Technical Report

A Systems Study of Fiber Optics for Broadband Communications

Activity No. 8
Outside Plant Considerations

BNR Project TR 6259
January 1978

Bell-Northern Research

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for
Communications Research Centre
Department of Communications
Government of Canada

under DSS Contract
File Number: 12ST. 36001-6-2350
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OUTSIDE PLANT CONSIDERATIONS

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1. SUMMARY AND CONCLUSIONS

This report considers a range of outside plant considerations relevant to the introduction of fibre optical networks, with special emphasis on rural areas.

Due to the wide range of subjects covered, it is hard to arrive at a unified set of conclusions. In general, little technical difficulty is seen in the installation of the required outside plant, although development work is needed in many areas to provide a network suitable for routine installation and operation by operating company craftspeople.

The powering cost estimates of chapter 3 of the report are very high, especially for the remote switches described in report 3. Prices of approximately $25,000 for 364 subscribers are quoted for powering equipment alone. In chapter 2 of the report, however, the assumptions on which this price is based are discussed, and it seems possible that this price could be halved.

The recommended cable installation technique in rural areas is by plowing. Where soil conditions do not permit plowing, the choice is between trenching, plowing in ducts and pole mounted installations.

Cable design is a subject still in its infancy, but the principles are understood and many promising designs have appeared.

Splices and connectors suitable for installation by skilled personnel are now available. The need now is to reduce the skill level required, to reduce the hardware cost, and to ensure stability of the completed splice or connector with time and changing operating environment.

Installation test methods are being developed in the laboratory, but much development work is needed to produce ruggedized test equipment which is suitable for field use by semi-skilled craftspeople.

2. INTRODUCTION AND STRUCTURE OF REPORT

2.1 INTRODUCTION AND OBJECTIVES

This report is the eighth in a series of reports which represent the output of a systems study of fibre optics for broadband communications, with special emphasis on rural areas. This study was performed by Bell-Northern Research (BNR) under contract to the Canadian government's Department of Communications (DOC). The present report is somewhat different from most of the others, since it consists of answers by several independent authors in separate groups within BNR to questions posed by the editor. The objective is to provide DOC with the latest information and opinions on the subjects covered by the contract work statement relevant to this activity report. The sections which follow in this chapter describe the areas of the work statement covered by each chapter and, where relevant, the assumptions implicit in the questions posed by the editor.

Two general comments are appropriate here - the first concerned with style, the second with content. Since five different authors have written the five succeeding chapters, differences in style and use of optional spellings will be observed. In the editor's opinion, such differences should lead to no problems of comprehension, and hence no attempt was made to edit for consistency in this area. As to content, the discussion with authors usually centered on the integrated network described in activity report 3 where a specific network was needed for illustration. However, for most of the chapters, this causes no loss in generality. For example, the nature of fibre cables, the outside plant environment in rural areas and the testing needed at installation are not strongly dependent on the network topology used. Although the location of splices and connectors and the number of couplers to be installed in the outside environment differs from network to network, the general technology and installation techniques used will be the same. Only in the chapter on powering does the network model significantly influence the figures, and this is discussed in more detail in the next section.

2.2 POWERING

Chapter 3 of this report, written by Sam Rosenberg of BNR, Dept. 2C41, surveys methods which could be used for powering repeaters, and bases the discussion on a range of power requirements. The power requirements were provided by the editor, and are discussed below. This work fulfills the contract work statement but additional work on the powering of remote switch locations as described in report 3, and of subscriber terminals are included because of their importance to the network.

The power requirements for a remote switch, as defined in report 3, are critical to the discussion in this chapter. The power requirements have been based on the assumption of 364 subscribers served by the remote switch, all of whom want one video channel and one telephony channel, one half of whom (182) want a second video channel, one quarter (91) want a third video channel and one quarter (91) want either a second telephony or a data channel. From inspection of the remote switch layout of report 3, one needs one DMS-I type switch for telephony, 364 subscriber terminals with one light source and one detector each, 455 voice frequency modulators, of which 364 are for the first telephony channel and 91 for the second telephony or the data channel, 273 video modulators, of which 182 are for second video channels and 91 for third channels. Finally, a data multiplexer and video switch with control unit are needed. It should be noted that, in this model, the first video channel is assumed to be transmitted at baseband, and therefore it does not need a video modulator. The power requirements for each of these components is shown in Table 3.1, and these figures are discussed below. Several figures may strike the reader as high. The 6W per light source and driver was based on prototype models developed within BNR. Much of the power is due to the use of two LED's in the quasifeedforward linearization configuration (ref. 2.1). How far this can be reduced is the subject of speculation. For shorter subscriber drops or lower multiplexing requirements linearization may not be needed, and power requirements of one to two watts will suffice for simpler drive circuits.

The 8 W per device for a video modulator is derived from a domestic Jerrold channel converter, rather than from the present modulators which use about three times as much power. The power consumption of these devices has never been a major consideration in their design, and it is believed that this power could be reduced, perhaps significantly. The power requirements for the VF modulators have been estimated at 5 W by analogy with the video modulators, and again could be substantially reduced by further development.

The 2 W for photodetector circuitry is based on present day technology. There is some room for reduction here, but this does not represent a large fraction of the total switch power. The power consumptions for the digital switch and data multiplexer are based on devices already produced, and are therefore not likely to change substantially.

Assuming thirty CATV channels input to the remote switch, with 364 first channels, 182 second channels and 91 third channels, the video switch needs 19,110 crosspoints. In the present model 10 extra channels for each of the 364 subscribers have been allocated for visual library, giving a total of 22,750 crosspoints. The power estimates for such a switch are based on reed relay technology. The power consumption of the control circuitry for a reed relay crosspoint is 10 mW average. Another 250 watts is needed for signalling and common control. Doubling to cover peaks in demand gives a figure of about 1kW, as expressed in the table.

It can be seen that the three principal areas of power consumption, namely light sources and drivers, video and voice modulators, could be significantly improved. The total power for the remote switch could be reduced from about 9kW to possibly 3 to 4 kW, of which anywhere from 1.5 to 4 kW would be "essential", defined as needing back-up in case of power failure.

A further change which could significantly lower the cost of powering is that of the voltage levels needed. In section 3.2.2, $4500 of the total $24,000 (approx.) for powering is used for voltage conversion. Circuit design could minimize or avoid the need for these converters. Applying some of the power reductions possible, as mentioned above, together with the use of a single voltage supply, shows that the powering cost could be reduced significantly - possibly as low as $12,000.

Similar comments apply to the other areas where power supplies are used, although the impact of reducing the power requirements will not be so dramatic as in the case of the remote switch.

In summary, because of the early state of development of most of the components needed for a network using fibre optics, the power requirements for components are very uncertain. The figures provided as a basis for chapter 3 are conservative, and much lower powers may be adequate. The author of chapter 3 has outlined in section 3.2.6 the effects which changes in power consumption would have on his results and conclusions.

2.3 INSTALLATION METHODS AND EQUIPMENT

Chapter 4 of the report was written by Fred Huszarik of BNR, Dept. 1D21. It describes the environments for both cable installation and operation. The necessary outside plant hardware and techniques for cable installation are also discussed.

2.4 CABLE DESIGN

Chapter 5 of the report was written by Bruce Board of BNR, Dept. 1D21. It is a very comprehensive review of the factors which need to be taken into account when designing a fibre optical cable. Cable design principles for underground and aerial applications are discussed, and the principles are illustrated by referring to existing cable designs.

2.5 CONNECTORS AND SPLICES

Chapter 6 was written by Grant Pacey of BNR, Dept. 1D42. It describes the types of situations requiring splicing and connecting as a result of system configurations, as well as methods for connecting and splicing under field conditions. In addition to this work which was set out in the work statement, this chapter discusses the relative merits of different methods of splicing and connecting in terms of the quality of splice or connector obtained, and also in terms of hardware complexity needed and of skill levels demanded of the craftspeople.

2.6 INSTALLATION TESTS

Chapter 7 was written by Jim Lougheed of BNR, Dept. 1D32. It discusses methods for cable testing and fault location during installation. The general principles guiding such testing are discussed, and specific examples of certain test methods are given.

2.7 REFERENCES

2.7.1 "Linearization of optical transmitters by a quasifeedforward compensation technique".
J. Straus, O.I. Szentesi
Electronics Letters 13.6, p. 159. 17th March 1977.

3. POWER COST ESTIMATES

3.1 INTRODUCTION

In this chapter cost estimates are determined for the powering requirements of each of the following installations;

1) The remote switch
2) The subscriber terminal
3) The repeater sites.

In each case only component costs could be estimated. Labour and installation costs were not included because they are very location dependent.

In each case commercial ac is shown to be generally the most cost effective power source. However, cost estimates are also given for photovoltaic, wind generators, thermo electric and fuel cell power sources for parts (1) and (3).

Scenarios are also discussed, for which these alternative power sources may be cost effective.

3.2 POWERING THE REMOTE SWITCH

3.2.1 General

The remote switch is assumed to serve 364 subscribers all of whom are assumed to want one video and one telephony channel. In addition 182 of these subscribers want a second video channel, and 91 of them want both a third video channel and a second telephony channel. Also 20 subscribers want two-way data capability.

The power requirements for the remote switch are summarized in Table 3.1. It is assumed that the essential power must have eight hours no break battery backup. This degree of backup is desirable for the non essential power as well, but some less reliable system could be tolerated if a cost savings results.

In this section the following powering schemes will be discussed.

a) commercial ac
b) renewable power (solar and wind)
c) fuel cell
d) thermo electric generator

Essential Power Requirements

	Peak Watts	Volts
a) DMS-1 switch	800	48
b) 364 light sources/drivers	2184	12
c) 365 photodetectors and circuitry	730	12
d) 455 voice frequency modulators	2275	48

Non Essential Power Requirements

	Peak Watts	Volts
e) 273 video modulators	2184	48
f) 24 channel data multiplexer	100	48
g) video switch	1000	5

Total power:
5000 W @ 48 V
3000 W @ 12 V
1000 W @ 5 V

Total essential power:
3000 W @ 48 V
3000 W @ 12 V

Total input power *; 10,300 W (Peak) @ 48 V

* Assuming 5 V and 12 V power is derived from 48 V at 75% efficiency.

Table 3.1 Summary of Power Requirements for a Remote Switch

3.2.2 Commercial AC

A commercial ac powering scheme for the remote switch would be very similar to the schemes presently used for telephone central offices if all services are provided with 8 hour backup. There would be significant difference only if essential and non essential powering were separated so as to provide backup for essential services only. Both cases are considered below, and the component cost breakdown is as follows:

	Cost in Canadian $ I (Essential backup only)	 II (Full backup)
a) Power plant meters, switches etc.	2000	2000
b) Rectifiers (48V) 3 x 100 A	7500	7500
c) Power Converters from 48 V		
10 x 500 W, 5 V, 75% efficiency	1500	1500
2 x 3000 W, 12 V, 80% efficiency	3000	3000
d) 8 hour battery backup @ 48 V		
I = 1140 Ah	2850	
II = 1680 Ah		4200
e) Isolating diode, 100 V, 150 A (for option I only)	50	
f) Power cables	7000	6000
Total Cost	23,900	24,200

Above costs are for components only, single quantity, October 1977 and do not include labour or installation. It should be noted that if commercial ac is not available, a line can be brought in from the nearest feeder. The cost of installing such a line varies from $10,000 to $30,000 per mile depending on the terrain.

3.2.3 Renewable Power

Renewable power sources such as solar or wind power are very expensive and are unlikely to compete with commercial ac at the power level required for a remote switch (i.e. 9 kW net dc power). At this power level the present and projected costs of solar and wind power systems are summarized in Table 3.2. It may be possible to reduce these costs somewhat by optimal design for specific local weather conditions and by designing for the 24 hour average consumption. However even then the total system cost could only be justified if it is less than the accumulated cost of commercial ac power, over the life of the system, discounted back to the installation date. It is not possible at this point to estimate either costs accurately and thus an exact comparison of renewable power and commercial power is not possible. However it is safe to say that renewable power sources for a remote switch will not be economical until commercial electricity costs increase by at least an order of magnitude from the present 2¢ to 3¢ per kWh.

		Cost in Canadian $ 1977	1986 (projected)
A	Solar power at 50° latitude	1,350,000	45,000
	solar array (80 kW rating)	1,350,000	540,000
	* batteries (30 days)	5,000	4,000
	voltage regulator		
	Total:	2,705,000	589,000
B	Solar power at 60° latitude	2,025,000	68,000
	solar array (120 kW rating)	2,250,000	900,000
	* batteries (50 days)	5,000	4,000
	voltage regulator		
	Total:	4,280,000	972,000
C	Wind power (10 mph average wind)		
	rotor	40,000	30,000
	tower	15,000	15,000
	alternator	10,000	5,000
	controls	5,000	4,000
	* batteries (10 days)	400,000	160,000
	Total:	470,000	214,000

* Gelled electrolyte lead acid batteries, present cost $5/Watt-day ($2 in 1986).

Table 3.2

Cost comparison of renewable power sources for a remote switch requiring 5 kW at 48 V, 3 kW at 12 V and 1 kW at 5 V.

3.2.4 Fuel Cell Power

United Technologies in the U.S. is planning to market a line of 40 kW fuel cells by around 1980. The projected cost is $14,000 U.S. It is expected that one of the models will produce 48 V dc. Fuel requirement for such a fuel cell are estimated at;

(a)	Propane: 2.7 + 1.5/kW	(kg per hour), or:
(b)	Natural gas: 50 + 7.25/kW	(ft3 per hour)

Using the above projections the cost of a fuel cell power system can be estimated as follows;

A Capital Costs;	Cost in Canadian $
a) 40 kW fuel cell (48 V output)	15,400
b) back up fuel cell	15,400
c) Piping, valves, regulators	1,000
d) Power Converters from 48 V	
10 x 500 W, 5 V, 75% efficiency	1,500
2 x 3000 W, 12 V, 80% efficiency	3,000
e) 8 hour battery backup 1680 Ah for all services	4,200
f) Power cables	5,000
Total:	$45,500 Capital Cost.

The above costs are for one site, components only and do not include labour or installation.

B Fuel Costs; October 1977, Ottawa, for 10.3 kW average power.

a) Propane @ 27.18¢ per kg; $118.40 per day, excluding delivery cost.
b) Natural gas @ $2 per 1000 ft3; $5.98 per day

In addition, if propane fuel is used, storage tanks would be required. A 1000 gallon tank (4.4 days fuel) would cost about $1200. For comparison purposes the cost of commercial ac power is about 2.5¢ per kWh and would work out to about $7.26 per day assuming an overall rectifier efficiency of 85%.

3.2.5 Thermoelectric Generators

The largest commercially available thermoelectric converter is rated at 108 W. Thus about 90 such units would be required to power a remote switch and provide the necessary redundancy for reliability. These converters can be assembled in 48 V, 12 V and 5 V banks and thus no power conversion is required and the total power requirement will be 9 kW. The cost of such a system can be estimated as follows:

A: Capital Costs;		Cost in Canadian $
a)	90 thermo-electric converters (108 W each)	300,000
b)	Accessories Spare parts, valves, regulators	25,000
c)	Power cables, breakers, etc.	7,000
d)	8 hour battery backups 1340 Ah for all services	3,350
	Total	335,350 Capital cost

The above costs are for components only and do not include labour or installation.

B: Fuel Costs; October 1977, Ottawa, for 9 kW average power.

a) Propane; 483 Kg/day @27.18¢/Kg = \$131/day (excluding delivery costs)
b) Natural gas; 26 K ft3/day @ \$2/Kft3 = \$52/day

In addition if propane fuel is used, storage tanks would be required. A 1000 gallon tank (4 days supply) would cost about \$1200.

3.2.6 Conclusions and Recommendations

At present, commercial ac is the most cost effective method for powering a remote switch. A commercial ac power system is outlined in Section 3.2.2. However, if commercial ac is not available, or if electric power costs increase by an order of magnitude or more then alternative energy sources, solar, wind, or fuel cells, would have to be considered.

