radius distribution area. For different assumptions, these figures can easily be changed in the program listing: replacing 0.667 in the main program and 40 in the subroutine SURF with the new figures. They could also be variables.

Fig. C-2 (4 of 4)

GRID DISTRIBUTION, SWITCHED VIDEO (Tables 4.10 - 4.12)

The network configuration is represented in Fig. 4.7 and 4.8. The details of the components count are given in Table C-6, where

N = number of channels provided by the system

MSL = subscriber line maximum length

NS = number of subscribers in a distribution cell

= $2 (MSL)^2$ x subscriber density

ASL = subscriber line average length. It is evaluated using the program given in Fig. C-3.

TABLE C-6

RURAL AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
GRID DISTRIBUTION - SWITCHED

| | |
|---|---|
| Repeater | $\frac{2\ MSL}{NS\ REPS}$ |
| Video Switch | $\frac{1}{NS}$ |
| Fiber | $ASL + \frac{2(N \times MSL)}{NS}$ <br> $N \Sigma = \frac{\text{length of the supplementary transmission lines}}{\text{number of subscribers served by the transportation trunk}}$ |
| Sources, Photodiodes, Amplifiers | $2 + \frac{2(N \times MSL)}{(NS \times REPS)} + \frac{N\ \text{(number of supplementary transmission lines)}}{\text{number of subscribers served by the transportation trunk}}$ |
| Directional Couplers | 2 |

```
C
C
C
C
        PROGRAM FOR EVALUATING THE AVERAGE LENGTH OF A SUBSCRIBER
        LINE (ASL)
        GIVEN:
              MSL - SUBSCRIBER LINE MAXIMUM LENGTH (KM)
                A - DIMENSION OF A SUBSCRIBER LINE (KM)
        PROGRAM STOPS WHEN MSL GIVEN IS LESS THAN .1
C
C
C
C
5       READ(5,*) REACH,A
        IF(REACH.LT.0.1) STOP
        FAC=1
        I=0
        TOFI=0
        TONU=0
10      FL=REACH-(2*I*A)
        SNUM=2*FL/A
        EXT=((SNUM+1)*SNUM*A/4)+(SNUM*A/2)+SNUM*(REACH-FL))
        IF(I.EQ.0) EXT=EXT/2
        IF(I.EQ.0) SNUM=SNUM/2
        IF(FL.LT.A) FAC=1-ABS((FL-(A))/2*A))
        TOFI=TOFI+(FAC*EXT)
        TONU=TONU+(SNUM*FAC)
        IF(FL.LE.A) GO TO 200
        I=I+1
        GO TO 10
200     FITOT=4*TOFI
        SNUTOT=4*TONU
        ASL=FITOT/SNUTOT
        WRITE(6,*) ASL
        GO TO 5
        END
```

FIG. C - 3 (1 OF 2)

program listing

program input:

```
------------------------
MSL , A
  .
  .
  .
 x,y
------------------------
```

program output:

```
--------------
ASL
 .
 .
 .
--------------
```

where

```
     MSL  :  subscriber line maximum length (km)
       A  :  dimension of a subscriber lot (km)
     x,y  :  numbers to indicate the program termination
             x:  less than .1
             y:  any value
     ASL  :  subscriber line average length (km)
```

Fig. C-3 (2 of 2)

APPENDIX D

# DETAILED METHODS FOR EVALUATING COMPONENT COUNTS - SUBURBAN AREAS

## DISTRIBUTION HUB APPROACH (Tables 5.1 - 5.6)

The network configuration is shown in Fig. 5.2. The repeater spacing on the distribution trunk is evaluated using the analysis of Appendix A for a trunk achieving a 43 dB SNR over the longest transmission line. This length is given by 1.414 x radius of the distribution area + one repeater spacing.

The components count for the distribution trunk only is given in Table D-1, where

N = number of channels provided by the system

REPS = repeater spacing on the distribution trunk

NR = number of subscribers served from a distribution trunk repeater

$\frac{3}{2}(\text{REPS})^2$ x subscriber density

K = number of fibers used in the SDM-FDM approach

Within the area covered by a distribution hub, signals can be distributed to the subscribers using a switched approach or a non-switched approach with electrical or optical tapping. The details of the components count for these three distribution approaches are given in Tables D-2, D-3 and D.4, where

N = number of channels provided by the system

MSL = subscriber line maximum length

NS = number of subscribers in a distribution cell

= $2(\text{MSL})^2$ x subscriber density

K = number of fibers used in the SDM-FDM approach

ASL = subscriber line average length ASL is evaluated using the program given in Figure C-3.

