COST OF RURAL TELEPHONE SERVICE

by

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Rural Communications Program

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1. INTRODUCTION

What does it cost to provide telephone service in rural areas? Is it $2,000.00, $5,000.00, $15,000.00, or $50,000.00? The answer is, of course, that all of these figures are correct; it all depends on the circumstances.

Telephone distribution networks are designed on the basis of feeder cables extending along a limited number of routes radiating from the switching office. Subscribers are picked up either singly or in clusters as the route progresses. Every route is different in terms of its primary parameters, such as the number of subscribers served, length, and construction details. Hence, costs per subscriber are also different depending on where they live and local geographic and serving company factors.

In this report we have attempted to describe the major factors which influence the costs of providing rural telephone service, and to show by means of specific examples what range of costs may, in practice, be expected. These examples have been computed for a cross-section of Canadian telephone companies, taking account of local design and construction techniques, so that we may have a picture of how geographic influences affect costs.

We have limited our analysis to the consideration of cable systems only. Our examples will serve as useful reference points for evaluating newer distribution technologies, such as subscriber carrier systems, which are finding increasing application in modern loop plant.

Each feeder route is divided into sections which are defined so that the number of pairs in the route may be matched to present and future demand as effectively and economically as possible. While the number of sections can be made quite arbitrarily large, forecast uncertainties and difficulties in constructing and rearranging a feeder network which changes gauge and size frequently make it impractical and uneconomic to administer a route with a large number of sections.

Feeder cables are generally in conduit near the central office emerging from the ground to be carried on aerial support structures inside a town and perhaps buried again on the outskirts. Alternatively a cable may be aerial or buried over its entire length depending on the office location and terrain. Eventually these cables terminate in the distribution network -- the system of cables and terminals to which individual telephone lines are connected. In urban areas distribution cables, which follow the streets where the subscribers are located, usually consist of 50 to 300 pairs and are no more than one half mile long. However, in rural areas a recognizable distribution system frequently does not exist. Distribution cable(s) are then considered to be those beyond the last loading or access point.

Cable construction methods directly affect costs. It is generally easier, and hence, cheaper to bury cable, but this is not always possible, and while maintenance may be low, to add to existing facilities may be difficult and expensive. The opposite conditions are true for aerial cable.

Long rural loops require special treatment to make sure that each station is within the central office signalling, supervision, and transmission limits. Actual details of the loop treatment techniques employed vary from company to company (some are described in Section 4), but they all usually require heavier than normal cable gauges (19, 22 or 24 as against 26 Ga for urban loops) and the use of electronic devices, such as range extenders, vf amplifiers, and ringing isolators.

Acting as a multiplier of all these parameters is the percentage utilisation of a cable (% fill). Cables are installed on the basis of initial subscribers plus expected growth over some reasonable planning period. Therefore at any given time only part of the available number of pairs may be actually used (70% is a typical figure). This factor is compounded by the necessity for choosing the next largest cable size above the expected number of subscribers on any given feeder route.

The way in which subscribers are distributed also has a direct bearing on costs. If they are clustered,then many subscribers can be served from one break in the cable (which involves cutting the cable and then splicing it again after the required number of pairs are broken out). Conversely, isolated single subscribers require many breaks and resplices which is costly in hardware and labour. Service from the cable to the subscriber is provided by means of drop-wires,which are normally one of the most vulnerable and therefore troublesome parts of the distribution system. In the rural areas drops are frequently very long and consequently costly.

Another major influence is terrain. Apart from the question of whether a feeder may be buried or aerial, natural barriers such as rivers, swamps, hills, etc., frequently dictate that the most direct route cannot be taken to the subscriber, so that the route length of outside plant facilities actually required may be as much as two or more times the most direct distance from the central office to the subscriber.

2. TELEPHONE COMPANY PROVISIONING AND COSTING METHODS

2.1 Rural Services Provisioning

In this section we will briefly review the main characteristics of rural cable networks. Installation and design practices vary between telephone companies; examples of actual practices will be given in later sections. Here we will give an outline of the techniques used and describe generally the factors that influence the cost of providing service.

Telephone systems in rural areas are usually composed of a number of relatively small switching offices distributed over a large geographic area. Normally each office is located in a small community which it serves together with the surrounding area where the subscriber density is generally low. A small number of main distribution cables (feeder cables) radiate from each office to pick up subscribers both within and outside the base rate area. Since the number of subscribers diminishes with distance from the central office the feeder cables are tapered, both in gauge and numbers of pairs, with large size small gauge cables near the Central Office and small size large gauge cables farther away.

Generally feeder routes consist of many multipair cables in parallel which are interconnected at intervals by splices. At various points branch cables, called laterals, leave the feeder route to pickup concentrations of subscribers, although in rural areas single subscribers are more likely to be connected directly to appropriate points on the feeder cable. Up to four different gauges of wire may be used in those cables, although an attempt is generally made to restrict any one route to only two consecutive gauges.

For these reasons the actual costs of providing service in rural areas are generally high,necessitating sharing the same circuit between many subscribers (party-lines), and vary from region to region and even between feeder routes in the same exchange. In this report we have attempted to demonstrate the range of expected costs by choosing a number of representative examples of routes and calculating their costs by using data for various telephone companies. These can be generalised and compared to produce a series of "average" costs across the country.

2.2 Planning Methods

Telephone plant is provisioned on the basis of current and projected demand for service. This may be done either by rearrangement of existing facilities, so that unused pairs become available where needed, or by adding new cables. The number of pairs added should be, ideally, that number which minimizes the total cost of the current plus all future relief projects. However, opposing economic forces are at work. The cost per pair is less for large cables and the time before further relief is required is increased. On the other hand large cables represent large idle investments which will not be revenue earning for long periods of time. This is the basic dilemma to be resolved: what is the economic optimum between buying more at once to take advantage of lower unit cost against the penalty of having to tie up more capital sooner?

The techniques of engineering economy studies can be used to resolve this problem. Any particular area or route requiring attention is first studied and a number of feasible alternatives for satisfying the demand are identified. These plans are then developed until all of the relevant factors and costs involved in each are identified. The plans are equivalent in that they all represent different ways of accomplishing the same objective over the study period (the period over which investments will no longer be required to obtain equivalence between alternate plans, usually 15 to 25 years). In other words they meet the same service demands for each year of the study period and provide service over the same period of time.

The correct choice between practicable alternatives depends not only on the comparison of the cost of installation and construction, but also on a thorough analysis of pertinent annual charges. Minor plant reinforcement and replacement decisions are sometimes made on the basis of general determinations. However, individual economic studies are completed where it is judged that the application of a general approach will not provide reliable accurate data on which to base a decision.

Engineering economy studies are used to determine the relative economy between two or more plans; they are instruments for making objective comparative evaluations. Annual charge and present worth studies are the two major analytical methods used in the telephone industry. The details of the methods used are covered in standard texts*, so only the outlines will be presented here.

Annual charges are the recurring annual expenses associated with owning, operating, and inflicting wear on a telephone system and keeping it in a functional condition. Usually additions and removals of plant and facilities are made several times during the period under study. The annual charges consequently vary throughout the period to such a degree that is is impossible to compare the plans without reducing the costs to a common time basis. The

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* "Engineering Economy", Western Electric Co., New Jersey.
"Engineering Economics", O. Smidt, Telephony Publishing Corp.

Present Worth of Annual Charges (PWAC) type of study is an analytical approach which allows such variations to receive full consideration and is, therefore, considered essential in performing economic analysis in planning and designing telephone systems.

First costs and annual costs are the two major factors which will normally be considered in performing PWAC studies. First cost is the actual and estimated "one time only" expenditure which will be needed for the construction/installation of plant and equipment. It also includes all associated overhead costs, and other related costs such as modifications, right-of-way procurement, and removals, i.e., these are the capital expenditures which will be entered on the company's property records. Normally, other things being equal, a plan requiring large capital investments is considered to be less attractive than one requiring small investments, because investments are not flexible.

Annual costs include cost of money, depreciation, income and property taxes, and maintenance. Overheads and other administrative expenses are not generally considered since they should be the same for all alternatives. The cost of money is a composite (weighted) percentage rate which reflects the interest which must be paid on debt capital and the return which must be earned on equity capital. Equity capital is the funds derived from the sale of stock, or from profits which are reinvested in the system instead of being paid out as dividends, or from the recovery of capital (depreciation) previously invested in the system. Return on equity capital is the net income available after the payment of all expenses, including interest on debt capital and taxes. Assuming an 8% interest rate on debt capital and a 12 % return on equity capital, Cost of Money based on a debt ratio (percentage of debt compared to total capital) of 50% will be 50% of 8% + 50% of 12% = 10%.

Capital recovery is the process of regaining the net investment which has been put into a project. i.e., the repayment of principal (taking into account net salvage) plus interest on the diminishing unrecovered balance. Depreciation accounting is the process of allocation of a net capital cost to an expense account.

Several methods are available for calculating depreciation expense; straight line depreciation is most commonly used in the telephone industry as the accounting method to reflect decreasing value of plant. With this method the first cost minus the estimated net salvage is pro-rated uniformly over the anticipated service life of the unit. Service life is the anticipated length of time a component will be in service before it is fully depreciated; this time generally does not correspond with the "physical life" which is the time period over which a component continues to function satisfactorily if subjected only to deterioration. Service lives cannot be forecast precisely although observation and experience in the industry indicate that the following times are realistic for the various plant categories shown:

a)	COE, electromagnetic, common control	30 years
b)	COE, step by step	25 years
c)	Electronics (processor controlled COE, pair gain devices	20 years
d)	Cable	25 years
e)	Buildings	30 years

Retirements may occur because of deterioration, obsolescence, insufficient capacity, or incompatibility. For PWAC studies the net salvage value (gross salvage less the cost of removal) is important, as is also whether it is retired at the start of or during the study period.

In any real-life situation rearrangements or additions to existing plant will occur. If the rearrangement involves labour and material costs which will be capitalised,there will be additional annual charges equal to these costs multiplied by the appropriate annual charge factor. For costs which will not be capitalised they are considered as maintenance expense in the year in which it occurs.

A PWAC Study consists of a comparison of known and estimated expenditures. The study period chosen is long enough to allow the annual charges associated with the last major investment to accumulate to the extent that their effects can be reflected in the study (usually 15 to 25 years). In this kind of study the annual charges (which may vary throughout the life of various plans) are converted to a present worth lump sum and brought back in time to a common point, the present.

Thus $$\text{PWAC} = \text{IFC} \times \text{AC} \times \text{DAF}$$

Where IFC is the installed first cost for each component or facility

AC is the Annual Charge Factor for the component or facility. This factor is computed periodically by each company for the various classes of plant. It generally is the sum of the cost of money, depreciation, income tax, maintenance, insurance and other taxes, rates expressed as a percentage of IFC.

DAF is the Deferred Annuity Factor for the component or facility i.e., the present worth of an annuity for the year "n"when action will occur $[(p/a)n]$.

If the following two conditions are met:

i) all jobs or plans of action start at the same time,

ii) all jobs or plans of action have uniform annual charges throughout their service lives,

then it is sufficiently accurate to compare alternative plans on the basis of annual charges only. This is the approach used in the following sections, where we are computing the cost of new facilities on the basis of different design techniques. These annual charges can be converted to PWAC by multiplying by the appropriate annuity factor, but these factors will be the same for all of the approaches studied.

To summarize: comparison of plans is performed on the basis of estimating the cash flows involved. The Cash flows normally considered are:

- capital expenditures for property
- gross salvage from the sale of retired property
- cost of removal of salvaged property
- income tax
- recurring annual charges such as maintenance, repairs, property taxes.

The annual charges are then computed for each plan. This is the amount of money set aside each year for the life of the plant in order to:

- pay a return to the people who loaned the money (cost of money),
- pay back the principal of the loans, bonds or stock,
- pay income taxes,
- maintain the plant during its life,
- pay insurance and other taxes.

Once all of the relevant factors have been identified and calculated the plans can be compared by converting the annual charges to their present worth.

One final point: annual charges can be related to revenue requirements by taking account of: --

a) non-revenue earning investment (NREI), the cost of keeping spare stock (with its depreciation and tax consequences),

b) rearrangements and changes (M- costs) averaged over the life of the plant,

and c) administrative (overhead) costs (OH).

Therefore the total revenue requirements (TRR) will be:

$$TRR = AC + NREI + M + OH$$

In this way it should be possible to estimate, at current telephone rates, at what point rural telephone service becomes 'uneconomic', but this is beyond the scope of the present report.