If the power requirements of the remote switch were to change then the above cost estimates would have to be revised as follows:

a) Commercial ac

The total cost of a commercial ac power plant (as given in part 3.2.2) would increase (or decrease) by a factor of about 1.6 for each doubling (or halving) of the total power requirement.

b) Renewable Power

The total cost of a solar (photovoltaic) power plant would vary linearly with the power level requirements. The cost estimate of a wind power plant given in Section 3.2.3 assumes 8 generators each producing 1 kW average power. Thus the cost of this system will vary by about 12% for each 12% increase or decrease in power requirement or fraction thereof. It is important to note that the aforementioned costs of renewable power systems were based on very conservative "worst case" designs. If the specific site of the remote switch is identified and local weather data can be compiled then an optimal, minimum cost system can be designed. In particular, for a "best case" system, the battery requirements may be reduced by a factor of three for photovoltaics and a factor of five for wind generators.

c) Fuel Cell Power

The capital cost of a fuel cell power plant would not vary significantly unless the power requirement exceeds the 40 kW rating of the fuel cell. Within the 40 kW range each doubling (or halving) of power requirements will increase (or decrease) the cost of a fuel cell power plant (including 5 V and 12 V converters) by a fact or of about 1.2. If the 40 kW power requirement is exceeded then the power plant cost will double for every 40 kW increase or fraction thereof. The annual propane cost of a fuel cell system will increase (or decrease) by about $3600 for each incremental kW of average power consumption. For natural gas, the annual cost increment is $127 per kW of average power consumption.

d) Thermoelectric Power

The cost of a thermoelectric power plant would vary linearly with the installed power requirement.

Thus commercial ac will generally be the most cost effective method for powering a remote switch at most foreseeable power levels. However, two exceptions are possible, firstly if the power requirements is 40 kW then the capital cost of a fuel cell system will be about 16% higher than that of a commercial ac power plant. However, the fuel cell system will also produce about 130,000 BTU/hr in waste heat which can be used to heat a small office building. Also the energy cost of the fuel cell will be about 30% less than commercial ac (assuming $2/1000 cu. ft. for natural gas vs. 2.5¢/kWh for commercial ac). Thus from a total energy point of view (including space and water heating), the fuel cell system is more cost effective than commercial ac at a power level of around 40 kW. This breakover point would be at a lower power level for regions such as Western Canada where commercial ac costs are higher and natural gas costs are lower.

A second alternative is a hybrid system consisting of a commercial ac power plant as described in Section 3.2.2 and a solar array or wind generator providing supplementary power on an intermittent, when available, basis. In such a system, the solar array or wind generator would not require standby batteries. The installed cost of these supplementary power sources would be about $6250/kW (average) by 1986. This cost could be recovered in energy savings over the ten year life of the system if commercial ac costs average above 7.5¢/kWh. Present cost of a wind generator system is about $8,750/kW (excluding batteries) and this could be recovered in 10 years if commercial ac costs average above 12¢/kWh.

3.3 POWERING THE SUBSCRIBER TERMINAL

3.3.1 Power Requirements

i) Telephone handset, (12 V)
   .12 W conversation
   .09 W ringing

ii) Video reception, (12 V), (Excluding the TV set itself)
   1.2 W during power failure
   1.2 W operating

iii) Interface circuitry, (12 V)
   2 W for telephony

iv) Total power 3.32 W (Peak) at 12 V during power failure 3.32 W (Peak) at 12 V operating

The bulk of the above power (3.2 W) will be required at the subscriber entrance unit only, for items (ii) and (iii) above. Power required for peripheral units such as handsets is negligible and could therefore be supplied from the central power source for items (ii) and (iii).

3.3.2 Power Source

a) Non Essential Services

These include services which are allowed to fail during a power failure, i.e. TV, teletype, data modems, etc. It is assumed that each such unit will be individually powered directly from commercial ac. The major advantages of this approach (as opposed to a common power source) is that additional services can be easily added on and no power distribution system is required. In addition, battery backup can be provided (as an extra cost option) for each of these services on an individual basis.

b) Essential Services

The essential services are all equipment which must be kept operating when the supply fails. This includes telephone handsets, telephone interface (modulator/demodulator) and the light source/detector for the video reception. This power system will have 8 hour no break battery back up. The basic block diagram for powering each subscriber location is shown in Figure 3.1. The individual blocks are described below.

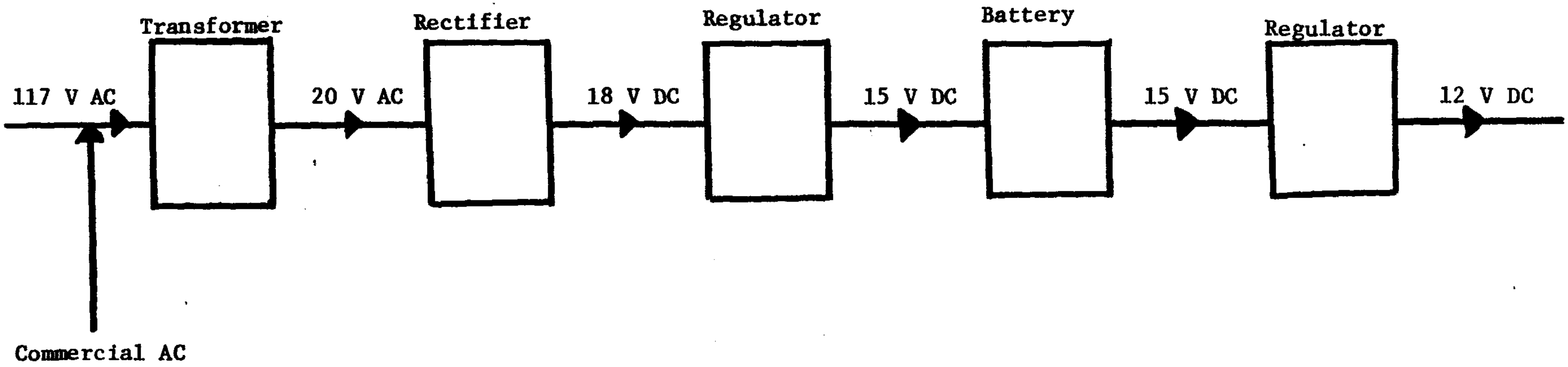

Figure 3.1. Block diagram of a 12 V DC power system for essential subscriber services.

(i) Commercial ac

The input power is assumed to be 117 V ac, 60 Hz, single phase, 2 wire.

(ii) Transformer

This will step down the commercial ac to about 20 V ac at full load. Power rating will be about 5 W. The transformer (and rectifier and regulator described below) can be encased in a plastic package complete with ac plug similar to the ac adaptors for pocket calculators. The transformer can be designed with sufficient internal impedance to be self current limiting and to be self protecting against line transients. A similar 2 W transformer made by Northern Telecom (NE-2012B-50) sells for $2.35. It is estimated that a 5 W version would cost about $4 in 500 quantity.

(iii) Rectifier

This consists of a single module bridge rectifier rated at 50 V ac, .5 A dc similar to Motorola part number MDA920A-2. Estimated cost is about $1.25 in 500 quantity.

(iv) Battery Voltage Regulator

This is a single IC fixed voltage regulator which performs two functions; it limits the battery charging current, and it maintains constant battery voltage against load changes and/or ac line fluctuation. This ensures maximum battery life. Typical ratings would be 15 V dc ± .5 V at 400 ma and an example device is Motorola part number MC7815CP which costs $1.75 in 500 quantity.

If battery voltage regulation is not required, as may be the case with nickel cadmium cells, then this voltage regulator can be removed and the internal transformer impedance can act as a current limit.

(v) Batteries

Assuming a power drain of 4 W (including output voltage regulator) and an eight hour backup a battery sizing of 32 W-hr. at 15 V would be required. This can be supplied by one of three types of cells; lead calcium, gelled lead acid, or nickel cadmium.

Lead calcium cells require at least an annual check of fluid level. They have an estimated 10-20 year life in standby applications. They cannot be sealed and have a liquid acid electrolyte which may result in a spillage and safety hazard. Estimated cost $50.

Gelled lead acid cells are completely sealed and require no maintenance. They have an estimated 4-7 year life in standby applications. Estimated cost $20.

Nickel cadmium (Ni-Cad) cells are completely sealed and require no maintenance. They have an estimated 5-10 year life in standby applications. Estimated cost $50.

Present cost situation indicates that gelled lead acid batteries would be preferable because of their maintenance free characteristic and low cost compared to Ni-Cads. However, because of their limited life it will probably be necessary to incorporate them into easily replaceable battery packs. Such packs could be dated and replacements obtained (by the customer) from a 'telephone store' (which has often been proposed for the future). If and when improvements in lead calcium cells or Ni-Cads make them more cost effective then these could also be offered as replacement battery packs.

It should also be noted that power failures of more than 8 hours duration are rare but they do occur. With the battery pack approach described above, the customer would have the option of purchasing additional battery backup.

(vi) Output Voltage Regulator

Normal battery voltage fluctuation between charge and discharge conditions is ±15% for gelled lead acid cells and ±8% for nickel cadmium cells. If this voltage range is acceptable to the various components described in Table 3.1 then no output voltage regulator will be required. If tighter regulation is required then an IC regulator similar to Motorola part number MC7812CP would be necessary. This part costs $1.75 in 500 quantity.

3.3.3 Cost Summary

The total parts cost of the 12 V subscriber power supply is summarized in Table 3.3. Costs are compared for various battery/ regulator combinations. Note that if the output regulator can be omitted then the losses inherent in this regulator do not have to be included in the system power rating, resulting in a 20% reduction in battery and transformer sizing. However, if the battery voltage regulator is eliminated, there are no savings in battery sizing but transformer size can be reduced. However, this may result in an increased failure rate in lead acid and gelled lead acid batteries.

The costs shown in Table 3.3 are for 500 quantity and do not include labour and handling. However, the labour costs for this system would be negligible and could probably be covered by the reduction in parts costs for higher quantities (1000+). Also coats shown are for 'name brand' products such as General Electric, Motorola, etc. Somewhat lower costs may be achieved by 'shopping around'.

3.3.4 Conclusion

It can be seen from Table 3.3 that considerable cost savings can be achieved if no voltage regulation is required. This implies that the loads (handset, interface, video reception, etc.) can be designed to accept ±15% voltage fluctuation and that battery life is not severely impaired. At present the life of gelled lead acid cells is a sensitive function of charging conditions. However improvements in gelled lead indicate that this sensitivity will be reduced significantly in the next 2-3 years. Thus a power system using gelled lead acid cells and no regulators should be the most cost effective by 1980-85. This system will cost about $20.25 (in 1977 dollars).

3.4 POWERING THE REPEATER SITES

3.4.1 General

Power requirements are as follows:

20 W at 12 V for 5 telephony channels
101 W at 12 V for 40 video channels, multiplexed at 3 per fibre

The telephony channels must have 8 hr backup. Similar backup for the video channels is also desirable but less reliable service could be tolerated if a saving results.

Repeater sites are distributed at 2 km intervals with a maximum of 19 repeater sites on one line and a maximum line length of 40 km.

Six different powering schemes are discussed in this section, they are:

a) On site commercial ac
b) Distributed ac
c) Distributed dc
d) On site solar power
e) On site wind power
f) On site thermo electric power

Fuel cells will not be considered in this report because 40 kW is the lowest power size of fuel cell that will be commercially available before 1990. This power size is about an order of magnitude larger than the total power requirement of an entire 40 km line. Thus it is expected that fuel cells will not be economical for this application.

For each of the powering schemes discussed in this chapter two options are considered; Option I assumes 8 hour backup for telephony only, and Option II assumes full 8 hour backup for all channels. Furthermore, in each case gelled lead acid batteries were assumed because of their low maintenance requirements as compared to conventional lead acid batteries.

		BATTERIES		
	POWER SYSTEM	LEAD ACID	GELLED LEAD ACID	NICKEL CADMIUM
a)	transformer + rectifier + battery regulator + battery + output regulator	58.75	28.75	58.75
b)	same as (a) but no output regulator	46.50	22.50	46.50
c)	same as (a) but no battery regulator	57.5	24.50	56.50
d)	same as (a) but no output regulator and no battery regulator	44.25	20.25	54.25

Table 3.3

Cost summary of powering a subscriber terminal using various regulator/battery combinations. All costs are; Canadian $, parts only, 500 quantity, September 1977.

3.4.2 On Site Commercial AC

When available, commercial ac is generally the cheapest source of power. However, it is prone to failures and thus battery backup would have to be provided for the essential services, i.e. 20 Watts for 5 telephony channels. The component cost breakdown is as follows;

			Cost in Canadian $			
			Per site		Per 40 kM line.	
			I	II	I	II
(i)	On site power conditioning		50	50	950	950
	includes: surge suppressor	$ 2				
	transformer	$20				
	rectifier	$ 2				
	filter	$ 7				
	(input power 200 W)					
(ii)	8 hours battery backup @ 12 V					
	I: 20 Ah		50		950	
	II: 80 Ah			200		3800
	Total:		100	250	1900	4750

Option I: backup for telephony only

Option II; full backup

Above costs are for components only, 500 quantity, Oct. 1977, and do not include labour or installation.

3.4.3 Distributed AC

The commercial ac power can be obtained at the remote switch and then distributed down each line. The voltage would have to be stepped up to about 2500 V in order to reduce current requirements and transmission losses. The on site transformers would then be connected in series. The backup can be either in the form of batteries at each repeater site as in 3.4.2 above, or a central battery/inverter at one of the line terminals. In either case the cost will be considerably more than for system 3.4.2 described above.

a) System A; on site battery backup

		Cost in Canadian $			
		Per site		Per 40 km line	
		I	II	I	II
i)	On site power conditioning same as 3.4.2 (i) & sites are connected in series	50	50	950	950
(ii)	8 hour battery backup same as 3.4.2 (ii)	50	200	950	3800
(iii)	Power cable ($350/km) 2500 V ac, 2 x #10AWG input power 5 kW			14,000	14,000
(iv)	Step up transformer * 600 V ac to 2500 V ac, 5 kVA			1,500	1,500
(v)	Power Plant Circuit breakers, meters, etc.			2,000	2,000
(vi)	Inside plant power distribution			2,000	2,000
	Total:			21,400	24,250

b) System B; central battery/inverter backup

		Cost in Canadian $			
		Per site		Per 40 km line	
		I	II	I	II
(i)	On site power conditioner				
	I: similar to 3.4.3 (a) (i) with separate system for telephony	75		1425	
	II: same as 3.4.3 (a) (i)		50		950
(ii)	Power cable				
	I: 2500 V ac, 2 x #10 AWG + 1 x #18 AWG, ($400/km)			16,000	
	II: same as 3.4.3 (d) (iii)				14,000
(iii)	Inverter (including H.V. Transformer)				
	I: 800 V VA 80% efficiency			5,000	
	II: 5 kVA, 80 % efficiency				12,000
(iv)	8 hour battery backup @ 48 V				
	I: 140 Ah			350	
	II: 840 Ah				2,100
(v)	Rectifiers (for battery charging)				
	I: 48 V, .1 A dc			50	
	II: 48 V, .625 A dc				100
(vi)	Power Plant (same as 3.4.3 (a) (v)			2000	2000
(vii)	Inside plant power distribution			2,000	2,000
	Total:			27,825	35,150

Option I: battery backup for telephony only.
Option II: full backup

Above costs are for components only, single quantity, Oct. 1977, and do not include labour or installation.

* Step up transformer will not be necessary if commercial ac is available at 2500 V.

It is significant to note that System A, (on site battery backup, is cheaper than System B (central battery/inverter backup). Furthermore, on site battery backup provides better reliability against breaks in the power cable.