FISUB = average feeder length per subscriber + drop length FISUB is evaluated using the program given in Fig. D-1.

SOSUB = average number of feeder sources SOSUB is evaluated using the program given in Fig. D-1

NSPT = number of subscribers per tap

TABLE D-1

SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
DISTRIBUTION HUB APPROACH, DISTRIBUTION TRUNK ONLY

| APPROACH | REPEATER | FIBER | SOURCES, PHOTODIODES, AMPLIFIERS | DISPERSER |
|---|---|---|---|---|
| FDM | $\frac{1}{NR}$ | $\frac{REPS}{NR}$ | $\frac{1}{NR}$ | - |
| SDM SWITCHED | $\frac{1}{NR}$ | $N\left(\frac{REPS}{NR}\right)$ | $\frac{N}{NR}$ | - |
| SDM - FDM | $\frac{1}{NR}$ | $K\left(\frac{REPS}{NR}\right)$ | $\frac{K}{NR}$ | - |
| WDM | $\frac{1}{NR}$ | $\frac{REPS}{NR}$ | $\frac{N}{NR}$ | $\frac{1}{NR}$ |

```
C
C
C
C
      PROGRAM FOR EVALUATING THE AVERAGE FEEDER LENGTH +DROP LENGTH
      (AFL + .707 A) AND THE AVERAGE NUMBER OF FEEDER SOURCES AFS
      (PER SUBSCRIBER)
      SUBURBAN AREAS - DISTRIBUTION HUB APPROACH
      OPTICAL TAPPING
C
C
C
      READ(5,*) DLOS,TLOS,ALPHA,A,REACH,NSPT,SMIN
      DBT=A*NSPT/2
1       IFEE=0
       FITOT=0
       SOTOT=0
       NUTOT=0
10     NMAX=0
       N2AX=0
        N3AX=0
      NTAP=IFIX(.5+(REACH-4*IFEE*A)/(2*DBT))
      IF(NTAP.LT.1) GO TO 3000
      I=1
      PINIT1=.667*10**(-2*IFEE*A*ALPHA/10)
      POTOT=0
100   B=(SMIN+DLOS+(I-1)*TLOS+(I*ALPHA*(2*IFEE-1)*DBT)/2)/10
      BEXP=NSPT*10**B
      POTOT=POTOT+BEXP
      IF(POTOT.GT.PINIT1) GO TO 300
      IF(I.EQ.NTAP) GO TO 1200
      I=I+1
      GO TO 100
300   NMAX=I-1
      I2=0
      POTOT2=0
350   B2=(SMIN+DLOS+I2*TLOS+(I2*ALPHA*DBT))/10
      BEXP2=NSPT*10**B2
      POTOT2=POTOT2+BEXP2
      F2LOS=-(((NTAP-(I2-.5))*ALPHA*DBT)+(2*IFEE*A*ALPHA))/10
      PINIT2=(.667)*10**F2LOS
      IF(PINIT2.LT.POTOT2) GO TO 400
      I2=I2+1
      GO TO 350
400   IF(I2.EQ.0)GO TO 900
      IF(I2+NMAX.LT.NTAP) GO TO 600
      N2AX=I2
      GO TO 1300
600   POTOT3=0
      N2AX=I2
      I3=0
650   B3=(SMIN+DLOS+(I3*TLOS)+I3*ALPHA*DBT)/10
      BEXP3=NSPT*10**B3
      POTOT3=POTOT3+BEXP3
      F3LOS=-(((NTAP-(N2AX+(I3-.5)))*ALPHA*DBT)+(2*IFEE*A*ALPHA))/10
```