DERIVATION OF LOOP COSTS

3.1 Cable Costs:

The cable costs for the route are worked out as follows:

Let the initial number of subscribers on the route be NSI. After NFP years (fill period), the number of subscribers on the route will be NSF.

$$NSF = NSI * (1 + SGR * NFP) \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

or

$$NSF = NSI + \sum_{t=0}^{NFP} SGR * NSI \ldots\ldots\ldots\ldots\ldots\ldots (1a)$$

where

NSI = Initial number of subscribers
NSF = Ultimate number of subscribers
SGR = Subscriber growth rate (percentage of initial no./year)
NFP = Fill period (years)

Let us consider an element Q of length ΔX located on the route at X Kft. from the central office.

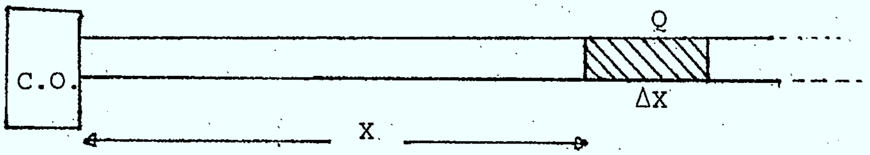


Fig. 3.1-1

If the subscriber's cumulative distribution is P(X) the number of subscribers located beyond Q ultimately will be

$$NS(>X) = NSF * \{1 - P(X)\} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where

NS(>X) = The ultimate number of subscribers beyond X Kft. from the central office.

Let the following functions be introduced:

$$F1(>X) = \frac{\text{Total number of 1 party subscribers beyond X Kft. from C.O.}}{\text{Total number of subscribers beyond X Kft. from C.O.}}$$

$$F2(>X) = \frac{\text{Total number of 2 party subscribers beyond X Kft. from C.O.}}{\text{Total number of subscribers beyond X Kft. from C.O.}}$$

$$F4(>X) = \frac{\text{Total number of 4 party subscribers beyond X Kft. from C.O.}}{\text{Total number of subscribers beyond X Kft. from C.O.}}$$

$$F8(>X) = \frac{\text{Total number of 8 party subscribers beyond X Kft. from C.O.}}{\text{Total number of subscribers beyond X Kft. from C.O.}}$$

The number of working pairs required at point Q will be

$$NPAIR(>X) = NS(>X) * \left[F1(>X) + \frac{F2(>X)}{2} + \frac{F4(>X)}{4} + \frac{F8(>X)}{8} \right]$$

where NPAIR(>X) = The number of working pairs at a point X Kft. from the C.O.

It has been found that the installed capital cost of a VF cable can be represented approximately by a linear equation. In figure 3.1-2, the installed capital costs per unit length for various gauges are plotted against the number of pairs.

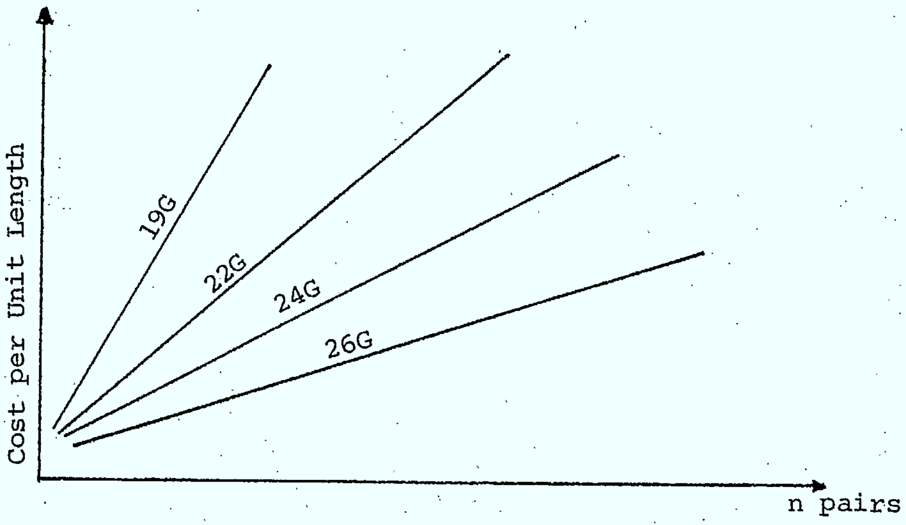


Fig. 3.1-2

For a particular gauge i, the installed capital cost/unit length for placing and splicing a cable may be estimated by using the expression:

$$C_i = A_i + B_i * N \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3a)$$

where C = Cost per unit length for gauge i.
N = Number of pairs in the cable.

A is the total labour and material cost per sheath foot and B is the material, placing and splicing cost per pair foot.

There will generally be a different set of A and B costs associated with the gauge of wire used in the cable as well as with the type of construction (aerial, buried or underground).

If we assume that the number of working pairs throughout ΔX (fig. 3-1.1) is constant and equal to NPAIR (>X) the installed capital cost for ΔX will be:

$$\Delta COST = K^* \left\{ A_i + B_i^* NPAIR(>X) \right\} ^* \Delta X \quad \ldots\ldots (4)$$

Where

A_i = Fixed cost per unit length cable gauge i.
B_i = Cost per unit pair length of cable gauge.
$\Delta COST$ = Cost of element ΔX
K = Constant

The constant K converts route miles (or Kft.) to the cable lengths. For example, Manitoba Telephone System estimate that a one mile section of a route requires 5500 ft. of cable. In that case, $K = 5.5/5.28 \simeq 1.042$.

To find the total cost of the cable for the route, we sum up $\Delta COST$.

$$\text{Total Cost} = \sum_{X=0}^{RLT} \Delta COST$$

where RLT = Total feeder length.

In practice, only discrete cable sizes are available so equation (4) has to be modified since excess cable pairs cannot be avoided at some points along the route.

We introduce the excess cable size factor (ECSF) which takes care of the cost implications of excess cable.

$$\Delta COST = K^* \left[A_i + B_i^* NPAIR(>X)^* ECSF \right] ^* \Delta X \quad \ldots\ldots (5)$$

As a consequence of the allowance for growth on the route and the excess cable size factor, at any given point on the route, less than 100% of the pairs will be used. The "fill factor" (ratio of number of working pairs to total pairs) varies along the route.

Supposing the maximum fill factor required on the route is F.F. then the cost of ΔX is:

$$\Delta COST = K^* \left[A_i + B_i \frac{^* NPAIR(>X)^* ECSF}{F.F.} \right] ^* \Delta X \quad \ldots\ldots (6)$$

The installed cable cost for the whole route will be

$$CIC = \sum_{X=0}^{RLT} \Delta COST \quad \ldots\ldots (7)$$

where $\Delta COST$ is given in Equation (6).

The annual charges for the cable are given by

ACC = ACCF*CIC ....(8)

where

ACC = Annual cable charges
ACCF = Cable annual charge factor.

Also, installed cable cost per initial subscriber would be

CICISUB = CIC/NSI ....(8a)

The installed cable cost per final subscriber would be

CICFSUB = CIC/NSF ....(8c)

and the annual cable charges per final subscriber would be

ACCFSUB = ACC/NSF ....(8d)

At this point, it should be pointed out that in the computer program 'CORTS' which works out route costs, both the fill factor (F.F.) and excess cable size factor (ECSF) are not required. This is achieved by the use of a subroutine 'PAIR' which works out the required number of working pairs at different points on the route and thus determines the appropriate cable size taking into account the projected subscriber growth and available cable sizes.

The length of the element ΔX is conveniently chosen to be the standard distance between loading points; 4.5 Kft. for D-66 loading and 6 Kft. for H88 loading.

3.2 Determination of Gauges

When determining the cable gauges to be used for a given route, it is assumed that the two finest gauges whose combined resistance meets the signalling limit, are chosen.

Let the following notations be introduced:

RLT = Total route length (feeder length)
RDL = The maximum loop resistance (a variable depending on the design technique used).
RL26 = Length of the section consisting of 26 gauge.
RL24 = Length of the section consisting of 24 gauge.
RL22 = Length of the section consisting of 22 gauge.
RL19 = Length of the section consisting of 19 gauge.

R26 = Resistance per unit length of 26 gauge.
R24 = Resistance per unit length of 24 gauge.
R22 = Resistance per unit length of 22 gauge.
R19 = Resistance per unit length of 19 gauge.

The two gauges to be used for a particular route are chosen as follows:

If $RLT \leq \frac{RDL}{R26}$ then 26 gauge is used for the route.

If $\frac{RDL}{R26} < RLT < \frac{RDL}{R24}$ then 26 and 24 gauge are used.

If $\frac{RDL}{R24} < RLT < \frac{RDL}{R22}$ then 24 and 22 gauge are used.

$\frac{RDL}{R22} < RLT < \frac{RDL}{R19}$ then 22 and 19 gauges are used.

If $RLT > \frac{RDL}{R19}$ then a design technique which permits a higher maximum loop resistance has to be chosen. In practice, this means an additional boost for the central office D.C. voltage is required in order to meet the minimum signalling current (23 ma) standard.

It is common practice to have the finer of the two gauges next to the central office since it is more convenient to connect to the main distribution frame (MDF).

The proportions of the route covered by the respective gauges are worked out as follows: for example if

$\frac{RDL}{R24} < RLT \leq \frac{RDL}{R22}$ (we use 24 and 22G)

then

$$RL24 + RL22 = RLT \quad \ldots\ldots (9)$$

$$R24*RL24 + R22*RL22 = RDL \quad \ldots\ldots (10)$$

From the two equations (9 and 10), the two unknowns RL24 and RL22 can easily be worked out.

$$RL24 = (RDL - R22*RLT)/(R24 - R22)$$

$$RL22 = (R24*RLT - RDL)/(R24 - R22)$$

For other lengths, the respective gauges can be worked out in a similar manner.

At this point, the route could be considered as being made up of two parts; part 1 and part 2.

In part 1, the gauge used is Gauge 1(G1) which might be 26G, 24G, 22G depending on the route length and signalling limit. The length of part 1 is RL1. In part 2 the gauge used is Gauge 2 (G2) which might be 24G, 22G or 19G depending on the signalling limit and route length. The length of part 2 is RL2. In figure 3.2-1 we have a possible route configuration.

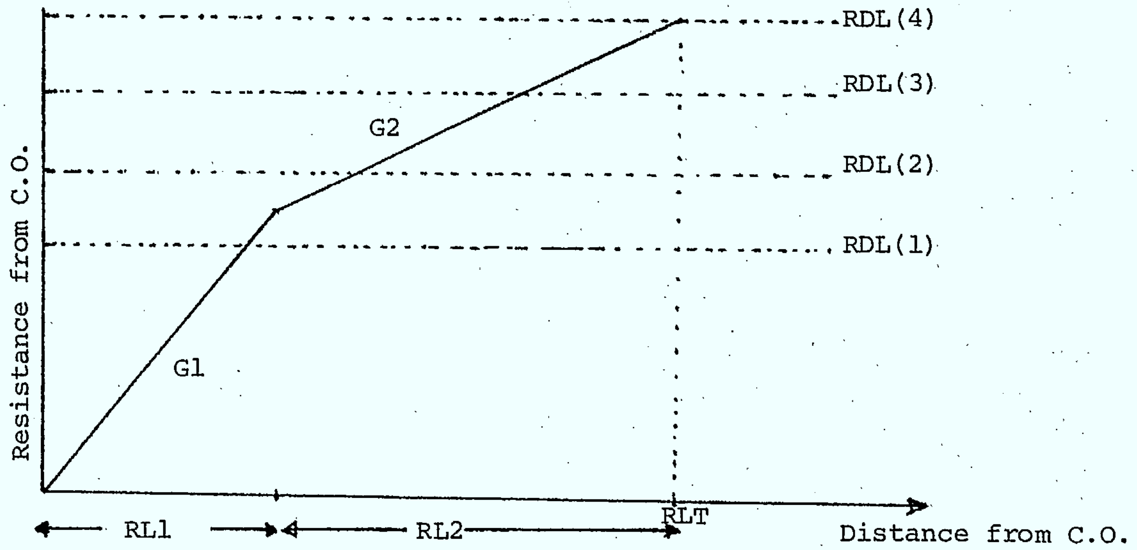


Fig. 3.2-1

In practice, the gauge change-over is usually done at a convenient place such as a loading point for example. Thus, RL1 might have to be slightly decreased and RL2 slightly increased so that the change takes place at a loading point.

3.3 Cost of Loop Electronics

Figure 3.3-1 shows the configurations typically used to extend the central office supervision and transmission limits. The resistance zone boundaries (RDL(1), RDL(2), RDL(3) and RDL(4)) are chosen to ensure the minimum current of 23mA required for satisfactory operation of the telephone set on all loops. A voice frequency repeater is required on loops where the expected measured loss (EML) at 1000 Hz exceeds the design objective. This objective varies between companies but it is generally in the vicinity of 8 dB (allowing for bridged taps, end sections etc.) with a further 0.5 dB allowed for central office losses. All loops over 18 Kft. are loaded to reduce transmission loss according to one of two commonly used plans - H88 or D66.