3.4.4 Distributed DC

In this system commercial ac power is rectified and converted to a high voltage current feed which is passed down to the repeater sites via a power cable. At each site a dc to dc converter provides power for the repeaters. The on site converters are all connected in a series string. The battery backup can be either on site or centralized at either end of the 40 km line. The cost breakdown for each case is as follows;

(a) System A; on site battery backup

		Cost in Canadian #			
		Per site		Per 40 km line	
		I	II	I	II
(i)	On site converters	75	75	1425	1425
	includes: input filter $10 switching regulator $50 transformer $10 rectifier $ 2 output filter $ 3 input power 200 W, input voltage 100 V dc				
(ii)	On site batteries 8 hrs @ 12 V				
	I: 20 Ah	50		950	
	II: 80 Ah		200		3800
(iii)	Power cable ($350/km) 2500 V dc, 2 x #10 AWG input power 5 kW			14,000	14,000
(iv)	Central power converter			15,000	15,000
	5 kW 1000 V dc output (without backup)				
	48 V input, 75% efficiency			2,500	2,500
(v)	Rectifier 48 V, 150 A				
(vi)	Power Plant same as 3.4.3 (d) (v)			2,000	2,000
(vii)	Inside plant power distribution			2,000	2,000
	Total:			37,875	40,725

(b) System B, central battery backup

		Cost in Canadian $			
		Per site		Per 40 km line	
		I	II	I	II
(i)	On site converters				
	I: separate converter for telephony	100		1,900	
	II: same as 3.4.4 (a) (i)		75		1,425
(ii)	Power cable 2500 V dc				
	I: 2 x #10 AWG, 1 x #18 AWG			16,000	
	II: same as 3.4.4 (a) (iii)				14,000
(iii)	Central power converter same as 3.4.4 (a) (iv)			15,000	15,000
(iv)	Backup converter				
	I: 800 Watts, 1000 V dc			6,000	
	II: same as 3.4.4 (a) (iv)				15,000
(v)	8 hour battery backup @ 48 V				
	I: same as 3.4.3 (b) (iv)			350	
	II: same as 3.4.3 (b) (iv)				2,100
(vi)	Rectifier (48 V) same as 3.4.4 (a) (v)			2,500	2,500
(vii)	Inside plant power distribution			3,000	3,000
	Total:			44,750	53,025

Option I: backup for telephony
Option II: full backup

Above costs are for components only, single quantity Oct. 1977, and do not include labour or installation.

3.4.5 On Site Solar Power

A solar power system consists of the following major components.

(a) A solar cell array which converts sunlight to dc electricity. These are sold on a "peak watt" basis and at 50° latitude 10 "peak watts" are required to produce one average watt (at 60° latitude 15 peak watts are required).

(b) A voltage regulator which controls the battery charging current.

(c) Batteries which provide energy backup for nighttime overcast conditions, and low winter sun. At 50° latitude 30 days of battery storage is recommended(50 days at 60° latitude).

A large degree of battery backup is thus an integral part of any solar power system, therefore full backup is inherently provided for both telephony and non-telephony channels.

The component cost break down is as follows;

	Costs in Canadian $ per site			
	1977		1986	
latitude	50°	60°	50°	60°
(i) Solar array (140 W average) 1400 "peak watts" at 50° latitude 2100 "peak watts" at 60° latitude $15/peak watt in 1977 50¢/peak watt in 1986	21,000	31,500	700	1050
(ii) voltage regulator and wiring.	150	150	150	150
(iii) batteries @ 12 V 7260 Ah at 50° latitude 12100 Ah at 60° latitude $2.5/Ah in 1977 $1/Ah in 1986	18,150	30,250	7,260	12,000
Total per site	39,300	61,900	8,110	13,300
Total per 40 Km line	746,700	1,176,100	154,090	252,700

Above costs are for components only, 19 sites, October 1977, and do not include labour installation or land costs for arrays, (approximately 30 m^2 per site at 50° latitude, 45 m^2 at 60° latitude. Cost projections for 1986 are based on U.S. Energy Research and Development Administration (ERDA) estimates which are in constant (1977) U.S. Dollars. Rate of exchange is assumed at $Cndn = .9 $U.S.

3.4.6 On Site Wind Power

A wind power system consists of a wind driven turbine which is mounted on a tower typically 5 to 20 m high for a horizontal axis turbine and 2-5 m for a vertical axis turbine. This turbine drives an alternator/rectifier which produces dc electricity. A battery is required for supplying electric power during "calms" or low wind conditions. The amount of battery storage will be determined by local wind conditions but typically will be 2 to 10 days. A current limiter/voltage regulator system is also required to control alternator current and battery charging.

A large degree of battery backup is thus an integral part any wind power system and therefore full backup is inherently provided for both telephony and non telephony channels.

The component cost breakdown is as follows:

		Costs in Canadian $ per site 1977
(a)	150 W* (average) wind generator, including controls	4,500
(b)	Tower (20 meters)	2,000
(c)	Wiring	500
(d)	Batteries (10 days backup) 2420 Ah @ 12 V	6,050
	Total per site:	13,050
	Total per 40 kM in line:	247,950

Above costs are for components only, 19 quantity October 1977, and do not include labour and installation.

* The assumed generator is rated at 2 kW at 25 mph. This will produce an average power of 150 W at an average wind speed of 8 mph. Average wind speed for most of Canada is greater than this.

3.4.7 On Site Thermoelectric Power

A thermoelectric generator consists of a propane (or natural gas) burner which directs its heat to a thermocouple. The thermocouple produces dc electricity directly. This system inherently produces continuous power (except for a few minutes during annual maintenance) as long as fuel is supplied. Thus no backup is required except during maintenance. The maintenance backup can be made portable and supplied as needed by maintenance personnel.

An integral part of a thermoelectric power system is a fuel supply, which can be either continuous feed as with a natural gas supply from a gas company or a stored supply from finite capacity storage tanks. For this study it is assumed that one year's supply of liquid propane is stored in tanks which are refilled annually.

The component cost breakdown is as follows:

			Cost in Canadian $per site	
			capital cost	annual fuel cost
(i)	Thermoelectric converters 2 units 108 W each		6880	
(ii)	accessories		780	
	automatic ignition	$290		
	voltage limiter	$350		
	spare parts	$140		
(iii)	storage tank 1100 gals. for 1 yr supply of propane.		1200*	
	pipes, valves, guages and regulators		400*	
(iv)	1 year fuel supply 2120 Kg propane @ 27.18¢/Kg (Aug. 1977 Ottawa)			575
	Total per site		$9,260	575
	Total per 40 Km		175,940	10925

Above costs are for components only, on site, January 1977, except as indicated by * in which case costs are based on 1973 quote including 1.5 inflation factor. Costs do not include labour, installation or transportation of fuel. Note: fuel storage could be replaced by cheaper battery backup if continuous natural gas supply is available or if regular (and frequent) propane delivery is feasible.

3.4.8 Conclusions

The cost of powering a 40 Km line using each of the aforementioned powering schemes are summarized in Table 3.4. It can be seen that the cheapest alternative is on site commercial ac. If commercial ac is not available at each site then a distributed ac system (with on site batteries) is the next cheapest alternative. However, such a distributed high voltage ac system may cause 60 cycle hum and interference with local communications. The degree of interference can only be determined by a more comprehensive study. The interference problem can be significantly reduced at slightly higher cost by using a distributed dc system with on site batteries.

In either of the above alternatives, on site commercial ac or distributed dc, the increased cost of providing full eight hour battery backup for all channels is relatively modest, as indicated in Table 3.3.

			Cost in Canadian $1000	
			Option I	Option II
(a)	On site commercial ac		1.9	4.8
(b)	Distributed ac with on site batteries		21.4	24.3
	- with central batteries		27.8	34.2
(c)	Distributed dc with on site batteries		37.9	40.7
	- with central batteries		44.8	53.0
(d)	On site solar power	1977	746.7	746.7
	(50° latitude)	1986	154.1	154.1
(e)	On site wind power	1977	248.0	248.0
(f)	On site Thermoelectric power (excluding $10,925/annum fuel cost)		175.9	175.9

Table 3.4

Cost comparison of six powering schemes for a 40 km repeater line. Option I; 8 hour backup for telephony channels only, Option II; full 8 hour backup for all channels.

It is significant to note that, at present prices, on site solar or wind powering is prohibitively expensive. However, by 1986 the projected cost reductions in solar cells and wind generators may make these systems potentially cost competitive with a distributed dc system. By then these renewable power sources will be particularly attractive in the context of anticipated significant increases in the cost of commercial ac power. It is also significant to note that the solar and wind power cost estimates are based on conservative "worst case" design assumptions. Once a particular site is identified and local weather data can be obtained a specific optimum system can be designed which may result in significant cost reductions.

In summary, the recommended powering scheme is alternative (a), on site commercial ac, as described in Section 3.4.2. If commercial ac is not available at a majority of sites then option (b), (distributed ac) or option (c) (distributed dc) are recommended. Solar or wind power may become cost effective in the future as solar power costs decrease, and commercial ac costs escalate.

From a reliability point of view, all systems with on site batteries are approximately equally reliable and are significantly more reliable than distributed power systems with central battery backup. In this study only eight hours battery was assumed, however, reliability can be increased somewhat by increasing the battery backup. In particular it is important that the backup time be greater than the mean time to repair for each powering scheme.

4. INSTALLATION METHODS AND EQUIPMENT

4.1 INTRODUCTION

This chapter discusses the factors and considerations pertinent to the installation of fiber optic cable systems. It must be remembered that field experience with handling and installing fiber cables has been limited to-date. The installations which have occurred have often been performed under controlled field conditions. Consequently, the results of such test installations should be considered as optimum in terms of future fiber cable installation results. Nevertheless, the general indication is that fiber cable installation methods and tools will not differ greatly from more conventional cable installation methods and tools.

This chapter initially describes the outside plant environment to which cables and apparatus will be exposed both during the construction phase and the long term operational phase. The environment is examined in terms of the three basic geographical subdivisions: urban, suburban and rural. Section 4.3 describes the cable installation techniques applicable to each of the urban, suburban and rural environments. Finally, section 4.4 discusses the structures aspects which must be considered for the fiber optic distribution network.

In this report the term 'structures' is defined to include manholes cabinets and huts. Also, the basic construction techniques are categorized as follows. Aerial construction includes all cases in which outside distribution cables and hardware are mounted above ground level on utility poles or similar structures. Undergrounding or underground construction refers to the practice of laying cable in underground conduit or in underground utility tunnels. In underground systems, electronic hardware is commonly located below ground level in manholes or vaults. Direct burial refers to the practice of laying cable directly in the ground without conduit. In buried systems, electronic hardware may be located above ground in pedestals. Joint trenching (in direct burial) refers to the sharing of a single trench by two or more utilities.

4.2 INSTALLATION AND OPERATIONAL ENVIRONMENTS

4.2.1 General

Table 4.1 illustrates the environmental conditions typically encountered in the field during and after construction. It should be noted that the limits cited in Table 4.1 should not be construed as design parameters.

	BURIED		UNDERGROUND		AERIAL	
	CONSTRUCTION	OPERATION	CONSTRUCTION	OPERATION	CONSTRUCTION	OPERATION
TEMPERATURE						
- Avg. (°C)	-40 to +32	0 to +15	-40 to +32	0 to +15	-40 to +32	-40 to +32
- Extreme (°C)	-50 to +50	-5 to +25	-50 to +50	-5 to +50	-50 to +50	-50 to +50
- Shock (°C/min)	20°C/min	5°C/min	20°C/min	5°C/min	20°C/min	20°C/min
HUMIDITY						
Max.	Immersion	Immersion	Immersion	Immersion	Immersion	Immersion
HANDLING FORCES						
Vibration	3.5g	0.5g	3.5g	0.5g	3.5g	0.5g
Crush	1000 lb	1000 lb	1000 lb	1000 lb	N/A	N/A
WIND						
Pressure Max.	N/A	N/A	N/A	N/A	25 psf	25 psf
SNOW						
Load Max.	N/A	N/A	N/A	N/A	0	100 psf
ICE						
Load Max.	N/A	N/A	N/A	N/A	0	½in @ 56lb/ft^3
DUST	Immersion	Immersion	Immersion	Immersion	Immersion	Immersion
GROUND FROST	0	Immersion	0	Immersion	N/A	N/A

TABLE 4.1

These figures merely represent an average for the most populated parts of Canada.

Temperatures during the construction phase can range from -40°C to +32°C, with extremes of -50°C to +50°C. Although the construction process may stop long before the extreme temperature limits are reached, cable and apparatus could still be exposed to these extreme temperatures. From an operational point of view, buried and underground systems will normally be exposed to temperatures in the range of 0°C to +15°C with extremes of -5°C to +25°C. Aerial installations will of course be subjected to much more extreme temperature conditions. Thermal shock is of importance primarily during the construction phase. Cable and apparatus is often moved from an indoor environment to an outdoor environment during the installation process. This type of activity can result in a temperature shock of 20°C/min. After installation the thermal shock for below-ground systems is considerably reduced.

The safest assumption with regard to humidity exposure is to assume total immersion of the cable and apparatus during both the construction and operational phases. One can be quite certain that in most parts of Canada a high proportion of the below-ground outside plant is either partially or completely submerged in water.

The maximum vibration forces are usually encountered during transportation. Crush forces on cables are of concern both during and after installation. However, experience has shown that most damages caused by crushing of the cable occur during the installation phase. Ground frost or ice pressures are the major contributors to crush damage during the operational phase.

Wind, snow and ice loads are factors to be considered primarily for the above-ground portion of the network. The magnitude of these loads will of course vary from location to location. For design purposes, reference should be made to the National Building Code of Canada, Supplement No. 4. The code provides wind, snow and ice data for many locations throughout Canada.

From a practical point of view one should consider cables and outside plant apparatus and hardware to be completely immersed in dust. Although the operational environment for some components of the system is specifically designed to eliminate dust, there is no guarantee that this requirement is met during the construction phase.

4.2.2. Urban and Suburban Environments

In addition to the general parameters described in Table 4.1, there are several environmental factors which must be considered as a function of location rather than method of installation.

Installations in urban or suburban locations are often exposed to much higher concentrations of pollutants than rural installations. Probably the most damaging below-ground pollutant that is frequently encountered at these locations is gasoline or other petroleum by-products. These pollutants often migrate through the soil from leaks or spills at gasoline stations and eventually end up in the manhole and conduit systems under the city streets. Aerial installations also can be affected by the higher concentrations of atmospheric pollutants usually found in urban and suburban locations.

The higher airborne dust concentrations found in heavy traffic areas can have a considerable impact on the successful performance of construction operations such as splicing. Also ground temperatures in urban and suburban locations tend to be lower than in rural areas. This is attributed to the removal of ground snow in the cities, which in the rural areas provides thermal insulation. Urban and suburban traffic congestion also contributes to the logistics problems encountered during system installation. For example, restrictions on working hours in the streets can result in much of the work being performed at night. Restrictions such as these can increase the time that cable and apparatus is exposed to the harsh above-ground environment.

4.2.3 Rural Environment

In some respects, the rural environment tends to be less damaging to cables and apparatus than the urban and suburban environments. In rural locations both above- and below-ground plant is exposed to fewer pollutants. The traffic problems associated with urban and suburban installations are considerably reduced in rural locations. On the other hand, aerial fiber cables will be exposed to higher wind, snow and ice loadings in rural locations. Because of the more rugged environment, below-ground installations are more subject to damage from soil or rock abrasion, tree roots, and other subsurface obstacles. From an electrical protection point of view, rural installations tend to be more susceptible to lightning damage since there are fewer above-ground structures to act as grounds.

4.3 CABLE INSTALLATION METHODS

4.3.1 General

As mentioned previously, fiber cable installation methods, tools and materials will probably not differ greatly from present concepts. It is important, however, to recognize that fiber cables may have physical and mechanical characteristics which are quite different from present copper or coaxial type cables. Therefore, a considerable amount of work still needs to be done to evaluate the detailed impact of these variations in cable characteristics on standard installation practices.

The general concepts deemed applicable to fiber cable installations in urban, suburban and rural locations are discussed below.

4.3.2 Urban Installations

In many Canadian cities and towns regulatory bodies are insisting that all utilities install their outside plant 'out-of-sight'. It seems inevitable that this requirement will become even more common in the near future. Along with the 'out-of-sight' restriction come the logistics problems and extremely high costs associated with excavating ground in an urban environment.