FIG. D - 1 (1 OF 3)

```
      PINIT3=(.667)*10**F3LOS
      IF(PINIT3.LT.POTOT3) GO TO 800
      I3=I3+1
      GO TO 650
800   IF(I3+N2AX+NMAX.LT.NTAP) GO TO 900
      N3AX=I3
        GO TO 1400
900   WRITE(6,901)
901    FORMAT('  NOT POSSIBLE TO REACH THE LIMIT')
       STOP
1200   FL=REACH
       IF(NSPT.LE.2) FIT=REACH+NSPT*NTAP*A
       IF(NSPT.GT.2) FIT=FL+1.4142*NSPT*NTAP*A
       NU=2*NTAP*NSPT
       NSO=2
       GO TO 2000
1300   FL=(2*NTAP-N2AX)*DBT+4*IFEE*A
        IF(NSPT.LE.2) FIT=2*FL+NSPT*NTAP*A
        IF(NSPT.GT.2) FIT=2*FL+1.4142*NSPT*NTAP*A
        NU=2*NTAP*NSPT
        NSO=4
        GO TO 2000
1400    FL=((3*NTAP)-(2*N2AX-N3AX))*DBT+6*IFEE*A
        IF(NSPT.LE.2) FIT=2*FL+NSPT*NTAP*A
        IF(NSPT.GT.2) FIT=2*FL+1.4142*NSPT*NTAP*A
        NU=2*NTAP*NSPT
        NSO=6
        GO TO 2000
2000  IF(IFEE.EQ.0) FIT=FIT/2
      FITOT=FITOT+2*FIT
      IF(IFEE.EQ.0) NSO=NSO/2
      SOTOT=SOTOT+NSO*2
       IF(IFEE.EQ.() NU=NU/2
       NUTOT=NUTOT+2*NU
       IFEE=IFEE+1
       GO TO 10
3000    FISUB=FITOT/NUTOT
        SOSUB=SOTOT/NUTOT
      WRITE(6,*) FISUB,SOSUB
      STOP
      END
```

FIG. D - 1 (2 OF 3)

Program input:

DLOS, TLOS, ALPHA, A, REACH, NSPT, SMIN

Program output:

FISUB, SOSUB

Where

DLOS : drop loss (dB)
TLOS : directional coupler throughloss (dB)
ALPHA: fiber attenuation(dB/km)
A : dimension of a subscriber lot (km)
REACH: length of the diagonal of the distribution cell (km)
NSPT : number of subscribers per tap
SMIN : mean optical power required on the detector to achieve a SNR of 43 dB over the longest transmission length occurring in the distribution cell (dBm0)
FISUB: average feeder length per subscriber + drop length (km)
FISUB= AFL + 0.707 a
SOSUB: average number of feeder sources per subscriber

FIG. D - 1 (3 OF 3)

TABLE D-2

SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
DISTRIBUTION HUB APPROACH - NON-SWITCHED - ELECTRICAL TAPPING
DISTRIBUTION ONLY (DISTRIBUTION TRUNK NOT INCLUDED)

| APPROACH | DISTRIBUTION HUB | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | PHOTODIODE SELECTOR | DISPERSER |
|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $ASL + 2\frac{MSL}{NS}$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | - | - |
| SDM | $\frac{1}{NS}$ | $N\left(ASL + 2\frac{MSL}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | 1 | - |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(ASL + 2\frac{MSL}{NS}\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | 1 | - |
| WDM | $\frac{1}{NS}$ | $ASL + 2\frac{MSL}{NS}$ | $N\left(1 + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | 1 | - |

TABLE D-3

SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
DISTRIBUTION HUB APPROACH - NON-SWITCHED-OPTICAL TAPPING
DISTRIBUTION ONLY (DISTRIBUTION TRUNK NOT INCLUDED)

| APPROACH | DISTRIBUTION HUB | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | PHOTODIODE SELECTOR | DISPER-SER | DIRECTIONAL COUPLER |
|---|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{NS}$ | $FISUB + 2\frac{MSL}{NS}$ | $SOSUB + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | $1 + \frac{1}{NS}$ | – | – | $\frac{1}{NSPT}$ |
| SDM | $\frac{1}{NS}$ | $N\left(FISUB + 2\frac{MSL}{NS}\right)$ | $N\left(SOSUB + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | 1 | – | $\frac{N}{NSPT}$ |
| SDM - FDM | $\frac{1}{NS}$ | $K\left(FISUB + 2\frac{MSL}{NS}\right)$ | $K\left(SOSUB + \frac{1}{NS}\right)$ | $K\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{K}{NS}$ | 1 | – | $\frac{K}{NSPT}$ |
| WDM | $\frac{1}{NS}$ | $FISUB + 2\frac{MSL}{NS}$ | $N\left(SOSUB + \frac{1}{NS}\right)$ | $N\left(1 + \frac{1}{NS}\right)$ | $1 + \frac{N}{NS}$ | 1 | $1 + \frac{1}{NS}$ | $\frac{1}{NSPT}$ |

TABLE D-4

SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
DISTRIBUTION HUB APPROACH - SWITCHED
DISTRIBUTION ONLY (DISTRIBUTION TRUNK NOT INCLUDED)

| | |
|---|---|
| Video Switch | $\frac{1}{NS}$ |
| Fiber | $ASL + \frac{2(N \times MSL)}{NS}$ |
| Sources, Photodiodes, Amplifiers | $2 + \frac{N}{NS}$ |
| Directional Couplers | 2 |

OPTICAL FEEDER WITH AMPLIFIERS APPROACH (Tables 5.7 - 5.9)

The network configuration is represented in Fig. 5.3. The distribution trunk has no significant effect on the components count, so it can be neglected.