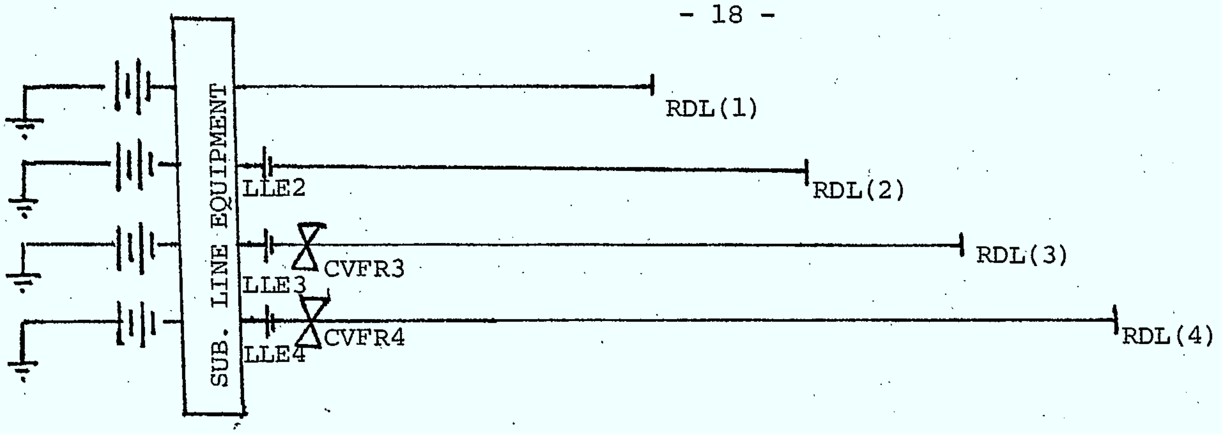


Fig. 3.3-1

The resistance range from zero (ohms) at the switching centre to RDL(4) is generally divided into four resistance zones (RZ). The equipment for each zone is as follows:

RZ1 (0 - RDL(1)) → No special equipment.
RZ2 [RDL(1) + 1 → RDL(2)] → 24V loop extender (Battery Booster).
RZ3 [RDL(2) + 1 → RDL(3)] → Loop extender + Voice Frequency Repeater.
RZ4 [RDL(3) + 1 → RDL(4)] → 48V Loop extender + Voice Frequency Repeater.

Some telephone companies (Manitoba Telephone System for example) have only 3 resistance zones. In that case, the equipment requirements are slightly different from the ones given above.

On a given route, when determining the cost of electronics, the graph of loop resistance versus loop length (length from the C.O.) is used. As shown in figure 3.3-2, the vertical projections from the intersections of the cable loop make-up and the horizontal resistance zone boundaries indicate where the theoretical resistance zone boundaries will occur.

RZ1 0 ——— H(1)
RZ2 H(1) ——— H(2)
RZ3 H(2) ——— H(3)
RZ4 H(3) ——— RLT

$H(I) = RLT - (RDL(4) - RDL(I))/R2 \quad \text{for } RL1*R1 \leq RDL(I)$
$H(I) = TDL(I)/R2 \quad \text{for } RL1*R1 > RDL(I)$

where I = 1, 2, 3, 4
R1 = Resistance per unit length of part 1.
R2 = Resistance per unit length of part 2.

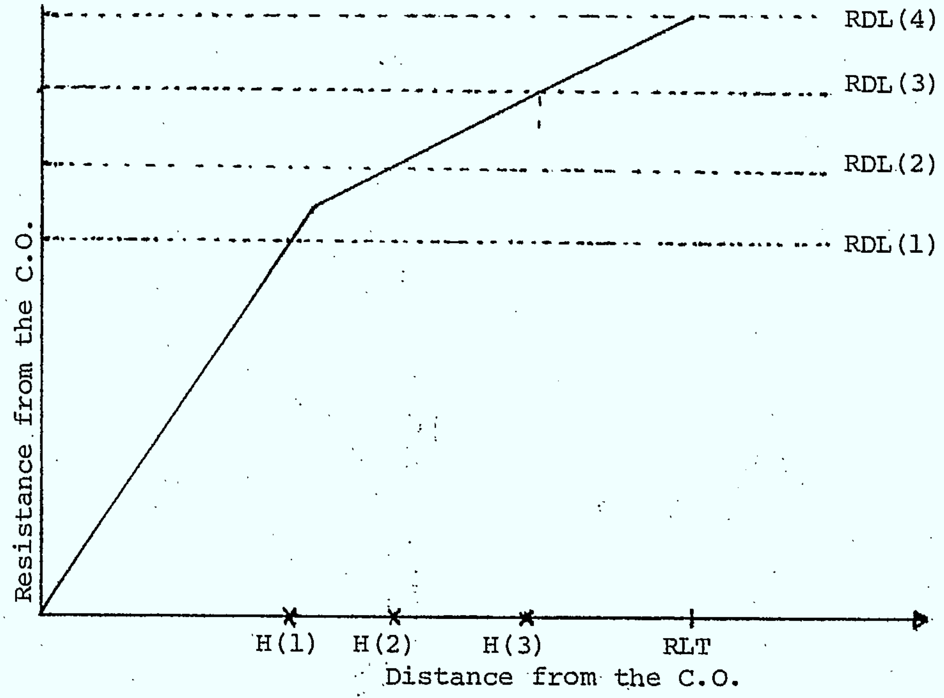


Fig. 3.3-2

Let the following quantities be introduced:

CIE = Installed capital cost of electronics.
ACE = Annual charges for the electronics.
CLLE2 = Installed cost of loop extender (LLE2).
CLLE3 = Installed cost of loop extender (LLE3)
CLLE4 = Installed cost of loop extender (LLE4).
CVFR3 - Installed cost of voice frequency repeater (VFR3).
CVFR4 = Installed cost of voice frequency repeater (VFR4).
ACFR = Annual charge factor for the electronics.

The installed cost of electronics is

$$\begin{aligned} CIE = {} & [NPAIR(H(1)) - NPAIR(H(2))]*CLLE2 \\ & + [NPAIR(H(2)) - NPAIR(H(3))]*[CLLE3 + CVFR3] \\ & + [NPAIR(H(3)) - NPAIR(RLT)]*[CLLE4 + CVFR4]. \end{aligned}$$

where NPAIR (X) is the number of working pairs beyond a point X units from the central office.

The installed capital cost for the electronics per ultimate subscriber is:

CIEFSUB = CIE/NSF .... (14)

The annual charges for the electronics are:

ACE = ACFE*CIE.. (15)

and the annual charges for the electronics per ultimate subscriber work out to

ACEFSUB = ACFE*CIE/NSF .... (16)

It should be pointed out, however, that in practice the cost of loop extenders are, for a given telephone company, essentially the same. This is true for voice frequency repeaters as well.

3.4 Cost of Support Structure

If the route being considered is aerial, then the cost of the support structure has to be included in the route costs.

The support structure includes:

1) The poles
2) Arms
3) Guys
4) Strands
5) Support (messenger) wire (for cables that do not have an in-built support)

The cost of the support structure is calculated as follows:

If we assume that there is 1 guy every 10 poles, and the pole spacing is POSP.

Average cost of the support structure is

AICSS = (cost of 10 poles + cost of guy + cost of anchor) / 10

Number of poles per unit length is 1/(POSP)

Installed cost of support structure per unit length is AICSS/POSP
Installed cost of support structure is CISS
CISS = (AICSS/POSP)* RLT ....(17)

Annual charges of support structure

ACSS = CISS*ACFSS

Installed cost for support structure per ultimate subscriber is

CISSFSUB = CISS/NSF ....(18)

Annual charges of support structure per ultimate subscriber is

ACCSFSUB = ACCSS/NSF ....(19)

3.5 Cost of Dropwire

The dropwire is used to connect the distribution plant to the inside wiring on the customer's premises. In practice, the dropwire length is restricted to 500 ft. (1/2 Kft.).

Before determining the dropwire costs, let the following quantities be introduced:

CIDRWSUB = Installed capital cost of dropwire per sub.
ACDRWSUB = Annual charges per subscriber for the dropwire.
ALDRW = Average length of dropwire.
CDRW = Cost per unit length of dropwire.
ACFDRW = Annual charge factor for the dropwire.

The installed capital cost per subscriber for the dropwire is:

CIDRWSUB = ALDRW*CDRW .... (20)

The annual charges per subscriber for the dropwire are:

ACDRWSUB = ACFDRW*ALDRW*CDRW .... (21)

3.6 Total Route Costs

The total installed capital cost and annual charges associated with the outline plant and electronics are obtained by adding up the following:

1) Cable costs.
2) Costs associated with loop electronics.
3) Support structure costs (for aerial plant).
4) Dropwire costs.

The installed capital cost per ultimate subscriber works out to:

TCICFSUB = CICFSUB + CIEFSUB + CISSFSUB + CIDRWSUB .... (22)

where

TCICFSUB = Installed capital cost per final subscriber.
CICFSUB = Installed cable cost per final subscriber.
CISSFSUB = Installed capital cost for the support structure per final subscriber.
CIDRWSUB = Installed cost of dropwire per subscriber.

The annual charges per ultiamte subscriber are worked out in a similar manner.

TACFSUB = ACCFSUB + ACEFSUB + ACSSFSUB + ACDRWSUB where

TACFSUB = Annual charges per ultimate subscriber.
ACCFSUB = Annual charges for the cable per ultimate subscriber.
ACEFSUB = Annual charges for the electronic per ultimate subscriber.
ACSSFSUB = Annual charges for the support structure per ultimate subscriber.
ACDRWSUB = Annual charges for the dropwire per subscriber.

The present worth of annual charges can be easily worked out by multiplying TACFSUB by the appropriate present worth of annuity factor ((P/a)n). The value of (P/a)n depends on the cost of money as well as the period over which the annual charges run.

3.7 The Computer Program ('CORTS')

The computer program 'CORTS' (Cost of Rural Telephone Service), See Simplified Flow-Chart, Figure 3.7-1, derives the costs associated with providing telephone services by VF cable to rural subscribers. Both the installed capital costs and annual charges are worked out for different numbers of subscribers and subscriber distributions. Let the following terms be defined:

The Installed Capital Cost - is the "one time only" expenditure which is needed for construction and installation of plant equipment.

Annual Charges - These are the recurring annual expenditures associated with owning, operating, and inflicting wear on a telephone system and keeping it in a functional condition. The annual charges include:

1) Cost of money.
2) Property tax.
3) Maintenance.
4) Depreciation.

The annual charge factor for a given item is the ratio of the average annual charges to the installed first cost.

$$ACF = \frac{\text{Annual Charges}}{\text{Installed Capital Cost}}$$

The computer program "CORTS" performs the following operations:

1) For loaded routes, it determines the location and total number of loading points.

2) For a given route length, it determines the gauges to be used and where the gauge changeover should be.

3) Calculates the number of working pairs required at different points on the route and thus the cable sizes needed for a given route length and subscriber distribution.

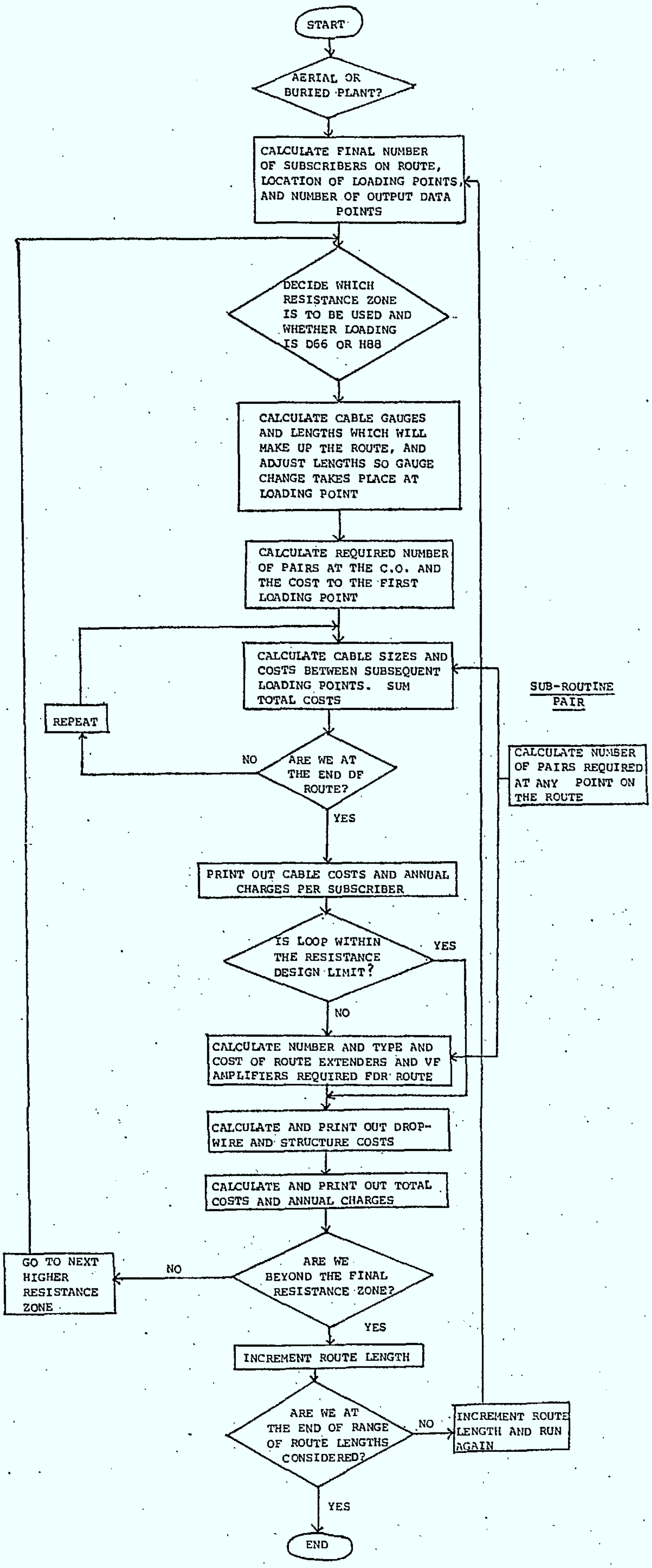


FIG. 3.7-1 Simplified Flow-Chart: Program CORTS

4) Works out the installed capital cost and annual charges for the cable.