In most large urban centers existing congestion under city streets and the problem of accurately locating existing plant has made the installation of new systems extremely difficult using conventional trenching techniques. In addition, traffic disruptions, limited work space for heavy machinery and stringent safety restrictions on activites such as blasting can result in monumental logistics problems. In order to alleviate some of these basic problems at least two solutions appear practical. First, the continued development of reliable high capacity transmission systems will allow for more efficient use of the available underground space. The replacement of copper conductor cables by fiber cables in urban conduit systems will greatly increase the transmission capacity per conduit. Second, deeper installations in the heavily populated urban centers will allow for the physical expansion of existing distribution systems. This approach implies, of course, the development of utility tunnels or 'utilidors'. Suffice it to say that many reports and papers have been published on the pros and cons of utility tunnels. It should be pointed out however, that from a construction point of view, new developments in the area of underground tunnelling are making this concept a more viable economic alternative. For example, recent tests have shown that high pressure water jets assisting a conventional roller cutter, rotary tunneler can double the cutting rate of that machine (see section 4.3.5). Although still in its embryonic stages, research in the area of small diameter rock melting tunnelers has met with some success. Technological advances such as these can have a major impact on reducing tunnel construction costs in the future. In addition to these 'exotic' tools, improvements in cutter designs, metallurgy and automation of more conventional boring machine are constantly reducing the costs and increasing the speed at which small diameter tunnels can be constructed. It is quite conceivable that in the near future the requirement for surface construction in major urban centers will be superceded by 'out-of-sight' tunnelling thirty or more feet below the surface.

4.3.3 Suburban Installations

As in urban centers, the policy of 'out-of-sight' distribution systems is becoming more and more prevalent in suburban and small town locations. The choice of installation methods is, however, more diversified than in urban locations. This is due primarily to the relatively uncongested below-ground conditions in the suburbs and the ability to install systems before streets and buildings are constructed.

In those cases where existing streets or sidewalks must be cut, the conventional trenching technique is normally used. One exception to this occurs at major road crossings where boring or tunnelling often becomes a more desirable alternative for two major reasons. First, the tunnelling operation results in minimal disturbance to the steady flow of traffic and therefore enhances both public relations and the safety of the workmen. Second, the problem of pavement removal and replacement is eliminated. Pavement replacement is often a major problem in terms of achieving adequate compaction in the trench to avoid seasonal pavement repair costs. In good soil conditions such as loose fill or sand, horizontal earth augers provide an efficient and economically attractive technique for crossing roads, sidewalks and driveways. In rocky locations horizontal rock boring machines can drill an 11 inch diameter hole at 20 feet per hour, or a 60 inch diameter hole at an average speed of one foot per hour in solid limestone. These machines drill harder rocks at slower speeds, while maintaining good accuracy at distances up to 500 feet. Research is presently underway to increase the effective drilling distances and accuracy of these small diameter rock boring machines.

In suburban locations where the ground can be easily penetrated and cables are to be buried rather than placed in ducts, the cable plow is by far the most efficient tool that can be used. As well as being the least damaging to the terrain, plowing is by far the least expensive and fastest cable installation method. The major deterrent to plowing in a suburban environment is the frequency with which one encounters obstacles such as driveways, fences, existing utilities and so on. In such problem locations consideration must be given to the use of continuous trenching machines.

Although many urban and suburban centers are located in areas with a reasonable amount of soil cover, bedrock or boulder concentrations are sometimes encountered. This situation can create severe problems, especially in a populated environment. Normal blasting techniques often cannot be applied due to stringent safety regulations. Even if blasting is allowed, restrictions on the size of explosive charge make this excavation method extremely time and money consuming. In suburban locations the alternatives to blasting include the use of pneumatic rock hammers, 'Hoe-rams', rock splitters and rock saws. Although all these devices are effective to varying degrees, none is particularly efficient and all are very costly to operate.

4.3.4 Rural Installations

A large percentage of below-ground installations occur in rural or relatively unpopulated areas. Even though the option to place systems above ground exists, it is often cheaper to bury. This is particularly true in areas where there is sufficient soil cover to permit plowing.

Plowing is the cheapest, fastest and most environmentally acceptable method of installing cable presently available. Cable plows can bury everything from small diameter drop wire to 3-inch diameter cable, up to six feet below the surface. Also plows which can bury up to four or five cables at a time are available. These machines can install cable at rates up to approximately 1 mile/hour with little disturbance to the ground surface and consequently minimal clean-up costs. Even more attractive is the fact that cables can be installed for considerably less than one dollar per foot. Plowing is, however, very sensitive to ground conditions and is therefore restricted to locations where good, obstacle free soil cover exists. To-date, there exists extremely little field experience in the area of fiber cable plowing. Some preliminary tests have recently been conducted, but the results have not yet been published. The general indications are, however, that fiber cable plowing is feasible with only minor modifications to the existing equipment.

Less than half of the North American continent consists of what is normally referred to as good plowable terrain. The rest is a mixture of boulders, bouldery till and bedrock which normally must be trenched. Bouldery areas or generally poor soil conditions can often create more problems than bedrock. Wet soils or heavy boulder concentrations can be extremely difficult to excavate. When they are excavated it is often difficult to maintain a good trench profile. Furthermore, considerable care must be taken in placing as well as backfilling cables or structures to prevent damage to the installed plant. The type of trenching equipment used is frequently determined by the soil type. Loose materials with stone sizes less than two or three inches can be excavated with continuous wheel or chain trenchers. Soils containing larger stone sizes or heavily compacted materials usually require backhoe type excavators. Associated with trenching is the requirement for wide rights-of-way and a considerable clean-up budget.

In some poor soil conditions an alternative to trenching that is becoming more popular is the concept of plowing a protective continuous duct prior to pulling the cable. Although more expensive than direct burial, this method is usually less costly and faster than trenching. Initially a rock ripper is used to create a slot and remove obstacles such as large boulders and tree roots along the proposed route. Once this has been accomplished a cable plow installs a continuous section of flexible polyethylene duct. The duct provides the mechanical protection which is usually supplied by sand padding around a trenched cable. After the duct has been installed and proven, the cable is pulled into the duct. This technique has been used successfully on projects where direct burial by plowing was not feasible due to poor soil conditions and where the more costly trenching method would normally have been used.

The problem of installing outside plant in rural locations where bedrock exists at or near the surface is somewhat less acute since blasting is usually an acceptable excavation method and the aerial placing option is available. Pole line installations are definitely less expensive than blasting a continuous trench. However, for a variety of reasons the amount of rock trenching presently being performed is significant and will probably increase in the future.

At the present time rock trenching on a continuous basis is limited to essentially three methods: breakage and excavation by machine; rock cutting with continuous saws, and blasting and excavating. Where soft, weathered rocks such as shale, weak limestone and sandstone exist, it is often feasible to break and excavate the material with a backhoe. Alternatively, rock rippers can be used to break the material which can then be excavated by backhoe. Cutting with circular rock saws is becoming a common method of trenching in rock. However, there are some drawbacks with these saws. First, they are normally limited to a 36 inch depth of cut. Second, they have limitations in the type of rock that they can cut effectively. Third, on long excavations the tooth replacement and general maintenance cost can be extremely high. Despite these limitations, the rock saw can be a useful tool for sections up to 100 feet in length. The third trenching methods, blasting and excavating, is the one used most frequently for major rural installations in rock. Blasting is, of course, noisy, dirty, somewhat hazardous and expensive; but in hard rocks it is often the only alternative.

4.3.5 Future Cable Installation Methods

Two technologies which may have an impact on fiber cable installation methods in the future are: (1) High Pressure Water Jetting, and (2) Rock Melting Subterrenes.

(1) High Pressure Water Jetting

Since the mid-1950's waterjets have been effective tools for cutting rock. Laboratory tests have shown that water passing through small diameter (0.1 inch) nozzles at pressures of 50,000 to 100,000 psi can easily cut into the hardest rock. However, pumping equipment that is capable of reliably maintaining the high pressures required for continuous cutting has only recently become available. During the past four years, a large number of waterjet cutting systems have been placed in industries for cutting a wide range of material. These machines have proven to be reliable and economically beneficial.

There are many ways in which waterjets can be used for cutting rock, and, among them, two stand out as the most effective. In the first method, the waterjet is used to assist or augment a mechanical system. This is done by making narrow slots, from 1/10 to 1 inch deep, in the rock with the waterjet. The slots weaken the rock and significantly reduce the mechanical forces required of the cutters to remove the rock between the slots. This method has been successfully used in waterjet-assisted drilling and tunnel boring projects.

The second method of cutting rock with waterjets is to cut a wide, deep slot in the rock by using a rotating or oscillating nozzle, which can enter the slot. In this way, the slot depth is limited only be the mechanical design of the system and not by the cutting ability of the waterjet. This method required more energy to remove a volume of rock than the mechanically assisted method, but requires no mechanical loads.

The attractive features of waterjet devices for utility construction applications include little noise and environmental pollution, safety in populated areas and increased productivity. In addition, since water is the cutting medium, no mechanical cutters need replacing thereby eliminating a major operational expense currently encountered with mechanical rock cutters. Although still in the preliminary stages of development, it is expected that this type of equipment will impact on utility construction as early as 1978.

(2) Rock Melting Subterrene

The Subterrene is a device which has the capability to melt small diameter holes in most rocks and some types of soil. In general rock and soil are composed of minerals which have a melting point about 1450 K (2150°F). Refractory metals, such as molybdenum and tungsten, have a higher melting point and are used for the penetrator body material. An electrical resistance heater operates the tip at 1800 K (2800°F). The melted rock is formed into a glass lining to seal and support the walls of the bore-hole. Any excess melt is chilled and formed into glass pellets which are extruded through the stem of the system. This concept of rock-melting offers more than just a new method of breaking or disintegrating rock. It provides simultaneously the three major elements of the conventional excavation process:

1. Making the hole or tunnel.
2. Supporting the wall.
3. Removing the debris.

Although this technique offers many advantages for 'out-of-sight' cable installations, there is still considerable research required in the area of penetration speed and penetrator life. Also the problems of safety and below-ground obstacle location require further study before this concept can be used for utility construction.

4.4 STRUCTURES

4.4.1 General

This section discusses considerations for the use of various types of structures for the fiber optic system. In this report the term 'structures' is defined to include manholes, cabinets, and huts.

4.4.2 Manholes

Below-ground manholes are used primarily as repeater or splice housings. Almost all of the manholes in use today are of either cast-in-place concrete or precast concrete construction. Due to the ease of installation and generally lower costs, precast manholes are usually preferred. An exception to this is in the case of non-standard size manholes which must be cast-in-place or constructed on-site. In many parts of Canada the major drawback to concrete manholes is the problem of water infiltration. Since one must anticipate that these manholes will be dirty, damp and quite possibly filled with water most of the time, measures must be taken to properly protect all the internal fiber optic equipment and apparatus. This implies the need for waterproof repeater cases and splice closures. Also practices must be developed which will protect the equipment from the manhole environment during routine maintenance procedures.

Consideration must also be given to the splicing operation during system construction. Since fiber splicing techniques rely on a relatively clean environment, the manhole environment may have to be conditioned during the splicing operation. Field experience in this area has shown that splicing can be performed successfully when the proper precautions are taken.

One alternative to conventional concrete manholes is the concept of a completely environmentally controlled underground equipment station. By providing a temperature and humidity controlled environment, repeater equipment can be installed on open equipment bays rather than in apparatus cases. This concept permits easy maintenance of installed line equipment and also allows for expansion and/or replacement of existing equipment with new systems. Pressurization systems would not be necessary to protect the equipment. High operating environment reliability would result in an increase in the overall system availability. BNR has recently designed and installed a prototype station. A field evaluation of the performance characteristics of this concept is in progress.

4.4.3 Cabinets

If the volume of the equipment that is to be housed is relatively small, say less than 6 cubic meters (≃ 200 cubic feet), then above-ground cabinets or pedestals could be used. The major drawback to these types of housings is the difficulty in achieving and maintaining the proper environment. This problem is especially acute when these housings are accessed for routine maintenance purposes. During this operation the equipment is often exposed to the weather-creating moisture and dust problems. Nevertheless, if this type of environment can be tolerated, cabinets are considerably less expensive when compared to manholes or above-ground huts.

4.4.4 Huts

The housings used most often for large equipment volumes are above-ground huts. Huts can be pre-fabricated or built on-site. The most common materials used for the construction of huts include concrete, brick, wood-frame, fiberglass and steel. The choice of construction material is usually dependent on local availability and costs.

The major advantages associated with huts are easy environmental control, ease of access and construction. The major disadvantage is not technical but legal or political. Many municipalities are becoming very strict in regard to utilities placing above-ground structures in built-up areas. This is especially true in urban and suburban locations. The restrictions often force utilities to house their equipment in the less desirable manhole environment or in existing private or commercial buildings. Both of these alternatives have their associated problems which can be overcome. It is important to consider, however, that because of the restrictions on above-ground huts the cost of housing electronic equipment in an urban or suburban location can be quite substantial. Certainly equipment housing costs tend to be higher in urban and suburban locations than in rural locations.

5. CABLE DESIGN

5.1 SCOPE

This chapter is mostly concerned with general cable designs for outdoor applications because, within this constraint, cables suitable for a particular placing environment will have much in common, with many similar design requirements. Discussion of particular features of an aerial, underground, or buried cable is limited to those aspects where differences exist. The basic design criteria are defined, and the importance of specifying the mechanical and environmental performance requirements of the cable is discussed. The individual components of a cable, and the component and cable characteristics required in order to survive the environmental conditions that prevail during installation and operation, are described in detail. Existing fiber optic cable designs are classified according to the strength member location and the method of fiber containment. These designs, and proposed large-capacity cable designs, are evaluated, and the required improvements are identified.

5.2 INTRODUCTION

For the networks described in Activity Report No. 3, a complete range of local trunk, feeder, distribution, and drop cables will be required. Physical differences between these cables will be largely a matter of size, governed by the number of fibers they are required to carry. Mechanical differences will be determined by the outdoor placing and operational environment described in Chapter 4. Thus these cables will be treated by addressing the subject of cable size and proposed solutions to the problem of cabling large numbers of fibers, as may be required with local trunk and feeder cables.

For rural integrated networks (Activity Report No. 3, Sections 6.5 and 6.6), underground (duct), direct buried, and aerial cables may be required: a complete range of placing conditions may be encountered. The method chosen will depend on the particular terrain, the relative cost of the various placing methods, and the level of security required from vandalism and the environment, which is dependent on the hierarchical importance of the cable (trunk, feeder, distribution, or drop cable). Similarly with suburban cables, all methods of placing may be used, although the proportion placed in ducts will probably be higher. In urban areas, only underground placing is employed.

5.3 CABLE DESIGN CRITERIA

The basic features of a sound cable design are as follows (Ref. 5.1):

(a) Adequate tensile strength, with strain on the fiber(s) severely limited to a value less than the breaking strain of the fiber (0.1% - 3%, depending on the fiber and its coating).

(b) Protection of the fibers from adverse mechanical effects that may degrade the fiber mechanically and optically. This includes isolating the fibers from stresses caused by thermal expansion or contraction of adjacent cable elements.

(c) Adequate flexibility without straining fibers.

(d) Protection from external mechanical and environmental influences.

In addition, matters relating to material and production costs and ease of manufacture of the cable will exert a controlling influence over design of a commercial cable.

In order to design a cable, it is necessary to specify the fiber and cable performance required for the application. The fiber optic cable must retain its desirable features during installation and throughout its operating life. It must also be capable of being installed and spliced by relatively simple and fast methods. This specification will influence not only the finished cable, but also the choice and assembly of the cable components, and therefore the manufacturing techniques employed. The principal properties usually included in such a specification are listed in Table 5.1, and some of the mechanical properties are discussed in References 5.2, 5.3. Examples of performance specifications for particular cables can be found in References 5.4, 5.5, 5.16. A number of papers (References 5.4, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.26) also describe in varying detail the evaluation and testing of cables to determine whether they meet their respective specifications.