The components count is based on the longest tapped feeder length given by 0.707 x radius of the distribution area.

Following the analysis of Appendix B, the maximum number of taps per repeater section is evaluated for different maximum numbers of cascaded amplifiers. The maximum number of cascaded amplifiers fixes the optical power required at the repeater detectors ($P_o$ in Appendix B). This minimum optical power required at the detector is once again evaluated using the analysis of Appendix A.

For every maximum number of cascaded amplifiers it must be verified that transmission through a distribution trunk and tapped feeder can be achieved where each is of length equal to 0.707 x radius of the distribution area. This iteration continues until the right number of amplifiers is found. Then the average number of taps per repeater section of the feeder, ANT, is evaluated.

The details of the components count are given in Table D-5, where

N = number of channels provided by the system

K = number of fibers used in the SDM-FDM approach

ANT = average number of taps per repeater section

a = dimension of a subscriber lot

NSPT = number of subscribers per tap

ANS = average number of subscribers per repeater section

= ANT x NSPT

TABLE D-5

SUBURBAN AREAS - COMPONENTS COUNT (PER SUBSCRIBER)
OPTICAL FEEDER WITH AMPLIFIERS APPROACH

| APPROACH | REPEATER | FIBER | SOURCES | PHOTO-DIODES | AMPLI-FIERS | DIRECTIONAL COUPLER | PHOTODIODE SELECTOR | DISPERSER |
|---|---|---|---|---|---|---|---|---|
| FDM | $\frac{1}{ANS}$ | $\left(\frac{1+\sqrt{2}}{2}\right)a$ | $\frac{1}{ANS}$ | $1+\frac{1}{ANS}$ | $1+\frac{1}{ANS}$ | $\frac{1}{NSPT}$ | - | - |
| SDM | $\frac{1}{ANS}$ | $N\left(\frac{1+\sqrt{2}}{2}\right)a$ | $\frac{N}{ANS}$ | $N\left(1+\frac{1}{ANS}\right)$ | $1+\frac{N}{ANS}$ | $\frac{N}{NSPT}$ | 1 | - |
| SDM - FDM | $\frac{1}{ANS}$ | $K\left(\frac{1+\sqrt{2}}{2}\right)a$ | $\frac{K}{ANS}$ | $K\left(1+\frac{1}{ANS}\right)$ | $1+\frac{K}{ANS}$ | $\frac{K}{NSPT}$ | 1 | - |
| WDM | $\frac{1}{ANS}$ | $\left(\frac{1+\sqrt{2}}{2}\right)a$ | $\frac{N}{ANS}$ | $N\left(1+\frac{1}{ANS}\right)$ | $1+\frac{N}{ANS}$ | $\frac{1}{NSPT}$ | | $1+\frac{1}{ANS}$ |

## APPENDIX E

## DETAILED METHODS FOR EVALUATING COMPONENT COUNTS - URBAN AREAS

Tables 6.1 - 6.6 are applicable. The proposed distribution approaches for urban areas are the same as for suburban areas, except that no distribution trunk is required for the distribution hub approach. Refer to Appendix D. Thus Tables D-2, D-3, D-4 can be used also for urban areas. However, for the distribution hub approach with optical tapping, the input of the program for evaluating the amount of fiber and the number of sources, Fig. D-1, must be modified. These modifications are necessary because subscribers can share the same lot in the urban model.

These modifications are:

NSPT = number of lots served from one tap.

SMIN = mean optical power required on the detector to achieve a SNR of 43dB over the longest transmission length ocurring in the distribution cell (dBmO) + 10 log (number of subscribers sharing a lot).

The program output must also be modified. The values to be used in Table D-3 become:

$$\text{FISUB}' = \left(\frac{\text{FISUB} - 0.707\ a}{\text{NSL}}\right) + 0.707\ a$$

$$\text{SOSUB}' = \frac{\text{SOSUB}}{\text{NSL}}$$

where

FISUB', SOSUB' = values to be used in Table D-3

FISUB, SOSUB = output of the computer program

NSL = number of subscribers sharing a lot

a = dimension of a lot

For the optical feeder with amplifiers approach, only the factor $\frac{1+\sqrt{2}}{2}$ needs to be modified in Table D-5. It becomes

$$\frac{1}{2\ \text{NSL}} + .707$$

where

NSL = number of subscribers sharing a lot