5) Determines the number of working pairs that need loop electronics and then works out the installed capital cost and annual charges for the electronics.

6) Calculates the installed capital cost and annual charges for the average length of dropwire.

7) For aerial routes, it calculates the installed cost and annual charges for the support structure.

8) Finally it sums up the different costs to obtain the installed capital cost per subscriber and annual charges per subscriber for different route lengths and subscriber distribution functions.

It should be pointed out, however, that the computer program 'CORTS' assumes that each of the planned activities with respect to items of telephone plant occur at the same point in time. The associated annual charges are considered to be uniform throughout the study period.

With the exception of long loop electronics only, the outside plant costs are worked out by the computer program. Depending on the data, the program can calculate the costs associated with providing telephone services for one particular route length, or a range of route lengths anywhere from zero kilofeet to 150 kilofeet.

Although only three subscriber distributions are considered in the next section, with slight modifications to the input data and the subroutine 'PAIR', any desired number of subscriber distributions can be dealt with. For example, if the fourth subscriber distribution to be considered could be represented by a quadratic function, then in the data, the space for SDFC (subscriber distribution function code) we would put in the value of 4.00. In the subroutine 'PAIR' on line 264.5, the following statement would be introduced.

```
If (FC.EQ.4.0) P(M) = ((V/CR)**2)
```

The results obtained from a SDFC of 4.0 would then be for a quadratic subscriber distribution.

4. CANADIAN TELEPHONE COMPANY LOOP COST MODELS

4.1.1 Introduction

The main objective of subscriber loop design is to provide good transmission to every existing and future subscriber in the most economical manner. In order to ensure good transmission of the signals, the telephone companies set both transmission and noise objectives on their subscriber loops. The objectives vary from company to company and will be examined when the design practices of different telephone companies are analyzed later in this section.

As explained in the previous section, there are two design procedures generally followed when dealing with rural subscriber loops.

1) Standard resistance design (coarse gauge design);
2) Long loop design (Fine gauge design).

With resistance design, no provision is made to extend the signalling limit beyond the nominal 1300 Ω, which ensures a minimum loop current of 23 ma in the worst situation.* This technique therefore requires extensive use of coarse gauge cables. However with long loop design techniques, the optimum gauge(s) are selected in combination with loop extender (battery booster) and voice frequency repeater electronics to extend the signalling and supervision limits beyond that of conventional resistance design, typically to a loop resistance limit in the vicinity of 3000 Ω.

Generally, the resistance range from zero at the switching centre to the maximum resistance limit is divided up into four resistance zones. The resistance zone boundaries are chosen to meet transmission and signalling standards set by the individual companies and therefore vary from one company to another. (See sections 4.2, 4.3 and 4.4).

As can be seen from figure 3.3-1, generally subscriber long route design techniques provide several design alternatives, all of which may meet the transmission objectives. Because these alternatives will vary as to gauge and size of cable, plus various types of electronic equipment, the economic choice must be made on a present worth of annual charges (PWAC) basis.

---

* 1300 Ω is the nominal supervision limit of most switching machines; offices exist, however, with limits in the range 900 Ω to 1600 Ω.

In the computer program 'CORTS' which calculates the installed capital costs and annual charges for various route lengths, three subscriber distributions are assumed:

1) Clustered subscribers,
2) Uniformly distributed subscribers,
3) Exponentially distributed subscribers.

The three cumulative subscriber distributions are shown in figure 4.1-1, and the corresponding variation of feeder pairs required along the route (normalised to the number of pairs required at the central office) is shown in Figure 4.1-2.

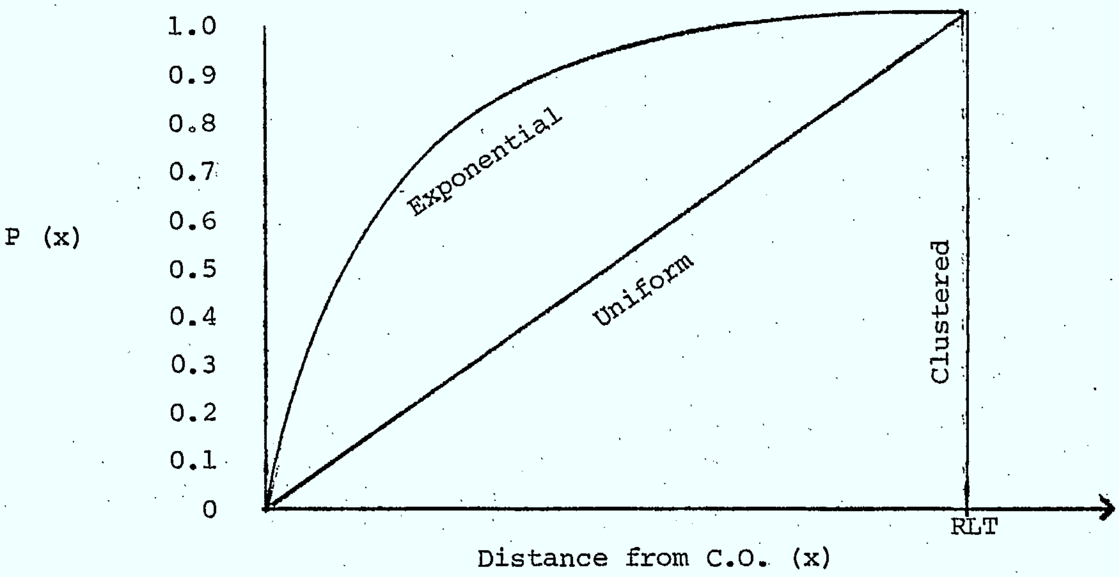
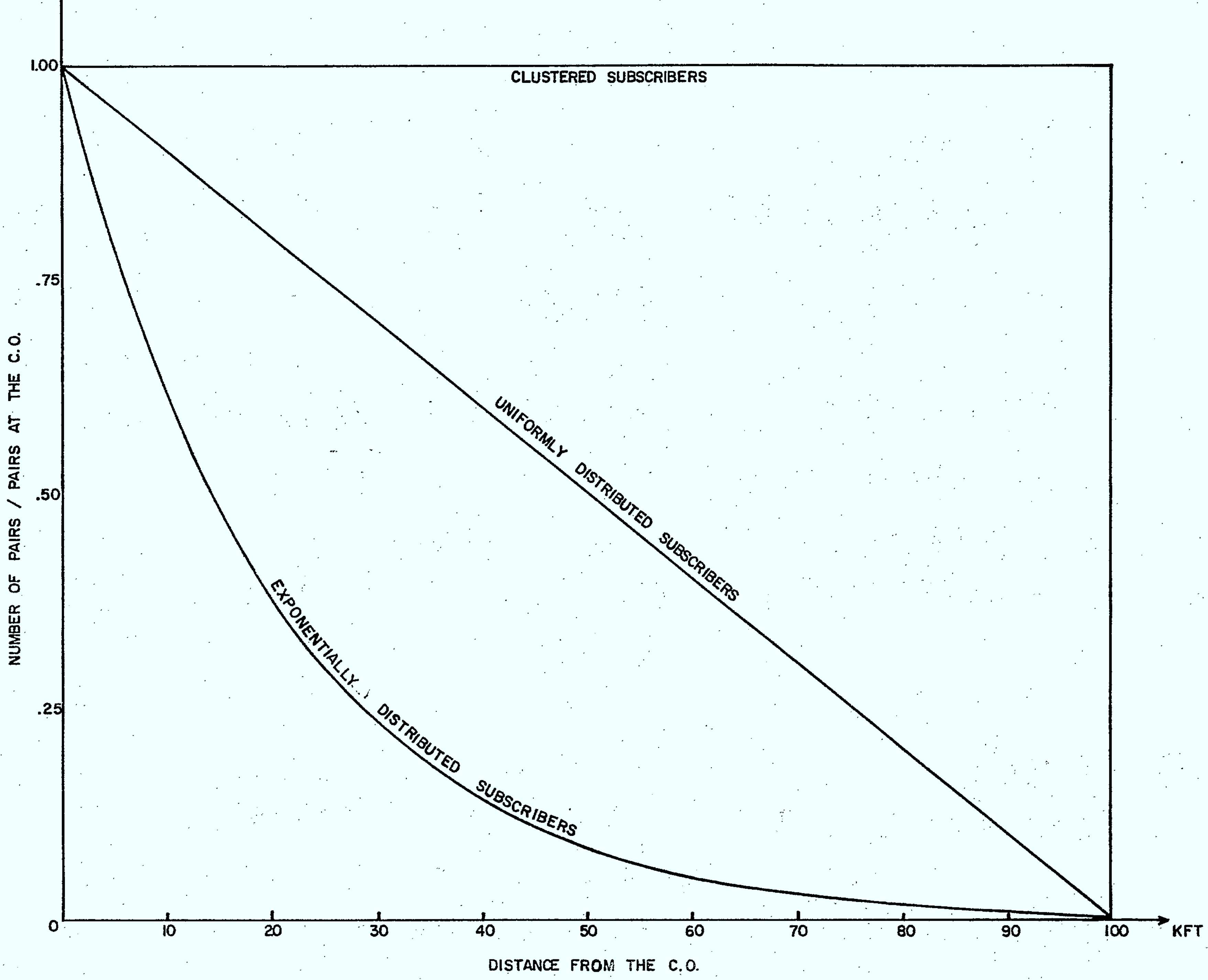


FIGURE 4.1-1

The three distributions, clustered, uniform, and exponential, were chosen because not only are they extreme cases, but they are also representative of typical situations. A small community (or village) located some distance from a switching office could be considered as having clustered subscriber distribution. Similarly, in many rural districts the sectional survey system has resulted in a uniform distribution of farms along the road system. Also, in practice, feeder routes generally originate in small communities and spread into the surrounding more sparsely populated country-

FIG 4.1-2 **CABLE PAIR REQUIREMENTS ALONG A 100 KFT ROUTE**



side. In this case the subscriber distribution can be approximated by an exponential function (see for example the results of the latest Bell System loop survey$^{(1)}$, which shows a subscriber cumulative distribution function which is quite close to exponential with a mean loop length of 11Kft).

Besides considering the distribution of subscribers with distance from the central office, the distribution by grade of service should also be taken into account in any costing study. For the examples considered in the next sections we have assumed two cases, all single party service, and the subscriber service distribution shown in Figure 4.1-3 (this figure is based on the Bell System loop survey referenced above).