5.4 CABLE COMPONENTS

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

(i) coated fibers

OPTICAL	PHYSICAL	MECHANICAL AND ENVIRONMENTAL
Attenuation Dispersion and/or bandwidth Numerical aperture Refractive index profile	Number of fibers Fiber dimensions: core cladding coating(s) Cable diameter Cable unit mass Lifetime Coating materials Sheath materials	Temperature Humidity & Moisture resistance Tensile strength Minimum bending radius Flexibility Torsional flexibility Crush resistance Impact resistance Abrasion resistance Vibration

TABLE 5.1: PRINCIPAL PROPERTIES SPECIFIED FOR FIBER OPTIC CABLES

(ii) tensile strength member(s)

(iii) sheath, including armour and moisture barriers

(iv) cushion layers and fillers

(v) insulated metallic conductors

(vi) core wrap(s)

The most critical of these components are the coated fibers and the tensile strength members. Some of these components were briefly defined in Ref. 5.3; they are treated in more detail in References 5.1, 5.8, 5.12, 5.13, 5.14, 5.15, and warrant some discussion here.

5.4.1 Fiber Coatings

It is widely documented that newly-drawn bare glass fibers have a very high tensile strength, but this strength deteriorates quite rapidly on exposure to the atmosphere, resulting in strengths that may be two orders of magnitude lower, and considerably reduced strain values at failure. This phenomenon is believed to be the result of the formation of stress concentration centres such as microcracks, or the deepening of existing surface flaws, caused by chemical reactions between the elements in the glass fiber and atmospheric compounds, such as water, in contact with the glass surface. These surface flaws, being centres of localized stress concentration, serve as initiation points for crack propagation and fiber failure. It is therefore essential that the fiber surface be protected from atmospheric exposure and external forces before degradation can occur. One approach is to carry out surface passivation of the glass by ion exchange to render the surface hydrophobic. The more common method is to apply dense organic surface coatings to the individual fibers.

Considerable attention has been directed towards the identification of suitable coating materials and application techniques. It is most convenient to apply the coating immediately after the fiber is drawn and in tandem with the drawing equipment. The coating may be applied in solution, and cured by thermal means, or by thermoplastic extrusion. Coating materials that have provided some measure of satisfaction to date (References 5.1, 5.9, 5.15, 5.17, 5.18, 5.19, 5.22, 5.24, 5.28) include Kynar (PVF), silicones, heat-cured epoxies, UV-cured epoxy-acrylates, PFA and FEP, nylon-6, nylon-12, Hytrel (a thermoplastic elastomer of the polyester copolymer group), amorphous polyethylene terephthalate (Arnite), PVC, polyethylene, polypropylene, EVA, and other polyolefins in non-aligned or longitudinally-aligned (Ref. 5.17) states. The first three of these materials are often applied in solution. The solution coating will necessarily be thin and tight-fitting, whilst the extruded coating may be either tight or loose in the form of a tube around the fiber.

These methods have their advantages and disadvantages, and no one technique is universally favoured at present. However, solution coatings, because of their limited thickness, do not provide sufficient protection for fibers, and they are usually employed as an initial or primary coating in conjunction with another coating. Loose extruded coatings cannot be used as a primary coating for fibers for obvious reasons, and are thus used to provide additional protection to tight coatings. Severe difficulties exist in extruding a single tight-fitting coating of sufficient thickness to provide the required protection and strength without adversely affecting fiber attenuation and environmental stability. The adverse effects are associated with improper extrusion conditions, such as the rate of extrusion, coating melt temperature and viscosity, non-concentricity of the coating, rate of cooling, and thermal shrinkage of the polymer. Because of these limitations, double or triple coatings (Ref. 5.24) of various combinations are generally preferred.

With this approach, the primary coating usually serves to provide environmental protection for the fiber cladding surface and thereby maintains the tensile strength of the fiber. Thus the primary coating need only be relatively thin. The secondary coating provides additional tensile strength and mechanical protection (from crushing, microbending, etc.) to the fiber during cable manufacture and service. Loose extruded coatings provide tensile strength by isolating the fiber from the load and bearing all the load themselves. Tight extruded coatings, on the other hand, provide tensile protection by sharing the tensile load carried by the fiber. With either type it is necessary that the polymer coating have a high elastic modulus at low strain (<1%). However, the elastic modulus of the coating material will be considerably less than that of the glass fiber, requiring the application of a coating that may be as much as an order of magnitude larger in thickness than that of the bare fiber in order to achieve the desired load-carrying capability (Ref. 5.1). Depending on the degree of protection desired, this thickness may be impossible to achieve in one extrusion without encountering the adverse effects mentioned in the previous paragraph, and may have to be applied in two or three stages. However, if the fiber already has a primary coating, this coating work can be done at a later date and at another location independently of the fiber drawing process, thus avoiding some production problems.

Although both loose and tight secondary coatings are being used by fiber cable manufacturers, it has been argued (References 5.15, 5.17, 5.23, 5.30) that minor longitudinal contraction of the loose coating or tube relative to the fiber causes a spiralling of the fiber within the loose coating. This is likely, given the relatively high values of the coefficients of thermal expansion of polymeric materials. The pitch of this helix can be very small, causing severe microbending, and empirical confirmation of this behavior has been made. However, the problems can be minimized in practice by judicious choice of the coating material and by exercising added care in specifying and controlling the relevant parameters, and some cables have been made which incorporate loose secondary fiber coatings and exhibit low additional loss over a reasonable temperature range. It is possible, however, that the difficulty in providing satisfactory loose coatings, coupled with their additional cable space requirements due to their relatively large diameter, may result in a preference for close-fitting secondary coatings in the future.

A consideration related to the topic and aims of coating is that of fiber containment and isolation within the cable. Several cable designs permit unrestricted radial movement and some degree of longitudinal movement in order to ensure freedom from radial compressive forces. Some manufacturers (References 5.9, 5.31) insist that this is an essential feature of a successful cable design, and achieve fiber isolation by the use of loose tube containment, structural, grooved elements commonly called 'spacers', soft, slippery layers of Teflon tape as part of the core wrap or cushion layers, silicone lubricants, or a combination of these approaches. Other cable designs attempt to limit radial forces on the fiber, rather than avoid them completely, by helical stranding of the fibers with a suitable degree of radial compliance, together with the protection afforded by adequate coating. This 'close-stranded' approach retains the fibers in a fixed geometrical configuration within the cable under all stress conditions. The optimum configuration is a helix wound closely around a central supporting member (in a single fiber cable this optimum configuration locates the fiber along the cable neutral axis). The supporting member may be a central strength member, or another fiber, or a (coated) metallic conductor. The pitch of the helix must be sufficiently long to minimize fiber bending and avoid microbending losses, but short enough to ensure adequate cable flexibility. In practice, the pitch must be very long relative to the fiber diameter, and calculation of these parameters is discussed in References 5.6, 5.13. The effect of the helix is to reduce the fiber strain relative to the other components. The fibers are retained radially by core tape wraps or additional layers of fibers, and retained circumferentially by close surface contact with adjacent fibers or 'fillers' to avoid microbending effects. The flexibility of this configuration can be enhanced by allowing some degree of longitudinal motion of the fibers relative to other components during bending. This is usually achieved by using layer wraps or fiber coatings with low frictional coefficients.

5.4.2 Strength Members

A strength member is a component added to the cable for the specific purpose of increasing the safe tension that may be applied to the cable. For some indoor applications for fiber optic cables, such as computer peripheral interconnections, a strength member may be considered unnecessary, and the cable may provide only radial protection to the fiber. However, for all outdoor applications and many indoor ones, a strength member is generally considered an essential component. It is particularly important in underground duct and aerial cables, where relatively large tensile loads are encountered during installation or service.

In the case of cables installed in ducts, the tension required to pull the cable is a function of the cable unit mass, the 'effective' coefficient of friction, and the length to be pulled; the tension increases greatly at any curve in the duct. Since it appears desirable to maximize the lengths of fiber optic cable installed in order to minimize the number of splices and the installation and splicing costs, the strength/unit mass ratio is an important measure of the tensile properties of the cable and its components. The term 'strength' refers here to the maximum tension at the cable strain limit, usually $\leq$ 1% for fiber optic cables. In practice, the Young's modulus/unit mass ratio is usually used in comparing individual materials.

With aerial and buried cable, the tension on the cable during installation and/or operation is also a function of the cable unit mass, as well as other parameters. Therefore the modulus/unit mass ratio remains an important measure of cable strength and the suitability of the various strength member materials being considered. (For further discussion of the factors contributing to installation tensions in plowed and underground cables, see References 5.2 and 5.33).

The main preferred properties of a strength member are:

(i) high Young's modulus.

(ii) yield strain higher than the specified cable strain.

(iii) low mass per unit length

(iv) sufficient flexibility to achieve the overall desired cable flexibility.

(v) thermal stability of its mechanical and physical properties.

The specific cable design and application may, in addition, require other features, such as a smooth surface, rigidity in compression, transverse hardness, a high coefficient of friction against a particular (adjacent) material, or even adhesion between the strength member and the adjacent material.

Not surprisingly, some of these requirements may conflict. The flexibility of a cylindrical rod is inversely proportional to the product of the Young's modulus and the cross-sectional area (Ref. 5.12), and the tensile requirement may make it impossible to achieve the desired flex properties with a solid cylindrical strength member. Fortunately, this problem can be overcome. Thin 'filaments' of the material can be stranded, bunched, or braided together, and formed into rods by coating this assembly. Various combinations of these assemblies have been used to date in fiber optic cables. If the strength member is in contact with any of the fibers, it is essential that the surface of the member be smooth in order to avoid the localized mechanical stresses that cause microbending. Thus a coating is usually applied to the strength member in these circumstances, particularly with textile fiber members. Although short lengths of coated fibers commonly withstand strains exceeding 1%, it is normal practice in cable design to assume a safe strain limit of 0.1% - 0.25% for fibers of the order of 1 km in length subjected to prolonged tensile stress. The maximum safe cable strain corresponding to this fiber strain is dependent on the design being considered, as discussed in Section 5.4.1, but is typically 0.5% - 1.0%. Thus the strength member must have a yield strain exceeding this value.

Classes of materials used for the construction of strength members of high Young's modulus are:

(i) steel wires

(ii) multiple textile fibers: Kevlar aromatic polyester yarns, polyamides (nylon), polyethylene terephthalate (Terylene, Dacron), and FRP (glass fiber-reinforced polyester)

(iii) plastic monofilaments: orientated amorphous polyethylene terephthalate (Arnite), nylon

(iv) glass fibers

(v) carbon and boron fiber composites

The important properties of these materials were tabled in References 5.1 and 5.15, and appear in Table 5.2. Further information appears in References 5.12, 5.34.

The values shown in Table 5.2, particularly the yield strain values, indicate that steel wire, Kevlar, and carbon fibers are technically the most suitable strength member materials. However, a recent report (Ref. 5.15) suggests that plastic-clad carbon fibers have not proved successful to date as flexible strength members. These construction problems with carbon fibers, and with more exotic inorganic fibers such as boron, may be overcome, but the cost is likely to limit severely their use in the short term.

Although steel and Kevlar appear to be the preferred materials, and their properties justify their popularity, they are not without their drawbacks. Steel has a high specific gravity and low modulus/unit mass ratio, and its use may increase the cable unit mass to an unacceptably high value, and greatly increase the pulling tensions necessary to install it in underground ducts, or increase the suspension tensions in aerial service. Alternatively, the cable design may be such that a steel strength member(s) does not add significantly to the cable unit mass. Steel also has the desirable features of being rigid in compression, high transverse hardness, a smooth surface, low coefficient of friction relative to most polymers, and stable mechanical properties over the outdoor ambient temperature range. Steel, or any conductive strength member such as copper or carbon fibers, will be automatically excluded from consideration if it is necessary that the cable include no conductors. It was originally envisaged that fiber optic cables would include no electrically conductive components in order to avoid the need for protection and isolation from lightning strikes and power induction, and the associated effect on system cost and reliability. Thus all-dielectric cables are a desirable goal, and have found application in power station and switching sub-station communications and control, and in computer peripheral interconnections. However, all-dielectric cables have their limitations which will be discussed further in Sections 5.4.3 and 5.4.5, and they are not considered essential for outdoor telecommunications and broadband applications. Steel strength members have been used in fiber optic cables for these applications, with appropriate electrical grounding and protection provided, and their use is likely to continue.

Both Kevlar 49 and Kevlar 29 have reasonably high

Material	Specific Gravity	Young's Modulus (MN/m^2)	Yield Stress* (MN/m^2)	Yield Strain* (%)	Normalized Modulus/Unit Mass Ratio	Tensile Strength (MN/m^2)	Breaking Strain (%)
Steel wire	7.86	20 x 10^4	4-15 x 10^2	0.2 - 1.0	1.0	5-30 x 10^2	25-2
Kevlar 49 fiber	1.44	13 x 10^4	30 x 10^2	2	3.5	30 x 10^2	2
Kevlar 29 fiber	1.44	6 x 10^4	7 x 10^2	1.2	1.6	30 x 10^2	4
Nylon yarn	1.14	0.6-1.3 x 10^4	>8 x 10^2	> 6	0.3	10-15 x 10^2	15-20
Terylene yarn	1.30	1.2-1.5 x 10^4	>8 x 10^2	> 6	0.3	10-15 x 10^2	15-20
FRP	1.45-1.70	0.8-1.4 x 10^4			0.3	1-2.1 x 10^2	1-5
Polyester monofilament	1.38	0.6-1.4 x 10^4	0.8-2 x 10^2	1.5	0.3	7-9 x 10^2	15-6
S-glass fiber	2.48	9 x 10^4	30 x 10^2	3	1.4	30 x 10^2	3
Carbon fiber (high strength)	1.5	10-20 x 10^4	150-200 x 10^2	1.5-1.0	2.6-5.2	15-20 x 10^2	1.5-1.0

* Yield point values are approximate only. Those values for glass or glass composites are variable because of the statistical nature of glass strength.

TABLE 5.2: IMPORTANT PROPERTIES OF STRENGTH MEMBER MATERIALS

Young's moduli, low yield strains, and excellent modulus/unit mass ratios, with Kevlar 49 being particularly impressive. However, Kevlar has very low transverse hardness and very low stiffness, and it buckles in compression. This is a serious drawback in cabling. Because the individual fibers are short, like natural fibers, they have to be spun or supplied in yarn form. Therefore the strands have a non-smooth surface, and have to be coated and contained, usually with extruded polymer coatings. Any thermal contraction of this coating or of other contacting cable components during any of the cabling phases or during the cable service life will result in buckling of the Kevlar member. These problems are compounded by the fact that Kevlar has a negative, albeit low, coefficient of thermal expansion, unlike all other common component materials. The opposing internal radial compressive forces generated at low temperatures, coupled with Kevlar buckling, may give rise to fiber microbending, unless the fiber is sufficiently isolated from these influences, and increased fiber attenuation will result. This degree of isolation of fibers from thermally generated radial and longitudinal stresses is expressed as a fiber attenuation temperature coefficient. Many current cables have a relatively high coefficient over a relatively limited temperature range, indicating poor isolation of fibers from these stresses. Although Kevlar has a high Young's modulus, it exhibits relatively large elongation at very low stresses, like many polymers. This is due to an initial slackness in the strands, and it is important that this slack be eliminated by pre-tensioning the strands during cabling in order to optimize the strain behaviour of the cable. Pre-tensioning may also prove to be a suitable technique for overcoming the problem of compressive buckling. In addition, although Kevlar has excellent abrasion resistance to other contacting components, it is a self-abrading material: the individual fibers abrade one another. This may be a long term problem in cables subjected to continually fluctuating tensions, such as aerial cables.

It was mentioned earlier that the desired flex properties of the strength member and cable can be achieved by stranding, bunching, or braiding together thin 'filaments' of the material into various assemblies. The location of the strength member within the cable will also affect the cable flexibility, as well as the torsional characteristics and the crush and impact resistance. This strength member assembly or assemblies may be located along the cable axis with the fibers stranded around it: this provides excellent bending performance. Alternatively, members may be stranded or braided concentrically around the fiber group, or the sheath itself may serve as the strength member in the form of armour wires or a tubular metal layer: this provides enhanced crush and impact resistance. Thus the application determines the strength member location; Table 4.1 suggests that underground and buried cables may require the latter construction, aerial cables the former, and underground cables may require both axial and concentric strength members. It is likely that such composite designs, as predicted in Ref. 5.15, will be developed for a range of applications and placing methods in order to minimize the number of designs and reduce production costs.