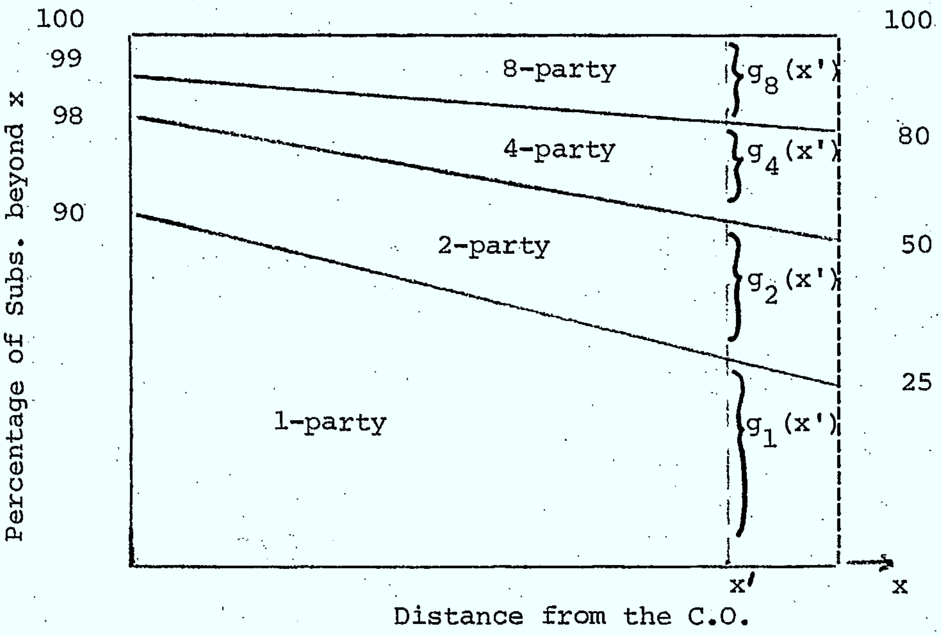


Figure 4.1-3

From Figure 4.1-3, if the subscriber distribution is P(x) and the total number of subscribers on the route is given by NSF, let us consider the situation at x' units from the central office. The total number of subscribers beyond x' units is

$$\left[1 - P(x')\right] * \text{NSF} \quad \text{-------------------}(23)$$

---

(1) "Physical and Transmission Characteristics of Customer Loop Plant" L.M. Manhire, BSTJ, January 1978.

Let the following quantities be introduced:

$N_1(x)$ = Total number of 1-party subs. beyond x units from CO

$N_2(x)$ = Total number of 2-party subs. beyond x units from CO

$N_4(x)$ = Total number of 4-party subs. beyond x units from CO

$N_8(x)$ = Total number of 8-party subs. beyond x units from CO

so

$$N_1(x) + N_2(x) + N_4(x) + N_8(x) = \left[1 - P(x)\right] * NSF \text{ --------- } (24)$$

From figure 4.1-3 and Equation -----(24) we deduce that

$$g_1(x') = N_1(x') \Big/ \left[1-P(x')\right] * NSF$$

$$g_2(x') = N_2(x') \Big/ \left[1-P(x')\right] * NSF$$

$$g_4(x') = N_4(x') \Big/ \left[1-P(x')\right] * NSF$$

$$g_8(x') = N_8(x') \Big/ \left[1-P(x')\right] * NSF$$

Where $g_i(x)$ is the linear function governing the variation of the i-party service along the route.

as expected,

$$\sum_{i \quad 1}^{8} g_i(x) = 1 \qquad \text{for all values of } x.$$

In the data for 'CORTS', the $g_i(x)$ for i 1, 2, 4 and 8, are given as percentages where:

$g_1(0)$ = PI1P/100 , $g_1(RLT)$ = PF1P/100

$g_2(0)$ = PI2P/100 , $g_2(RLT)$ = PF2P/100

$g_4(0)$ = PI4P/100 , $g_4(RLT)$ = PF4P/100

$g_8(0)$ = PI8P/100 , $g_8(RLT)$ = PF8P/100

If the route has only single-party service for example, then all the other $g_i(x)$ are zero except $g_1(x)$ which is Set to 100.0

The computer program calculates the cost of providing service to subscribers located at various distances from the central office in increments whose size may be set at any convenient value (in the following sections loop costs have been calculated at 15 Kft intervals). For a particular route, therefore, curves drawn from the program output data represent the loci of the total costs calculated for various fixed points, and as such do not show the fine detail of cost variations along the route.

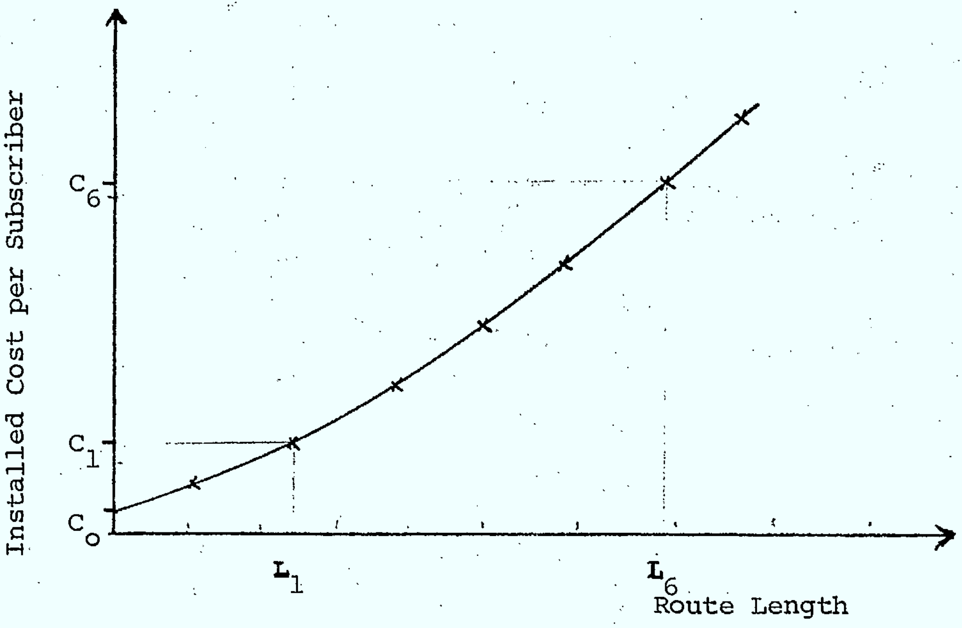


FIGURE 4.1-4

In Figure 4.1-4 for example, the installed cost per subscriber for a route of length L_1 is C_1, whereas the installed capital cost of a route of length L_6 is C_6. The intercept C_o on the y-axis represents costs which have to be incurred eventhough the route length is zero. In the examples of the next sections, $100 per subscriber has been allowed to cover the cost of C.O. protector, and terminal, drop wire, protector and ground connection at the customer's end of the loop.

The program calculates the total costs and annual charges for outside plant and central office loop extension equipment on a per (initial or final) subscriber basis. The range of subscriber sizes and subscriber growth rate considered have been chosen to be representative of the rural situation. Thus we have considered small numbers of subscribers (less than 400 ultimately) and low growth rates (60% total growth) on very long routes (100 to 180 Kft). To estimate the total cost of providing service to rural subscribers we must add approximately $400 for central office switching and trunk equipment, and $50 for inside wiring and station installation costs.

One final factor which should be considered in calculating total costs is the ratio of route to airline distance from the central office of any given subscriber. In practice feeder cables do not radiate in straight lines from central offices but are constrained by road patterns, surface geography population distribution, etc. This means that the route length to a given subscriber is typically 50% more than the airline distance (the route/airline ratio varies from 1.0 for subscribers located close to the central office to about 3.0 for subscribers at the end of very long routes). Route/airline distance ratio acts as a direct multiplier on the cable and structure portion of the outside plant costs, and while the examples of the next section assume a ratio of 1.0, costs for any given ratio can be estimated by multiplying route length by this ratio and reading off the appropriate cost from the cost/distance curves.

In the following examples for a given route length, all of the possible design alternatives allowed for in the telephone company design practices are considered, and, in the case of fine gauge design, the cheapest alternative is selected for graphing. These examples have been chosen so that the feeder cable at the central office is at (or close to) exhaustion at the end of the fill period. The curves are drawn as costs per final subscriber; but the number of initial subscribers is less than the final subscribers so that when the route is constructed the cost per subscriber is higher by a factor equal to the total growth on the route.

4.1.2 Broadgauge Unit Costs

Broadgauge unit costs are developed as average costs for all items of material and equipment to be used in engineering economy studies. They are usually updated annually to take account of changing material and labour rates as well as productivity factors*. The principal costs utilised in this report are for installed cables which include material, installation, and splicing. To these costs we have added a reasonable allowance for terminals (3 or 4 per mile) and loading coils (one case per 4500' or 6000' depending on the loading plan used). On top of these costs we have added a 5% markup to take account of materials and labour for miscellaneous items such as pressurisation equipment, stubbing, auxiliary splices, cross-connecting boxes, protectors, bonding and grounding, etc.

This "blended" cost is then the total cost of installing the cable with all its associated hardware. This is then divided into its appropriate "A" and "B" factors which are used in the computer program to approximate the installed cost of cable.

The second major item of plant of interest is the cost of the supporting structure for aerial cables. Here we have calculated costs per pole allowing a pole spacing of 200' and a reasonable allowance for guys and other hardware. We have also included in the cost of the structure the cost of supporting strand for the cable adding the cost of 200' of strand to the cost of each pole.

In connection with the supporting structure it should be noted that the program apportions the total cost of the structure among all of the subscribers on the route. However there are two points of interest here; First, telephone companies usually have agreements with the local hydro authorities for sharing the use of poles, with the telephone company bearing 40% of the cost. And secondly, the pole line may support more than one cable route. Typically the pole line cost (including the supporting strand) may be shared by 3 cables near the central office whereas beyond about 30Kft the full pole line cost must be associated with only one cable.

---

* BGV cost data used in this report was of 1976 vintage. These costs, and their relative relationships, are generally different for 1979.

It should be noted that the actual cost of constructing a given route can vary widely from the average of a given company. Therefore, the costs developed for the various companies in the next sections should only be considered as representative and not absolute. Their usefulness lies mainly in that they allow comparisons to be made between various conditions under the same set of assumptions.*

4.2 MANITOBA TELEPHONE SYSTEM

4.2.1 Loop Design Practices

Manitoba Telephone System design procedures follow the general objectives with regard to transmission and supervision summarised below:

i) The transmission net losses to the furthest subscriber in any loop should not exceed 8.5 db at 1 KHz including the losses at the central office.

ii) The average echo return loss for uniform cable gauge should be 25 db or better for 500Hz to 2500 Hz range. For mixed gauges, a return loss of 20 db or better is the objective.

iii) The minimum telephone set current is 23 ma.

Resistance design is employed for loops up to the office signalling limit, or 1300 Ω, whichever is less. All loops greater than 18 Kft are loaded according to the D 66 loading plan (although some facilities with H88 loading exist). Long loop (fine gauge) design is used for loop lengths greater than 30Kft up to a maximum loop resistance of 3000 Ω. Where loop resistance exceeds 1300 Ω, loop extenders are added to compensate for loop resistance. (Cook Electric) Loop Extenders automatically compensate for loop resistance up to 3000 Ω and apply 23 ma to the loop. Voice frequency repeaters are added as necessary to achieve 8.5 dB maximum attenuation. (Cook Electric) VF Repeaters are manually adjustable in 5 gain steps; 2.5, 3.5, 4.5, 5.5 and 6.5 dB.

---

* To develop some of the cost relationships certain assumptions were necessary (e.g. pole spacing) which, while we have attempted to make realistic choices, may not necessarily be adhered to exactly in any particular telephone

The use of 26 gauge cable is restricted to urban areas or lengths up to the first load coil from the central office. Only 19, 22 and 24 gauge cables are considered for ploughing in rural areas due to handling considerations. The number of changes in cable gauge beyond the first loading point is restricted to one to maintain a high structural return loss.

In practice, there is little (if any) cost difference in the loops designed to 2100Ω or 3000Ω limits (where the length of the loop permits these alternatives) because the same equipment with different gain and boost settings are used in each case.

4.2.2 COST OF SERVICE

MTS broadgauge cable costs were derived from Figure 4.2-1. At this point it should be pointed out that the use of 26 gauge cable in fine gauge design is restricted to urban areas or lengths up to the first load coil point from the central office. The computer program, however, assumes that there is no restriction imposed on the 26 gauge or any other gauge for that matter, since it will choose for costing purposes appropriate lengths of the two smallest cable gauges which can be used for a given route length while staying inside the resistance limit.

The installed cable costs include:

1) Material cost of the cable and labour for ploughing and placement.
2) Cost of pedestals
3) Cost of splicing
4) Cost of loading
5) 5% contingency.

From the graph of Installed Capital Cost/Kft vs Cable size, the installed capital costs for the different gauges can readily be written as:

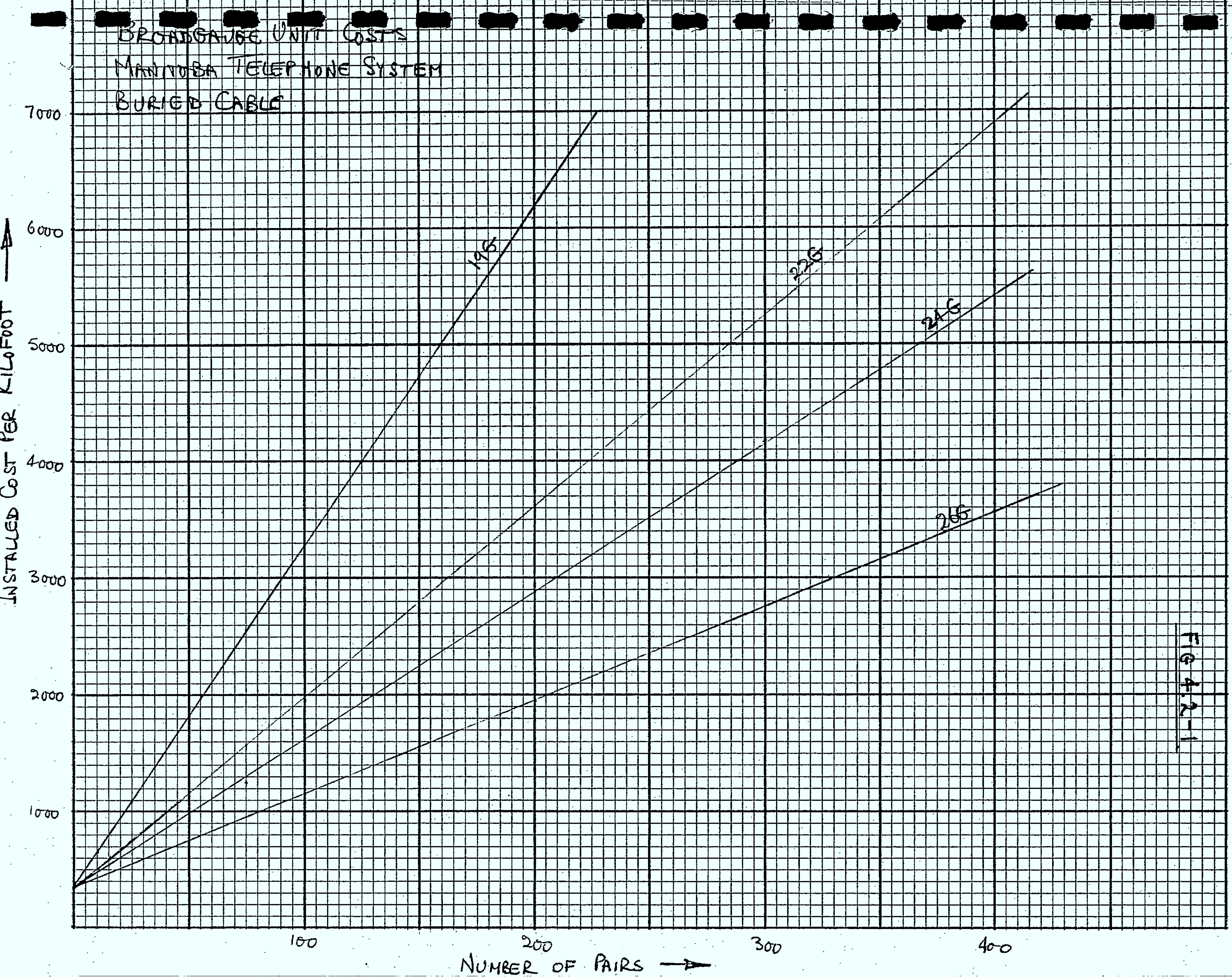

BROADGAUGE UNIT COSTS
MANITOBA TELEPHONE SYSTEM
BURIED CABLE

FIG 4.2-1

Installed Capital Cost for 19 gauge cable	350 + 28.75 n	$/Kft
Installed Capital Cost for 22 gauge cable	350 + 16.25 n	$/Kft
Installed Capital Cost for 24 gauge cable	350 + 12.53 n	$/Kft
Installed Capital Cost for 26 gauge cable	350 + 8.00 n	$/Kft

Installed first costs and annual charges have been calculated for the four subscriber distribution cases considered (single-party linear, clustered, and exponential, and exponential with party-line service) on a per initial and final subscriber basis for buried plant coarse and fine gauge design. Figures 4.2-2 to 4.2-6 show a number of representative cases.

Figures 4.2-2 shows, for the uniform subscriber distribution case, how the cost per (final) subscriber varies with number of subscribers served. Here the final number of subscribers in each case have been chosen to exhaust (or nearly exhaust) standard size cables. This figure shows how strongly dependent the cost per subscriber is on the number of subscribers served. Thus the cost per subscriber for 9 subscribers is 4 times the cost per subscriber for 400 subscribers. Also shown in this figure is a comparison between coarse (1300Ω) and fine gauge (3000Ω) design. Fine gauge design is the cheaper design technique for route lengths between 30 and 45K depending on the number of subscribers served.

Figures 4.2-3 to 4.2-6 show installed first costs and annual charges per subscriber for serving 9 and 400 subscribers with various distributions. Both coarse and fine gauge design cases are shown out to their respective useful design limits (about 70Kft and 170 Kft respectively). The curves shown in these figures demonstrate how subscriber distributions affect costs. In each case clustered subscribers represent the worst case, followed by uniformly distributed subscribers, and finally exponentially distributed subscribers. While the differences in these cases is only about 25% for small numbers of subscribers this increases to almost 400% for large numbers of subscribers (400). Obviously the manner in which subscribers are distributed has a very important bearing on the cost of serving them. Note also the effect of averaging route costs over the total subscribers on the route (a reasonable approach since the route is constructed to serve all of the subscribers) is to favour those subscribers located farthest

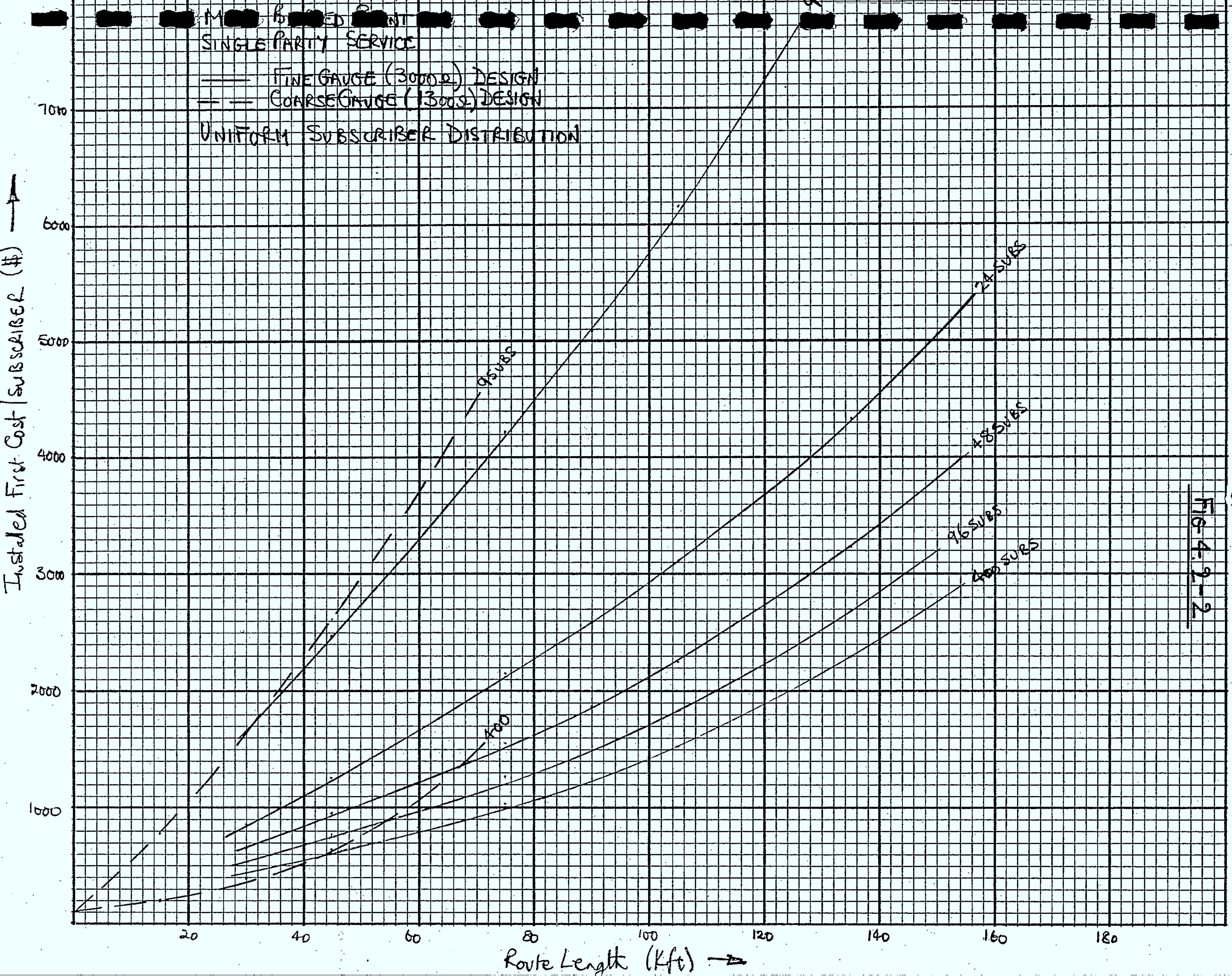

[redacted]
SINGLE PARTY SERVICE
FINE GAUGE (3000Ω) DESIGN
COARSE GAUGE (1300Ω) DESIGN
UNIFORM SUBSCRIBER DISTRIBUTION
Installed First Cost / Subscriber ($) →
7000
6000
5000
4000
3000
2000
1000
20
40
60
80
100
120
140
160
180
Route Length (Kft) →
24 SUBS
48 SUBS
96 SUBS
400 SUBS
9 SUBS
400