5.4.3 Sheaths

The most common outer jacketing materials are P.V.C. and polyethylene. P.V.C. has greater flame resistance and therefore is used almost universally for indoor telecommunications cables, whilst polyethylene in various density grades and with various additives is the preferred material for outdoor applications because of its lower coefficient of friction, relatively low moisture absorption, and cold temperature performance. Neoprene and PVC are used extensively in subscriber drop wires. Some fiber optic cables, mostly developed for military applications, have used materials such as FEP, neoprene, and polyurethanes for jacketing. These materials offer extended temperature ranges, increased flexibility, and greater abrasion resistance, but at the expense of reduced transverse hardness, higher coefficients of friction (excluding FEP), and cost. Their widespread use in fiber optic broadband cables appears unlikely at this time.

The sheath may consist of one or several layers of materials, depending on its functions. In addition to jacketing the other cable components and providing nominal protection to them, the sheath may serve the following additional functions:

(i) tensile strength member

(ii) radial reinforcement or armouring

(iii) moisture barrier

(iv) suitable jacket integrity to permit cable pressurization

It is likely that the same elements would provide both (i) and (ii). Armouring is usually necessary in buried or submarine cables, and may be provided in the form of steel wires or polyolefin twines stranded around the cable, helical, close-wrapped steel tapes, or a corrugated steel welded tube, together with a bedding layer of oil-impregnated, stranded jute or synthetic yarns. PIC and coaxial telecommunications cable armourings are shown in the Appendix (Ref. 5.35).

Although there is now some consensus that the tensile strength of (coated) high-silica and borosilicate fibers under stress will degrade on exposure to water, the practical implications of this phenomenon for the long-term reliability of cabled fibers in various moist service environments are not obvious at this stage. Some manufacturers have adopted an attitude that moisture ingress will be ignored until it is proved to be a problem. Others have adopted a more cautious approach. Polymer sheaths will not prevent moisture diffusion into cables, and longitudinally-applied sealed metallic layers of aluminum or corrugated steel are commonly used as moisture barriers in conventional telephone cables, often in conjunction with asphaltic or grease flooding and corrosion-inhibiting compounds. These designs, despite their use of metal, are likely to be used in fiber optic cables where it is considered necessary or prudent. PIC telephone cables (polyethylene insulated copper pairs) used in direct buried feeder and distribution applications are commonly of the filled-core type, in which the cable core is filled with a paraffin-based grease which inhibits the migration of any water along the cable core. Powder is also being incorporated into cables for this purpose. However, the use of powder or grease-filling compounds in fiber optic cables would pose problems for successful fiber splicing.

Pressurization of cable cores using dry air or nitrogen is a standard telephony practice on trunk and feeder cables, and has been a successful feature of several fiber optic systems trials. This internal air flow (typically at 10 psig) inhibits the ingress of water into the cable if the sheath is damaged, and assists in drying out the core if moisture is present. Cable pressurization also serves two other important purposes. If the sheath of a pressurized cable is punctured, either by lightning or mechanical damage, the flow of air from the dryer/compressor will increase, and the extent of this flow increase is dependent on the distance of the fault from the compressor, as well as the size of the puncture. Therefore, if the air flow in monitored, the pressurization system can be used as a sheath fault alarm, and also for limited fault location.

Various PIC and coaxial cable sheaths are being considered for fiber optic telephony and broadband cables. These sheath constructions, and the cable sizes and placing environments for which they are used, are described in Ref. 5.35, and are shown in the Appendix. The use of metallic sheaths will, however, render the sheath and, possibly, the cable core vulnerable to damage by lightning, and also pose a safety hazard. Therefore electrical protection and grounding of the metallic elements may be necessary.

5.4.4 Cushion Layers and Fillers

The importance of protecting and isolating coated fibers from internal radial stresses which can give rise to microbending was discussed in Sections 5.4.1 and 5.4.2. Cushion layers, as the name implies, are soft materials separating concentric fiber layers from one another and from other adjacent components, thereby providing further radial protection. These layers, which are usually soft crepe or cellular paper, cellular polyester, or low-density polyethylene, are applied as helical or longitudinal wraps. In some designs they also serve to decouple the fibers from the frictional forces of adjacent layers.

Fillers maintain the circumferential spacing of coated fibers and provide circumferential cushioning to each fiber. Soft polyester yarns, nylon extruded rods, or even plastic-coated metallic conductors are normally used, and incorporated into the cable by stranding with the fibers (Ref. 5.9).

Some alternative cable designs feature structural elements, 'spacers', which serve the same purpose as cushion layers and fillers. These solid extruded elements are usually located along the cable axis, and have helical surface grooves in which the coated fibers are loosely contained. One or several fibers may be located in each groove, and a core wrap over the 'spacer' serves to isolate the fibers from the other cable components. The spacer may serve as the strength member, or it may be extruded around a central strength member.

5.4.5 Insulated Conductors

Insulated conductors can be included in the cable for powering and controlling repeaters and remote switches, for subscriber signalling, and for cable and equipment alarm purposes. However, it may be more economical in many cases to power field equipment from local sources. The incorporation of conductors into the cable will render it more susceptible to lightning strikes and sheath damage, and will necessitate the use of fuse protection on these conductors. Whether such lightning strikes will damage the fibers or their coatings, and therefore affect the overall system reliability, is not clear, but will be dependent on the radial location and proximity of the conductors relative to the fibers, the dielectric properties of the non-metallic components, and the presence of metallic sheath elements and strength members, as well as the external conditions.

5.4.6 Core Wraps

Core wraps are thin tapes or binders applied helically during the fiber stranding and the strength member stranding processes. They contain the stranded assembly and provide some heat shielding during subsequent cabling processes. Mylar, polypropylene, and p.t.f.e. tapes are most commonly used.

5.5 CABLE DESIGNS

It was emphasized in Section 5.4 that the arrangement of the components within the cable is of the utmost importance in determining cable performance. Because the coated fibers and the strength members are the most important components, it is logical that cable designs be classified according to fiber containment and fiber and strength member location, in order to distinguish the major differences between the various cable designs. Thus the cable designs may be classified according to:

(a) the strength member(s) is located centrally along the cable axis

(b) the strength members are located around centrally-placed fibers in a concentric (stranded) or planar layout.

The cable may also be categorized on the basis of the following features:

(i) tight-coated fibers, stranded

(ii) individual loose tube (coating) fibers, stranded

(iii) multiple fibers in a loose tube 'coating': unit loose tubes

(iv) fibers contained in a helically-grooved structural 'spacer'

5.5.1 Current Designs

Various existing cable designs (References 5.1, 5.3, 5.16) are classified in Table 5.3 according to the above criteria. Peculiar or anomalous features of cables are described.

This classification indicates that the design having a central strength member(s) with tight-coated fibers concentrically stranded around it is the most popular of the current designs. This is not surprising, as this design provides maximum flexibility with good bend performance.

STRENGTH MEMBER LOCATION	FIBER CONTAINMENT AND LOCATION	CABLE		COMMENTS	REFERENCE
		MANUFACTURER	MODEL		
Central	Tight-coated, concentrically stranded	STL/STC	OFC-SIG		5.1, 5.15
		I.T.T. (Roanoke)	GS-20H		5.4, 5. 8
		Pirelli	------		5.36
		Cables de Lyon	18 fiber cable		5.21
		Fujikura	------		5.20
		Furukawa	------		5.16
		Sumitomo/NEC	SCP, SCI		5. 9, 5.31
		Dainichi-Nippon	------		5.19
	Individual loose tubes concentrically stranded	Felten & Guilleaume Carlswerk	------		5.38
	Unit loose tube(s)	------			
	Helically-grooved spacer	Hitachi	Underground		5.32
		CNET	------		5.23
Outer concentric	Tight-coated, concentrically stranded	FORT	TIS-LD		5.22
		ITT (Roanoke)	------		5.27
		BTL/WE	------	Fibers in 12x12 matrix core Matrix is spiralled	5.26
	Individual loose tubes, concentrically stranded	Siemens	SIECOR		5.37
		Cables de Lyon	37 fiber cable		5.21
		Corning	Corguide	Two planar strength members	5. 6
		NTL *	------		-----
	Unit loose tube(s)	BICC	PSP	Two planar strength members	5. 7
		Hitachi	Aerial	External bearer strength member	5.32
		TCL (GEC)*	------		-----
		STL/STC	------		5. 1
	Helically-grooved spacer	General Cable	------	Fibers held in polymer rbn. Ribbon is loose within spacer	5.14, 5.39

* No cable diagrams or specifications published.

However, where substantial radial protection is required, as is the case with most buried and underground applications, some form of armouring is necessary with this design. Therefore its future popularity is not a foregone conclusion. STL/STC favour this layout, and have proposed a hybrid design (Ref. 5.1) which overcomes these limitations. It features an additional outer layer of concentrically-stranded strength members which also serve as armouring. They believe this hybrid construction will gain wide acceptance as a preferred design. Designs which feature individual loose-tubed fibers are also popular, as was mentioned in Section 5.4.1, being relatively easy to handle and cable when protected in this manner.

5.5.2 Large Cable Designs

Most of the existing fiber optic cables contain less than twelve fibers. However, it is inevitable that there will be a strong demand for cables containing many more fibers than this in the future. The maximum fiber counts of future cables and the required dates of availability for various applications are subjects of much dispute, but it is likely that cables containing at least 100 fibers will be required for telecommunications trunk and feeder applications within the next ten years. Cables with larger diameters will be a result, the size being dependent also on the layout of fibers within these cables.

Three different approaches to the layout and construction of cables with a large number of fibers have been proposed. They are:

- (i) multiple concentric layer structure
- (ii) unit structure
- (iii) matrix structure

In approach (i), the coated fibers are directly stranded (around a central supporting member) in concentric layers, with cushion layers separating each fiber layer. This approach has been proposed for both tight-coated and loose-coated (Ref. 5.21) fibers. It uses space very efficiently, and therefore results in relatively compact cables. However, the difficulty of cabling fibers in this fashion without adversely affecting fiber optical performance increases with the number of layers. Superior fiber protective coatings and sophisticated cabling equipment and process control will likely be required to make this approach successful. The technology has not developed to this stage, and there have been no reports to date of success with this layout for large numbers of fibers.

With the unit structure, a limited number of coated fibers are assembled into a group, which is then jacketed to give adequate radial protection. This sub-cable is a 'unit'. The unit may include a tensile strength member. Units are stranded together to give the required size of cable. The fibers in each unit may be stranded together, loosely laid in unit tubes, or contained in the grooves of a 'spacer'. Furukawa (Ref. 5.16), Hitachi (Ref. 5.32), CNET (Ref. 5.23), and Felten and Guilleaume Carlswerk (Ref. 5.38) have proposed designs based on this approach. The CNET proposal is particularly interesting. The unit is a sheathed, grooved spacer containing eighteen fibers, and nineteen of these units are stranded concentrically around a central strength member, resulting in a 342 fiber cable. The unit approach, whilst it tends to be less efficient in its use of space, restricts the delicate cabling process to the assembly of a limited number of fibers into a unit; the relatively rugged units lend themselves more readily to cabling with conventional cabling equipment and processes. The unit approach is therefore favoured for future large cables.

The only known example of the matrix structure is Bell Telephone Laboratories' 144 fiber cable (Ref. 5.26). That particular design uses space very efficiently, and the matrix layout lends itself well to multiple splicing. However, because the matrix is twisted and also lacks symmetry, each fiber experiences a different strain, and the matrix and twist parameters must be very carefully specified and met in order to avoid substantial fiber damage or cabling losses (Ref. 5.40).

The ribboning process adds more loss than the cabling of the stacked ribbons. This loss can be substantial. However, the added losses decrease over a period of time (Ref. 5.26), indicating some relaxation of the cabling stresses that cause microbending. The attenuation temperature coefficient of this cable is also higher than desirable (Ref. 5.25), suggesting insufficient isolation of each fiber from any thermal stresses.

5.5.3 Future Improvements

The following improvements in cable technology and experimental investigations are desirable for future fiber optic cables:

(i) suitable fiber coating materials with improved mechanical properties, low thermal expansion coefficients, and low moisture absorption.

(ii) new coating techniques, cable designs, and cabling equipment for isolating fibers from cabling stresses. Ref. 5.29 reports that cabling losses for low attenuation fibers are higher than for higher attenuation fibers. With future demand for lower cabled fiber attenuations of the order of 2dB/km, sophisticated purpose-built cabling equipment, with superior designs and coating techniques, will be essential.

(iii) improved strength member materials.

(iv) identify the precise effect of prolonged exposure to moisture on coated fibers, and therefore the need for cable moisture barriers. If exclusion of moisture from the cable is necessary for long-term fiber reliability, improved sheath materials will be required in order to achieve (v).

(v) development of successful all-dielectric cables suitable for outdoor broadband applications, to avoid the need for electrical protection and grounding of cable metallic elements, and to optimize cable reliability.

(vi) develop suitable constructions for large size cables.

5.6 SUMMARY

A successful fiber optic cable design ensures that the optical performance and mechanical integrity of the fibers are maintained according to specification in all the intended application environments. The protection that the cable provides to the fiber must be substantial in harsh environments such as those associated with rural broadband communications distribution. The fiber mechanical and environmental properties must be improved by suitable polymer coatings, applied as soon after fiber drawing as possible. There is some current preference for thin, tight primary coatings, applied in solution or by extrusion (fluoroplastics, silicones, and epoxy compounds are favoured materials), supplemented by close-fitting secondary or even multiple extruded coatings. The fibers are stranded in this condition, or contained loosely in some form of extruded structural 'spacer' which affords further fiber protection and isolation. A tensile strength member or members with high Young's modulus (steel and Kevlar are popular materials) must be incorporated into this fiber assembly in a layout which limits the cable and fiber strains at the required cable tensions to a value less than the fiber breaking strain, without adversely affecting the fibers. This layout must also exhibit suitable flexibility. Radial mechanical protection in the form of armouring elements may be required, as well as moisture barriers, for underground and buried applications. This entire assembly, contained within an extruded jacket, forms the cable, or the sub-cable unit of a large-capacity cable.

Many successful solutions to the problem of cabling small numbers of fibers exist. However, cable design is still in its infancy. Although some preference appears to be shown for certain materials, techniques, and assembly layouts, there are few areas where these preferences have matured into established, binding practices. The options that exist are the result of limited cabling equipment and manufacturing resources generally, as well as limited development of the most suitable materials for any cable component and insufficient operating data on existing cables.

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6. CONNECTORS, SPLICES AND DIRECTIONAL COUPLERS

6.1 GENERAL

Connectors and splices are used in fiber optic systems to couple the optical signal between or to each of the separate elements. Typical situations requiring this interconnection are:

(1) The joining together of individual cable lengths.
(2) The joining of optical/optoelectronic components to the system.
(3) To provide flexibility (eg. cross-connected features).
(4) To provide for ease of component replacement and maintenance.
(5) To provide access to the system for monitoring or fault detection.

The requirement for both connectors and splices is to provide low loss devices at a reasonable cost. Ease of installation is also a major criterion to be met in a practical system. Many sources have been successful in achieving low loss devices in the laboratory. However, there is still a large amount of development to be done to produce practical components meeting field use requirements. This is particularly true for small diameter (125 - 150 μm) single fibers that will be used in telecommunications sytems.

Directional couplers (Report 1, Chapters 7 & 8) are devices used to access a portion of the signal from the main communication path, or to split it out equally for distribution purposes.

They can also be used as dual purpose devices (bidirectional) for the simultaneous input or output of signals. This makes two-way transmission viable in a single fiber, thus allowing for a significant savings in fiber quantities.

6.2 SYSTEM APPLICATIONS

6.2.1 Connectors and Splices

The decision to splice or connectorize is based on the application. The major need for splicing is the joining together of cable lengths. This is a practical necessity because of the limitations on the length of cable that can be manufactured, cable reel sizes and weights, and field handling limitation with respect to pulling, manhole spacing and such.

Splicing is also attractive as a means of coupling devices into the system which will seldom require replacement. Taps, splitters and directional couplers are typical examples.

Connectors, on the other hand, are used where a mate/remate type of joint is required. This feature typically makes optical fiber connectors more complex in design than splices. Allowance is made within the accuracy of fiber alignment to accommodate remating and consequently connectors are typically more lossy than splices.

Connectors, however, are indispensible in any fiber optic system. Many applications require the mate/remate feature, for example, in cross-connect terminals or in situations where interchangeability is required between a number of fiber optic links. They are also desirable for maintenance and monitoring purposes, where component replacement may be necessary or where fault detection requires access to the fiber.

6.2.2 Directional Couplers (Ref. Section 7 & 8, Report 1).

It has been pointed out that bidirectional couplers make single fiber transmission possible. (Ref. sec. 5.3.5.3, Report 3). Directional couplers should also be useful as test points for maintenance testing and fault location. Conventional copper distribution systems have a number of interconnect points (eg. Jumper Wire Interface, Pedestal, Aerial Drop Terminals) which provide easy access for testing.

However, interconnect points in fiber optic systems do not provide access to the signal without interrupting transmission. Therefore, to provide an in-service testing capability in a fiber optic distribution system it will be necessary to build in permanent test points. Such test points will probably be required in the central office, at the remote switch and possibly at the subscriber's premises. The additional losses introduced by directional couplers will have to be considered in the system design.

Practical bidirectional couplers will probably be factory encapsulated as prepackaged units and be provided with leads for splicing or the installation of connectors. In this prepackaged form the device will be installed using similar procedures as employed for splicing or installing connectors.

Bidirectional couplers for single fiber transmission will probably be spliced to the transmission fiber at the subscriber and at the switching point. Connectors will probably be used to interconnect the bidirectional couplers to transmitters and receivers. Directional couplers used as test points will be spliced into the line with the test port being connectorized.

6.3 RELIABILITY

At the present time little data has been published on the reliability of connectors and splices. Splices are inherently more reliable than connectors. Splices are sealed, passive devices which have no inherent catastrophic failure modes, barring of course physical abuse beyond their design capabilities. The most likely potential failure mode, if any, will be a gradual signal deterioration due to aging (the process by which the physical properties of a material change slowly with time). Connectors are intrinsically more susceptible to degradation (ie. increased insertion loss) because they are mate/remate devices and hence are subject to more degeneration mechanisms. Amongst these are: accidental damage to the fiber ends in the unmated condition or during remating, contamination which can partially block the optical signal or introduce abrasive materials, and mechanical wear which will increase fiber-to-fiber misalignment. Connectors are also subject to aging.

The aging process of most concern is with polymeric materials (ie. plastics and adhesives). Some typical manifestations are discolouration, dimensional changes, deterioration of mechanical and chemical properties, loss of elasticity and reductions of bond strength.

The rate and the extent of the deterioration is dependent on the severity of the operating environment (eg. temperature, humidity, etc..).

Differential thermal expansion (or contraction) caused by using materials with significantly different thermal expansion (or contraction) coefficient can similarly cause deterioration by reduction of bond strength and dimensional changes.

Preliminary reliability testing indicates that with proper material selection, deterioration due to aging and differential thermal expansion can be controlled. Because aging effects are not evident until well after the initial installation, thorough reliability test data is essential for the system design to establish the long term performance of splices and connectors. These reliability tests should be based on the conditions cited in table 4.1.

From a reliability point of view splicing by fusing the fiber ends together by the application of heat (eg. electric arc) is very promising. In addition to low insertion loss there are no foreign materials introduced between the fiber ends, thus reducing the opportunity for aging and differential thermal expansion.

For connectors the situation is not as clear as no one preferred technique has yet emerged. The design requirements for a reliable connector include; protection of the fiber ends against accidential damage during the unmated condition and during remating, access to the fiber ends to remove contaminents and, wear-resistant material combinations.

6.4 CONNECTOR AND SPLICE INSTALLATION

6.4.1 Introduction

The step taken in going from the conventional copper conductor to a fiber optic telecommunication system represents a significant change in technology. New equipment, skills and techniques will be required for this new technology. Optical fibers, because of their small size and relative fragility (compared to copper conductors) will require more sophisticated connector and splice installation tooling and techniques than the existing systems. The installation tooling and techniques are evolving in conjunction with the development of splices, connectors and directional couplers.

6.4.2 Tooling and Equipment

The tools and equipment required for the installation of connectors and splicing in the field fall into four major categories, detailed in the four sections.

6.4.2.1 Cable Sheath Removal

Cable sheath removal tools are used to remove the outer protective sheath of the cable which is usually a PVC or polyethylene. Currently conventional copper wire cable equipment is being used.

Many cable designs use a metallic sheath inside the outer covering to provide both tensile and crushing strength. This sheath is usually made of heavy foil or a corrugated sleeve. The secondary operation of removing this element is usually accomplished with standard tooling. Some caution is required in this operation to avoid damaging the fibers beneath the sheath.

6.4.2.2 Fiber Preparation

Fiber preparation consists of stripping of buffer materials, clearing or polishing the fiber end and cleaning.

The stripping of the fiber buffer, usually a polymer such as nylon , Kynar or silicone, can be done in a number of ways. For fibers with large (0.5 to 1.0 mm) buffer diameters and relatively low fiber-to-buffer adhesion, mechanical stripping has been successfully used in the field. Conventional wire stripping tools have been modified for use with fibers. For fibers with a thin (a few microns) highly-adherent buffer, chemical stripping is most commonly used. Use of chemical stripping in the field is hampered by the problem of toxicity or flammability of the stripping medium. Burning off the fiber buffer is effective but reduces the bending strength of the fiber.

The preparation of the stripped fiber end face can be done by one or two methods; polishing or cleaving. In the former the stripped fiber is usually potted in a portion of the device (eg. connector part), and then this assembly is put into a polishing jig. This device is designed to hold the potted fiber assembly perpendicular to a flat surface which carries the abrasive medium. The medium is generally silicon carbide paper and polishing is done by using consecutively finer grits, generally down to number 600 grit. This will give a smooth, square face to the potted fiber. An index matching medium can be used to reduce the effect of surface roughness which may exist.

The second method involves the use of a specifically designed tool which breaks the fiber at a right angle to its axis. The fiber is pulled taut over an arched anvil and then a crack is initiated by scribing lightly with a knife edge tool. This method gives excellent results and is significantly faster than polishing. However, some connector designs require the polishing technique.

The last category of tools used in fiber preparation are for the cleaning of contamination. During the end preparation activity, contamination of the fiber end may be introduced from a number of sources: particles of buffer material, glass fragments and ambient matter such as dust, lint and other airborn particles. Swabbing and flushing with a solvent such as methanol just before assembly is usually adequate to remove these.

6.4.2.3 Inspection

Inspection tools are used to check the quality of the prepared fiber ends. This equipment is generally very simple and consists of a low power (50 to 100x) magnifier of preset focus. An inspection capability is a definite asset in the field for detecting poor fiber end preparation.

6.4.2.4 Installation

The main function of installation tooling is to accurately position the prepared fiber ends into the associated splicing or connector hardware and to facilitate the handling of the very small fibers. The form this tooling takes depends on the method or design of components used. In splicing for example, there are two general approaches; fusion of the fibers or encapsulation in alignment guides which form the body of the completed splice. Installation tooling for fusion splicing would include a power supply and the necessary alignment jig to hold the fibers. This type of tooling, packaged for field use is still in the development stage. Field considerations will include designing for shock (electric) protection and enclosure of the electric arc to prevent the possibility of explosion from combustible gases sometimes present in manholes. Additional tooling is required to jacket the fused fibers.

The encapsulated type requires jigs to place the fibers and hold them during the curing period of the adhesive or encapsulant. Fusion splicing offers advantages of lower insertion loss and higher installation speed.

Connector installation tooling is highly dependent on the connector design, of which many now exist. Generally speaking, the tooling will be used to position and maintain the alignment of the fibers in the connector's parts for encapsulation or bonding.

6.4.2.5 Splice Closure

Hardware and tooling are required to apply a protective enclosure to the completed fiber splices. The splice closure requirements are similar to those used in the copper systems; cable strain relief, electrical continuity for metallic members and environmental protection. Like copper systems, these enclosures will be either plastic, light-weight cast metal, or the lead sleeve type. It may be possible to apply existing conventional enclosures directly, however, care must be taken with fiber optic cables to store the excess slack required for splicing in an orderly way so that the fiber is not overstressed or bent beyond the critical radius at which light is coupled out of the core.

6.4.3 Contamination

The minimization of contamination in a fiber optic system is a prerequisite of good performance. Contamination at an optical interface can increase insertion loss. It can also cause misalignment by introducing seating errors in fiber positioning jigs and hardware. It is therefore essential that fibers, splice and connector hardware and the critical alignment areas of installation tooling be clean. The degree of cleanliness required can be achieved in the field without difficulty. Trial installations indicate that simple precautions are adequate.

Some of these are:

(1) Cleaning the prepared fiber ends just prior to insertion in the splice or connector hardware.

(2) Cleaning the immediate splice location prior to set-up.

(3) Protection of the splicing area from falling a wind-blown dust. In vaults and manholes a simple protective sheet strung over the work bench is adequate. For buried or aerial splicing a tent is suitable.

(4) Prepackaging of splicing and connector hardware such that its exposure to the installation environment is minimized.

(5) Proper cleaning of tools as part of the maintenance program.

6.4.4 Testing

The philosophy of attenuation testing has as yet not truly solidified. Immediate post-installation testing of each joint is the common practice during trial installations. This is a very time consuming method which requires a measurement of the attenuation of each cable after it is placed. Then as each joint is made, it is compared to the sum total attenuation of the foregoing lengths and joints. Under these circumstances, a high loss joint will be detected and can be corrected immediately.

For operating systems, however, the above method will probably not be required. As with any new system, the amount of installation testing required decreases with experience and standardization of components.

It is also probable that such techniques as time domain reflectometry (TDR) and measurement of backscattered light intensity will be used to do single-ended testing of joints and cable and therefore reduce substantially the time and manpower required. Both of these methods are under development at present. These are discussed further in chapter 7 and in activity report seven.

6.4.5 Working Skill

The skill level required for the splicing of small glass fibers is higher than presently required for copper pair cable and comparable to that required for coaxial cable splicing. The required skill level is a trade off with the sophistication of the tools to be used. It is expected that with training existing personnel will be able to successfully splice fibers.

6.4.6 Factory vs. Field Installation

A certain amount of factory/workshop splicing or connectorizing of cables may be possible and advantageous. Relatively less complex tooling can be used. The installation can be done faster because the equipment does not have to be set up in different locations. Finally, weather conditions do not inhibit installation.

Factory installation can take two forms:

(1) Presplicing of cable lengths, which requires accurate route engineering to determine the location of drops on feeder cables and lengths of drops.

(2) Connector-ended cables which are of standard length, pre-connectorized and quickly mated in the field.

7. INSTALLATION TESTING

7.1 INTRODUCTION

This section considers the normal testing associated with installing the Outside Plant portion of a fibre optics system, including broadband repeaters. A probable test philosophy is advanced, an assessment of tools and methods to implement it is made and some comments on current technology offered.

7.2 INSTALLATION TEST PHILOSOPHY

Outside Plant installation traditionally minimizes testing to a few verifications of basic parameters of the communications path, eg. continuity and pairing in copper cables. This happens not because the technical staff of a communications utility are disinterested in transmission parameters, but because economics, field conditions and field skill levels discourage elaborate routines. While the first few optical fibre installations will be closely monitored, regular installation will include minimal testing since it, too,will be subject to the same pressures.

A rational philosophy for testing is to pick a minimum set of measurements to achieve the desired confidence level of correct first-time operation, and to be concerned only with those parameters that can be grossly affected by installation variables. In a broadband analog FOTS system, for example, frequency response might be critical but primarily controlled by cable construction; installation testing would only include frequency response if no simpler measurement were available to confirm that the cable was correctly connected.

A second facet of sound installation strategy is preparation for likely faults, with corresponding checks as the work proceeds. This not only verifies a specific communications path, but has a feedback effect on the quality of the job. For example, if cable crushing during backfill in rocky terrain was considered likely, immediate attenuation tests would be prudent and a fault-locate test set would be standard issue. Less urgent testing, or simplified continuity checks might suffice for plowed cable.

7.3 TYPES OF INSTALLATION TESTING

Based on extrapolation of current construction practices, some or all of the following would be required on every job:

(a) fiber identification

(b) fiber and splice attenuation testing

(c) local communication

(d) continuity of conducting pairs, if any

(e) fiber fault location

(f) sheath insulation/continuity

(g) power system testing

Equipment for physically locating the F.O.T.S. cable would not normally be needed during construction unless an unusually long time interval to first powering-up occurred. Also, construction tests would not include repeater tests (if the line is so equipped) as these would probably not be installed until very close to cut-over. Apparatus cases or bays and associated spliced-in stubs would be tested during construction, however.

7.4 CURRENT AND NEAR-TERM STATUS OF INSTALLATION TEST SETS

(a) fiber identification - for now, mechanical identification of fibers suffices, or alternatively an attenuation test set could be used. If the use of F.O.T.S. extends to multiple subscriber fibers, a simpler identification set will be needed.

(b) attenuation testing - trial installations using prototype attenuation test sets have been carried out. Such testing verifies cable integrity following handling, and can be invaluable for monitoring the splicing operation. Stable transmitters and receivers of sufficient ruggedness and portability for field operation are necessary, and adaptors for connection to bare fibres are needed. At present, test set calibration such that attenuation figures are consistent for varying lengths of interconnection (including back-to-back zeroing of the test sets) is difficult due to propagation differences between core modes and transient modes.

(c) local communication - some form of installation communication is vital, particularly since fibre splicing quality cannot easily be verified at the splice location. Various solutions are available: copper pairs may be accessible, radio communications may suffice, or a talk channel on one fibre may be established. This has not been a pressing problem to date, but may loom larger when fibre systems are installed in totally new plant.

(d) air continuity - if the F.O.T.S. cables use conductors, existing test hardware will be adequate with perhaps some adapting fittings.

(e) fiber fault location - a major development is necessary here. Some techniques are known to be possible in the lab, eg. a form of time domain reflectometry (TDR), or some backscatter measuring techniques, but they are a long way from field use. Also, the present use of TDR on copper cables has not proven very popular with maintenance groups, due to high skill levels needed for use, ambiguous results and high equipment costs.

(f) sheath installation/continuity - the need depends on the F.O.T.S. cable construction that ultimately becomes standardized, and existing methods will be available.

(g) power system testing - specific test methods, but not unusual test equipment, will likely be required.

7.5 INSTALLATION TESTING DIFFICULTIES

Most testing of FOTS will rapidly evolve into standard routines easily handled by existing construction personnel. One key procedure has not yet been addressed, however: the physical location of fibre faults. Distance-to-fault equipment will yield a figure adequate for sectionalizing a fault, and may even point the finger of suspicion at a splice, For a craftsperson contemplating opening of a cable sheath, however, the fault should identify itself locally such that cable loops, wander and fibre propagation speed variations are accounted for. If an obvious damage site is not visible, there is at present no known unique identifier of a fibre fault. The need to avoid unnecessary fibre breakage for testing, as would occur using an interactive approach to physical fault location, assumes great importance in systems with low-loss fibres (in which the dominant losses are at splices and connectors).

7.6 INSTALLATION TEST ENVIRONMENT

The physical and human factors environment is normally harsh on installation equipment and methods. Not only are operations performed under widely varying climatic conditions, but the skill level and incentives for quality workmanship are generally lower than those found in indoor operations. Optical fibre systems are at least as susceptible as conventional facilities and perhaps more so, given the small fibre sizes and requirements for precision and cleanliness during splicing.

FOTS may well accelerate a trend to better installation environments that is already visible. If so, thermal, humidity, handling and operating stresses may be lower than presently regarded as normal. Although no standard environment is presently defined for installation test sets, most are expected to operate from -20°C to +40°C, in humidity up to 100% RH (and exposed to rain or snow), and are expected to survive pounding while being transported by truck (without protective padding) and accidental drops of a few feet. Hopefully it will be unnecessary to build FOTS test sets to these stringent levels, as the cost to do so can be great.