FIG 4.2-2

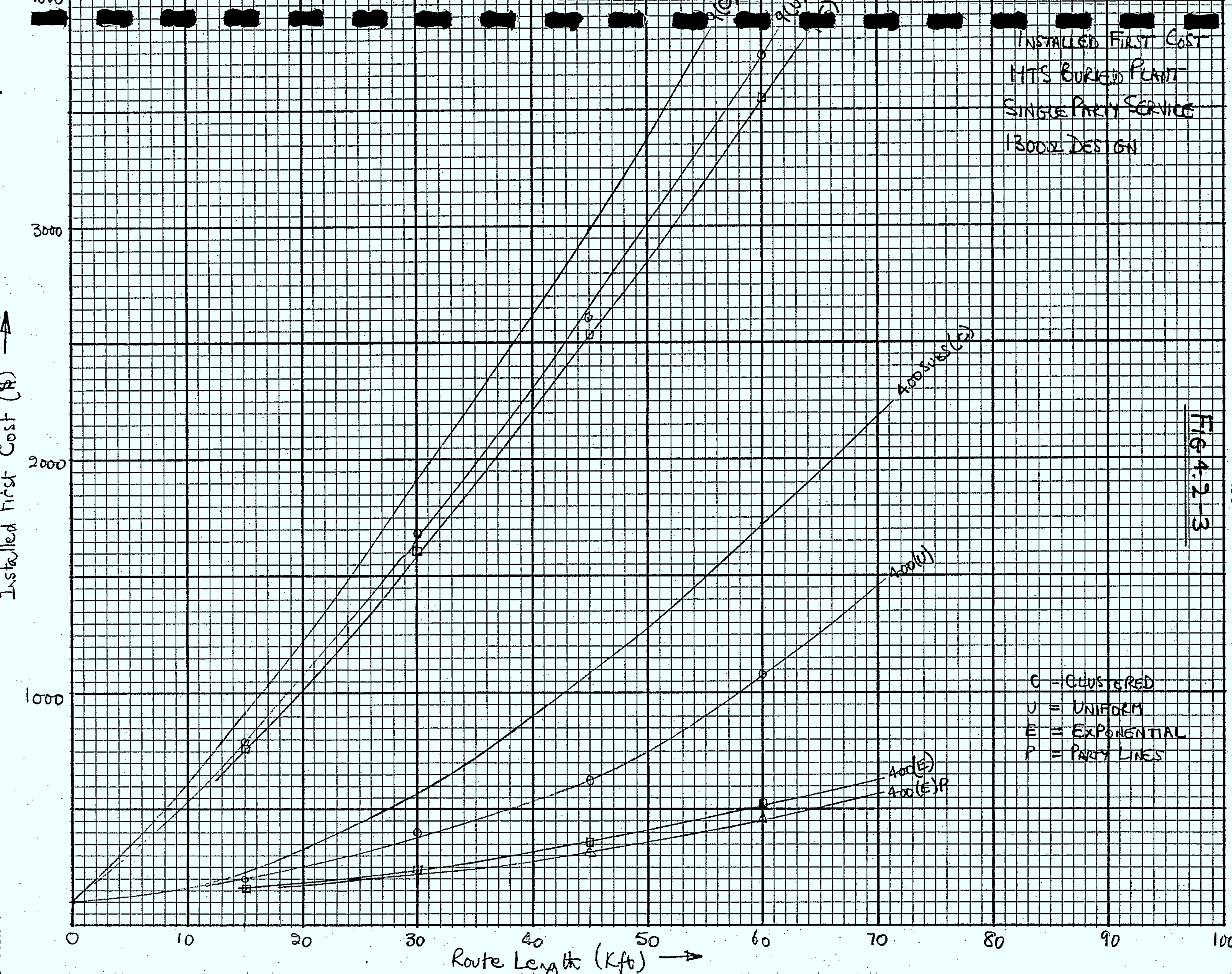
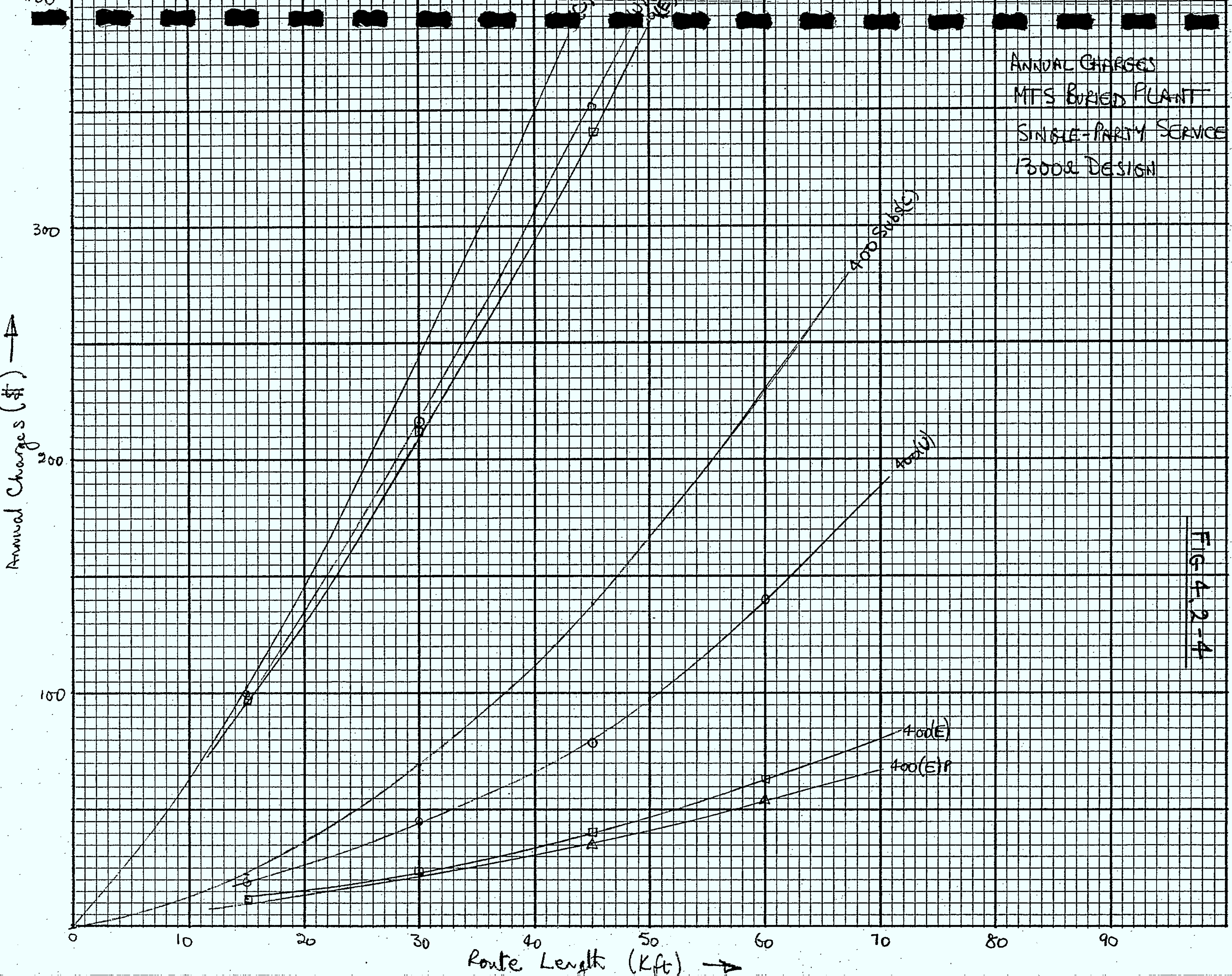

INSTALLED FIRST COST
MTS BURIED PLANT
SINGLE PARTY SERVICE
1300Ω DESIGN
9(C)
9(U)
(E)
400 SUBS (E)
400(U)
400(E)
400(E)P
C = CLUSTERED
U = UNIFORM
E = EXPONENTIAL
P = PARTY LINES
Installed First Cost ($)
3000
2000
1000
0
10
20
30
40
50
60
70
80
90
100
Route Length (Kft)

FIG 4.2-3



[redacted]

FIG 4.2-4

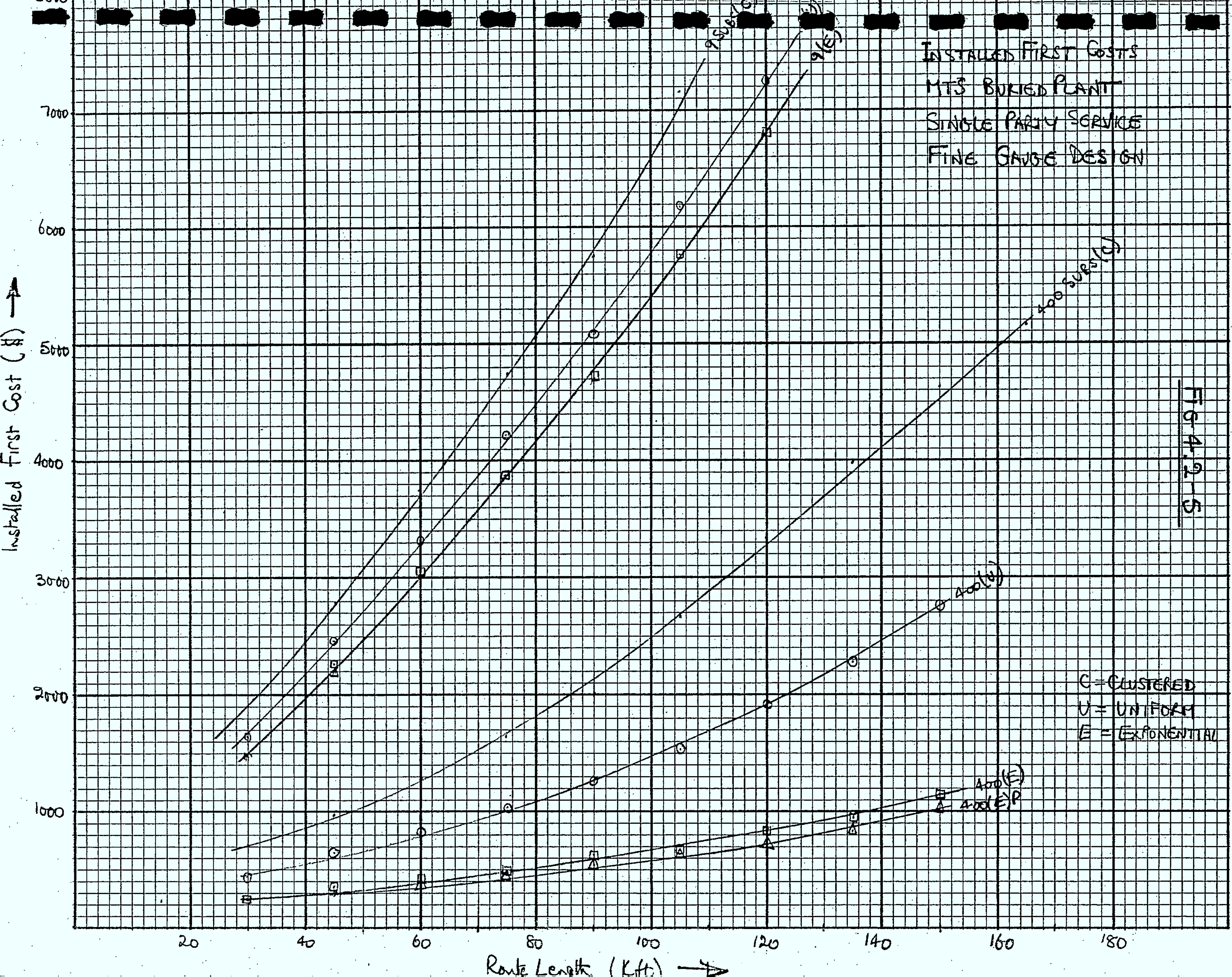

INSTALLED FIRST COSTS
MTS BURIED PLANT
SINGLE PARTY SERVICE
FINE GAUGE DESIGN
9SUB(C)
9(U)
9(E)
400 SUBS(C)
400(U)
400(E)
400(E)P
C = CLUSTERED
U = UNIFORM
E = EXPONENTIAL
Installed First Cost ($) →
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100
120
140
160
180
Route Length (Kft) →

FIG 4.2-5

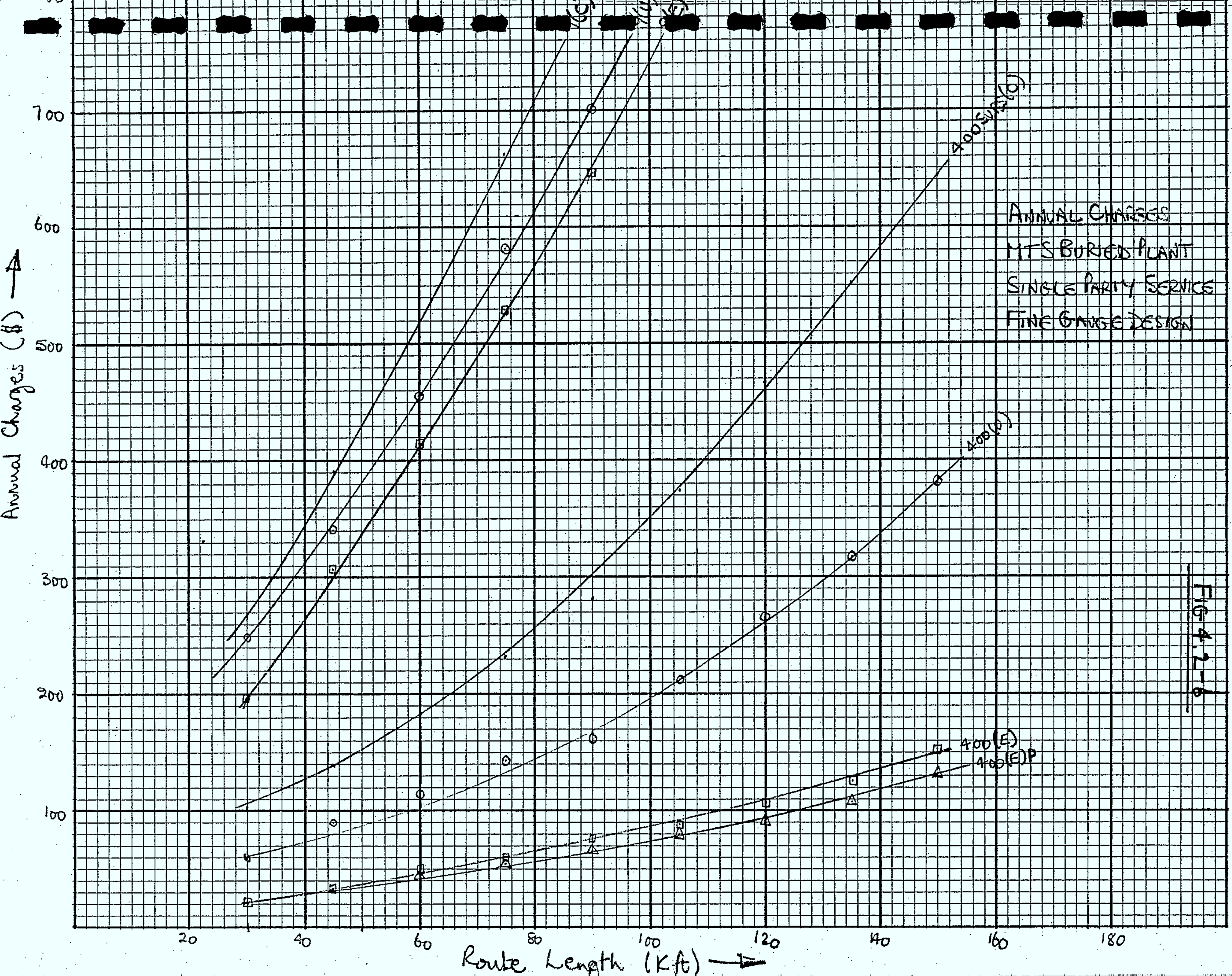

ANNUAL CHARGES
MTS BURIED PLANT
SINGLE PARTY SERVICE
FINE GAUGE DESIGN
Annual Charges ($)
Route Length (Kft)
700
600
500
400
300
200
100
20
40
60
80
100
120
140
160
180
400SUPS(C)
400(C)
400(E)
400(E)P

FIG 4.2-6

from the Central Office where the individual cost of providing service to each subscriber may be astronomical.