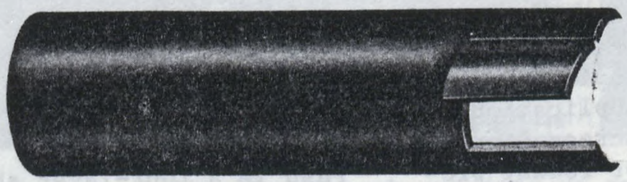
It is also of overriding importance to design operator manipulation out of field test sets as much as possible. During the pressure of construction, an arduous test method will be skipped or will prove to be the limit to installation efficiency. Similarly, ambiguous test results (particularly while fault locating) will create large consequential expenses as it ties up manpower and causes delays. Self-stabilizing, self-calibrating test sets with display processing for optimum presentation will be preferred in this new market.

APPENDIX (Ref. 5.35)

1. POLYOLEFIN INSULATED CABLE (PIC) SHEATHS

Sealpeth*
(Sealed Alpeth)

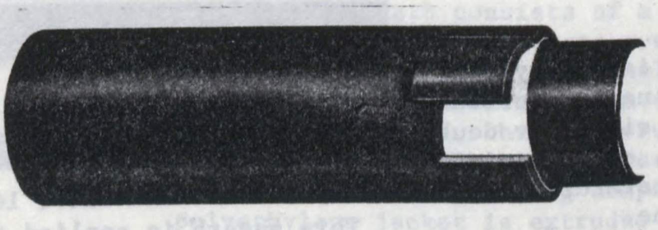
Sealpeth sheath is intended primarily for aerial lines. It may however, be used in underground ducts where damage from lightning or mechanical abuse is not anticipated. Sealpeth is the only standard sheath applied over filled-core PIC cables.



Sealpeth sheath is applied over the non-hygroscopic tape which covers the conductors. The sheath consists of two layers: a flat aluminum tape, formed longitudinally and overlapped. Next, an outer polyethylene jacket extruded over and sealed to the sheath. The outer jacket is shown cut away to reveal the aluminum tape sheath.

Seal Pap*
(Sealed Pap)

Seal Pap is intended for underground or direct buried service where there is a likelihood of lightning hazard or moderate physical abuse.



Sealed Pap is a three-layer sheath which is applied over the non-hygroscopic tape. The first layer is an inner polyethylene jacket (P), the second is a flat aluminum tape (A) and an outer polyethylene jacket (P). This combination is referred to by its initial letters PAP. The inner jacket consists of black polyethylene. The aluminum tape is flat 0.008" ribbon which is coated on both sides with an 0.002" polymeric film and applied longitudinally. The film and tape are bonded to the inside surface of the outer jacket. The outer jacket is shown cut away to reveal the aluminum tape sheath.

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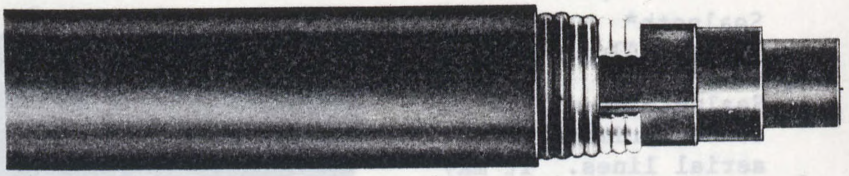
Pasp

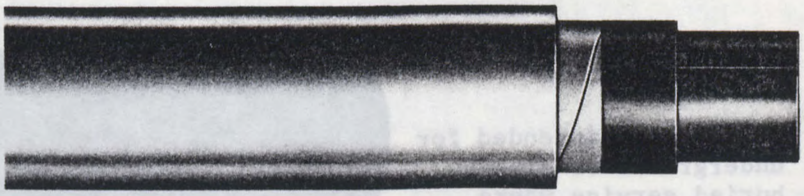
Pasp is recommended for direct burial and underground applications where increased mechanical or rodent protection is required.



Pasp is a four-layer sheath which is applied over the non-hygroscopic tape. The inner layer is a polyethylene jacket (P), the second is a corrugated aluminum tape (A) applied longitudinally but not overlapped. Over these two, a third layer of corrugated steel tape (S) also applied longitudinally, overlapped and soldered. The steel tape is covered by a thermoplastic compound and finally by an outer polyethylene jacket (P).

Lepeth

Lepeth is mainly for submarine use, often with a single or double armour, or in environments harmful to polyethylene.

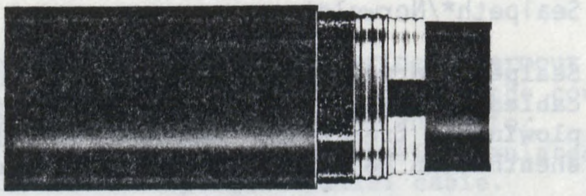


Lepeth is an extruded lead alloy sheath (1% antimony). This sheath is applied over the inner polyethylene jacket of a PIC cable. It would take the place of the aluminum tape and outer polyethylene jacket of a PAP type cable. A layer of paper wrap is wound spirally between the polyethylene jacket and the lead.

2. COMPOSITE COAXIAL CABLE SHEATHS

Pasp

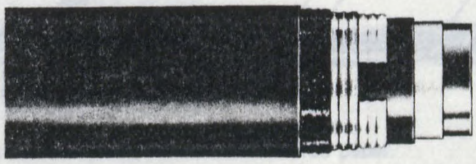
Pasp-sheathed composite coaxial cables are recommended for duct installations.



The Pasp sheath consists of an inner jacket of polyethylene, over which is applied a corrugated aluminum tape with a gap, and a corrugated steel tape, overlapped, soldered and flooded with waterproofing compound. A polyethylene jacket is extruded overall.

Sealpasp*

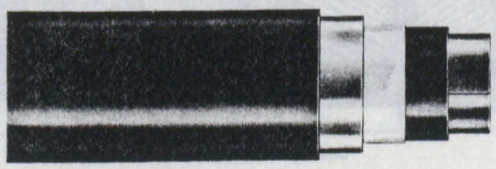
Sealpasp-sheathed composite coaxial cables are recommended for direct burial by plowing or trenching.



A Sealpasp sheath consists of a flat copolymer coated aluminum tape overlapped and sealed to an inner polyethylene jacket. A corrugated aluminum tape is applied with a gap, then a corrugated steel tape is overlapped, soldered and flooded with waterproofing compound. A polyethylene jacket is extruded overall.

Lepeth-PJ

Lepeth-PJ-sheathed composite coaxial cables are recommended for direct burial by trenching. Lepeth-PJ can be used as a base for armour.



Lepeth-PJ consists of an inner jacket of polyethylene, a heat barrier tape, and a lead alloy jacket containing 1% antimony. The lead is flooded with a waterproofing compound and a polyethylene jacket is extruded overall.

Sealpeth*/Norweld*

Sealpeth/Norweld-sheathed composite coaxial cables are recommended for direct burial by plowing or trenching. Sealpeth/Norweld sheaths can be used as a base for armour.

Sealpeth/Norweld sheaths consist of a co-polymer coated aluminum tape sealed to an inner jacket of polyethylene. Over this is applied a helically-corrugated welded steel tube flooded with several layers of adhesive waterproofing compound. A polyethylene jacket is extruded overall.

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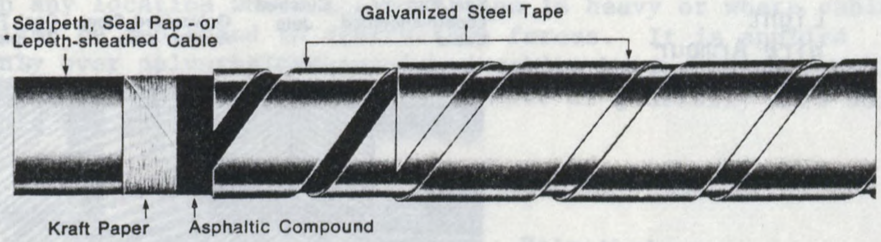
3. PROTECTIVE COVERINGS AND ARMOUR

Under adverse environmental conditions, a protective covering or armour is needed over the cable sheath. The type used will depend upon the conditions of service. The following are standard designs intended for specific applications. All seven types are used on polyolefin insulated cable; only LWA, SWA, and DWA are used on composite coaxial cable.

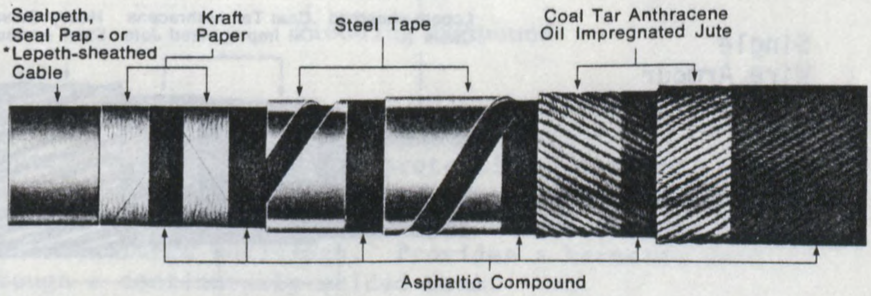
Aerial Tape Armour (ATA)



*ATA over Lepeth sheath has asphaltic compound under the kraft paper.

Used on aerial cables which may be subjected to abrasion, to mechanical vibration, or to low frequency induction from nearby power lines. It is used mainly over Sealpeth sheaths but can be supplied over Seal Pap or Lepeth sheaths.

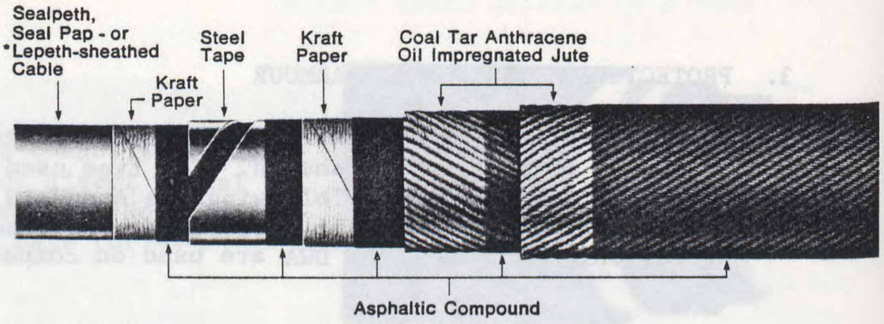
Buried Tape Armour (BTA)



*BTA over Lepeth sheath has asphaltic compound under the first layer of kraft paper.

Supplies protection against physical damage for cables with Sealpeth, Seal Pap, or Lepeth sheaths buried directly in the ground. It also protects the Lepeth sheath from corrosion.

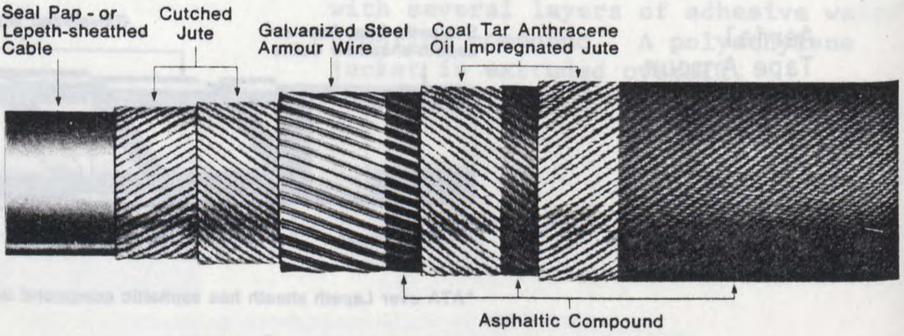
Gopher Tape Armour (GTA)



*GTA over Lepeth sheath has asphaltic compound under the first layer of kraft paper.

Provides physical protection against gopher attack. It can be supplied over Sealpeth, Seal Pap, or Lepeth sheaths.

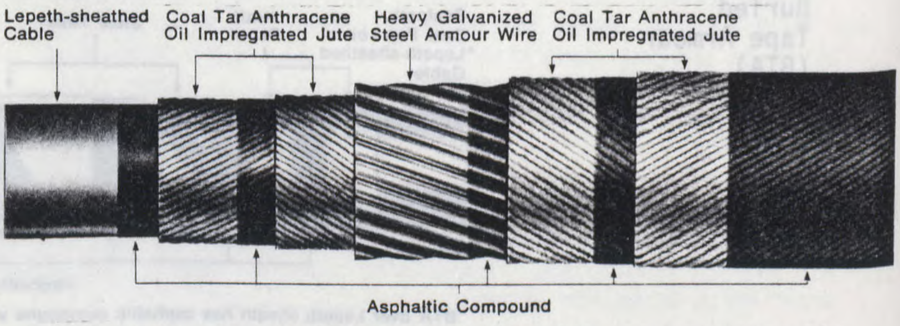
Light Wire Armour (LWA)



*LWA over Lepeth-sheathed cable has coal tar anthracene oil impregnated jute instead of the cutched jute, and has asphaltic compound over the sheath and both layers of jute.

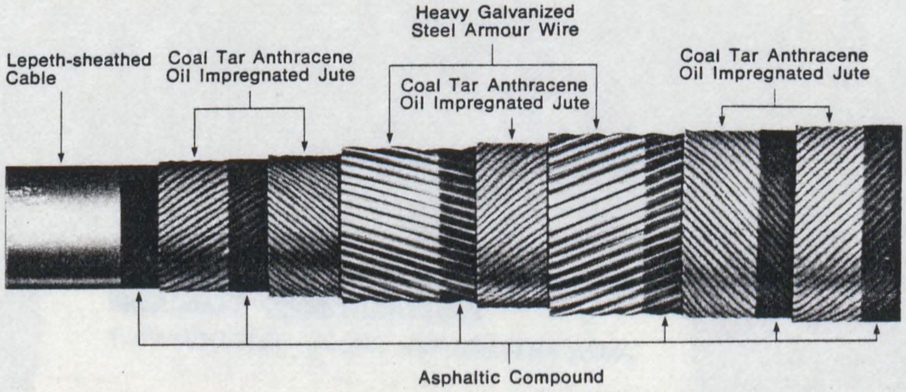
Affords longitudinal strength and mechanical protection for cables used in crossing gullies, small streams, marshes, or embankments. Such cables are often referred to as "gully-type cables". This armour is used on polyethylene-insulated cable having a Seal Pap or Lepeth sheath.

Single Wire Armour (SWA)



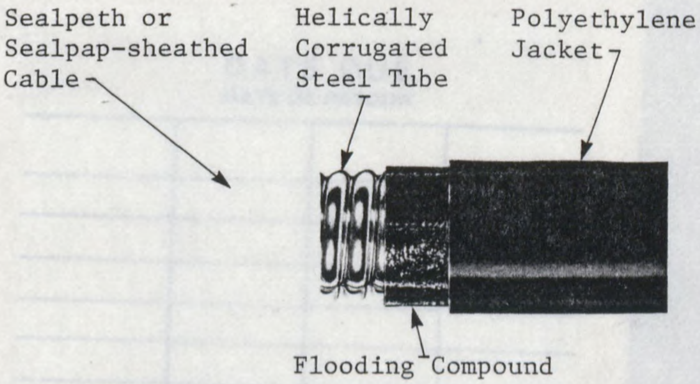
Similar in construction to light wire armour but made with heavier armour wire. Designed for use in crossing larger bodies of water, such as rivers, it is applied only over polyethylene-insulated cables having a Lepeth sheath. (Paper-insulated, lead-sheathed cable is recommended where the cable has to go through long stretches of water.)

Double Wire Armour (DWA)



Used for submarine cables in deep water, in strong tides, or in any location where ice formation is heavy or where cable might be subjected to destructive forces. It is applied only over polyethylene-insulated cables having Lepeth sheaths. (Paper-insulated, lead-sheathed cable is generally more suitable for these locations.)

Norweld*



Provides rugged mechanical protection for direct burial by plow or trenching. Used over Sealpeth*, or Sealpap* sheaths. Unjacketed Norweld can be used for vertical cables in large buildings. Provides a hermetic seal through a continuously welded seam.

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A SYSTEMS STUDY OF FIBER OPTICS FOR
BROADBAND COMMUNICATIONS
v.8--Outside plant considerations.

DATE DUE
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