Comparing the two exponentially distributed cases (all single party, and multiparty service) in Figures 4.2-3 to 4.2-6 does not reveal more than 12% difference in costs for routes with 400 ultimate subscribers and negligible difference for routes with small numbers of subscribers. This is because the program is unable to design a route with party lines with few numbers of subscribers, and for large capacity routes the preponderance of single party subscribers in the distribution function chosen (Figure 4.1-3) coupled with the fact that the existence of party lines may not affect the size of cable required at the C.O. end of the route (because of the necessity of choosing standard size cables) tends to mask any difference in costs except for very long routes. However, it is interesting to note that even though party lines may significantly reduce costs for subscribers at the extremes of long routes their effect on the cost per subscriber when averaged over all of the subscribers on an individual route <u>may</u> be relatively small.

4.3 BRITISH COLUMBIA TELEPHONE COMPANY

4.3.1 Loop Design Practices

British Columbia Telephone Company sets the following objectives with regard to transmission and signalling:

i) The net transmission losses to the furthest subscriber in any loop should not exceed 8.5 db at 1 KHz including the losses at the central office.

ii) The minimum telephone set signalling current is 23 ma.

H88 Loading is generally applied to routes that are more than 18 Kft including all bridged taps.

Standard resistance design is employed on loops to 1200Ω (or 1350Ω depending on the type of central office). Loops greater than about 22 Kft use long loop design practice which has a limit of 3000Ω. The resistance from zero ohms at the switching centre to 3000 ohms is divided up into zones each of which needs different types and quantities of electronic devices.

Zone 1 (0 - 1200Ω)	-	No special equipment
Zone 2 (1201 - 1700Ω)	-	24v Battery booster
Zone 3 (1701 - 2300Ω)	-	48v Battery booster + 4.6 dB VFR
Zone 4 (2301 - 3000Ω)	-	48v Battery booster + 6.5 dB VFR

It should be noted that while the use of aerial cable by BC Tel has been decreasing slightly in recent years, it still accounts for more than 50% of the annual plant additions.

4.3.2 Cost of Service

For BC Tel we have considered both buried and aerial plant cases. The broadgauge unit costs for cables are devised from Figures 4.3-1 (buried) and 4.3-2 (aerial). Since the telephone company publishes a wide range of costs for each cable gauge (the spread can be as much as 2:1), evidently indicating great variations in construction conditions in the province, in these Figures we have attempted to plot average costs for each gauge which generally do not follow closely linear progression with cable size. Bearing this in mind the installed capital cost per kilofoot for buried cable can be approximated by the following:

26 gauge	450 + 9.5 n
24 gauge	450 + 12.5 n
22 gauge	450 + 16.3 n
19 gauge	450 + 27.8 n

and for aerial cables:

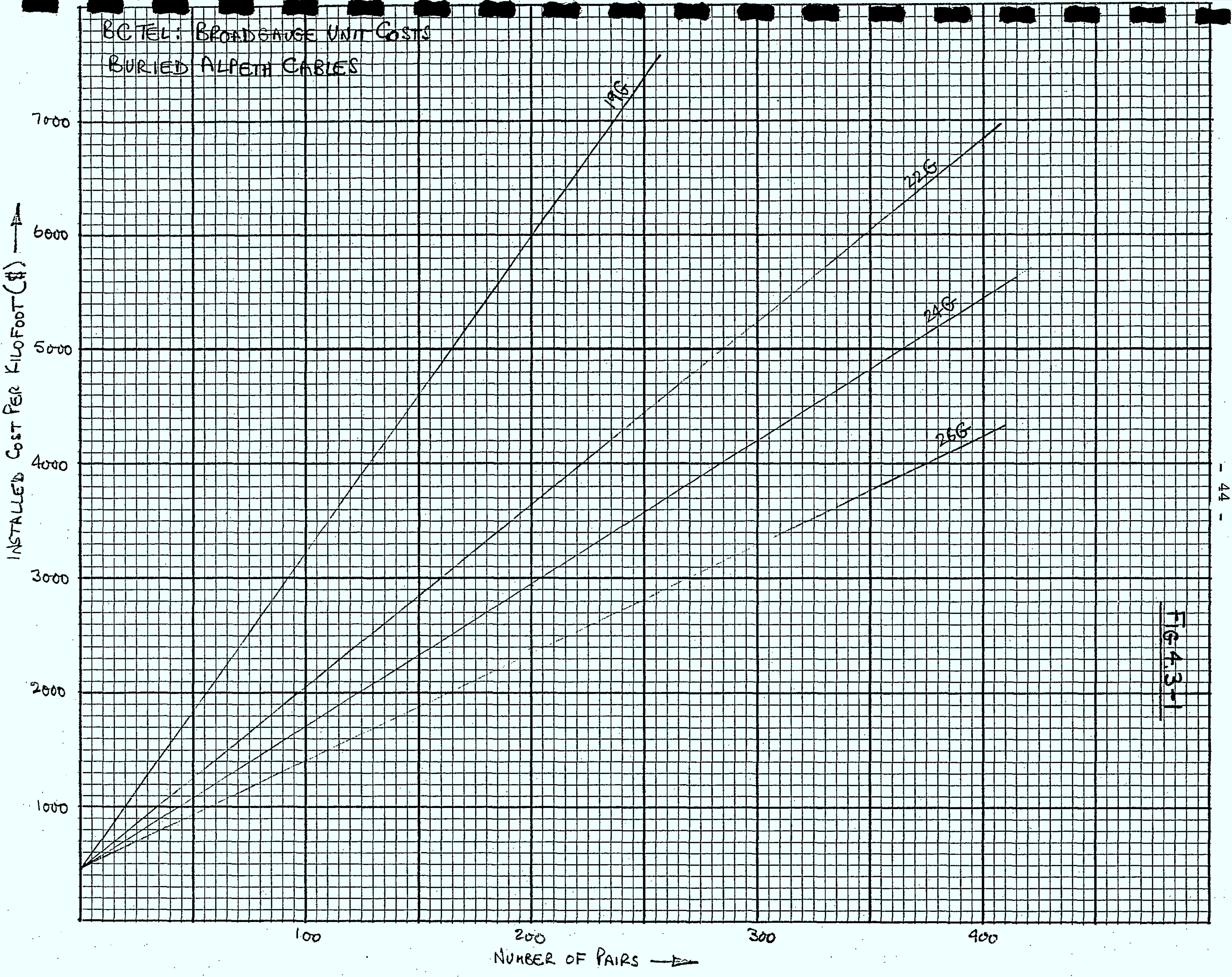

BC TEL: BROADGAUGE UNIT COSTS
BURIED ALPETH CABLES
19G
22G
24G
26G
7000
6000
5000
4000
3000
2000
1000
INSTALLED COST PER KILOFOOT ($)
100
200
300
400
NUMBER OF PAIRS

FIG 4.3-1


BROADGAUGE COSTS: B.C. TEL
ALPETH AERIAL CABLES
19G
22G
24G
26G
INSTALLED COST PER KILOFOOT ($)
1000
2000
3000
4000
5000
6000
7000
100
200
300
400
NUMBER OF PAIRS

Fig. 4.3-2

26 gauge	375 + 11.3 n
24 gauge	375 + 15.6 n
22 gauge	375 + 20.8 n
19 gauge	375 + 31.0 n

Installed first costs and annual charges have been calculated for the same subscriber distributions and routes as were considered for MTS. For the aerial plant case the computer program prints out the cost of support structure (pole line) as well as cable and electronics cost which have been summed to give the total cost per subscriber plotted in the figures. Pole spacing for aerial cables has been assumed to be 200 ft (27 poles per mile) and an allowance of $44/pole has been made to take account of the support strand.

Figures 4.3-3 to 4.3-5 show installed first costs and annual charges for various subscriber distributions with buried plant. For the uniform distribution case shown in Fig 4.3-3 the break point between coarse and fine gauge design occurs at approximately 30 Kft. In this figure we have a 5:1 spread between costs per subscriber for 9 to 400 subscribers. The effect of subscriber distribution on costs and annual charges is shown in Figs 4.3-4 and 4.3-5. Again we have as much as a 3:1 spread between the lowest cost case for a particular subscriber group size (exponential distribution) and the highest cost case (clustered subscribers). For the median cost case (uniform distribution) the existence of party lines lowers the cost per subscriber by about 20% at the 400 subscriber level but has no noticeable effect on costs at the 9 subscriber level.

Figures 4.3-6 to 4.3-8 show similar results for aerial plant. These figures demonstrate the large effect of the pole line costs ($1770/Kft) which approximately doubles the cost per subscriber over the buried case. In Fig 4.3-7 we have shown the installed first cost/subscriber for the structure only as well as the total IFC. Obviously the greater number of subscribers the structure cost is distributed over the smaller will be its impact on the total cost per subscriber. Thus for 9 subscribers the structure accounts for 75% of the total IFC/Sub, whereas for 400 subscribers it accounts for only 25%.

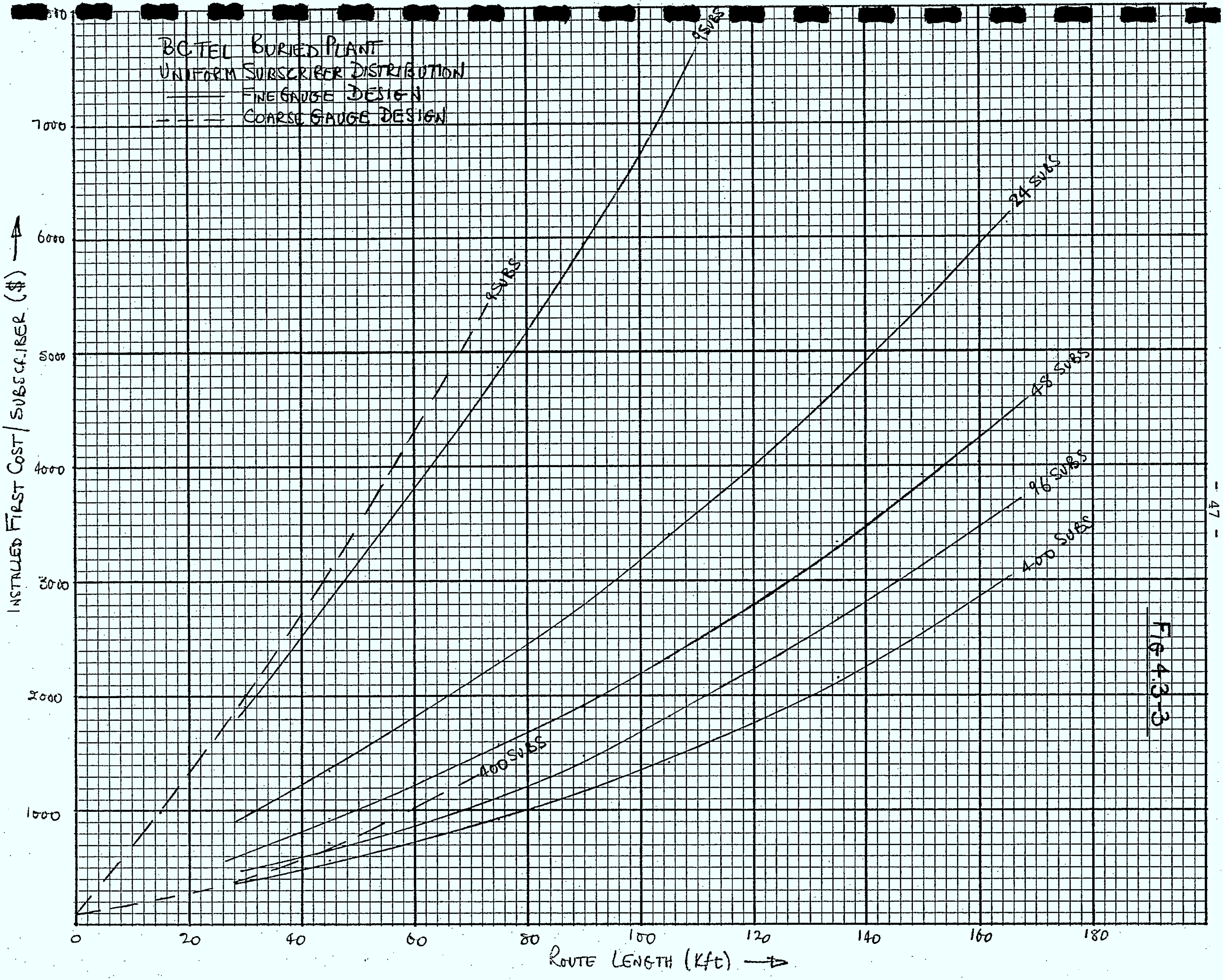
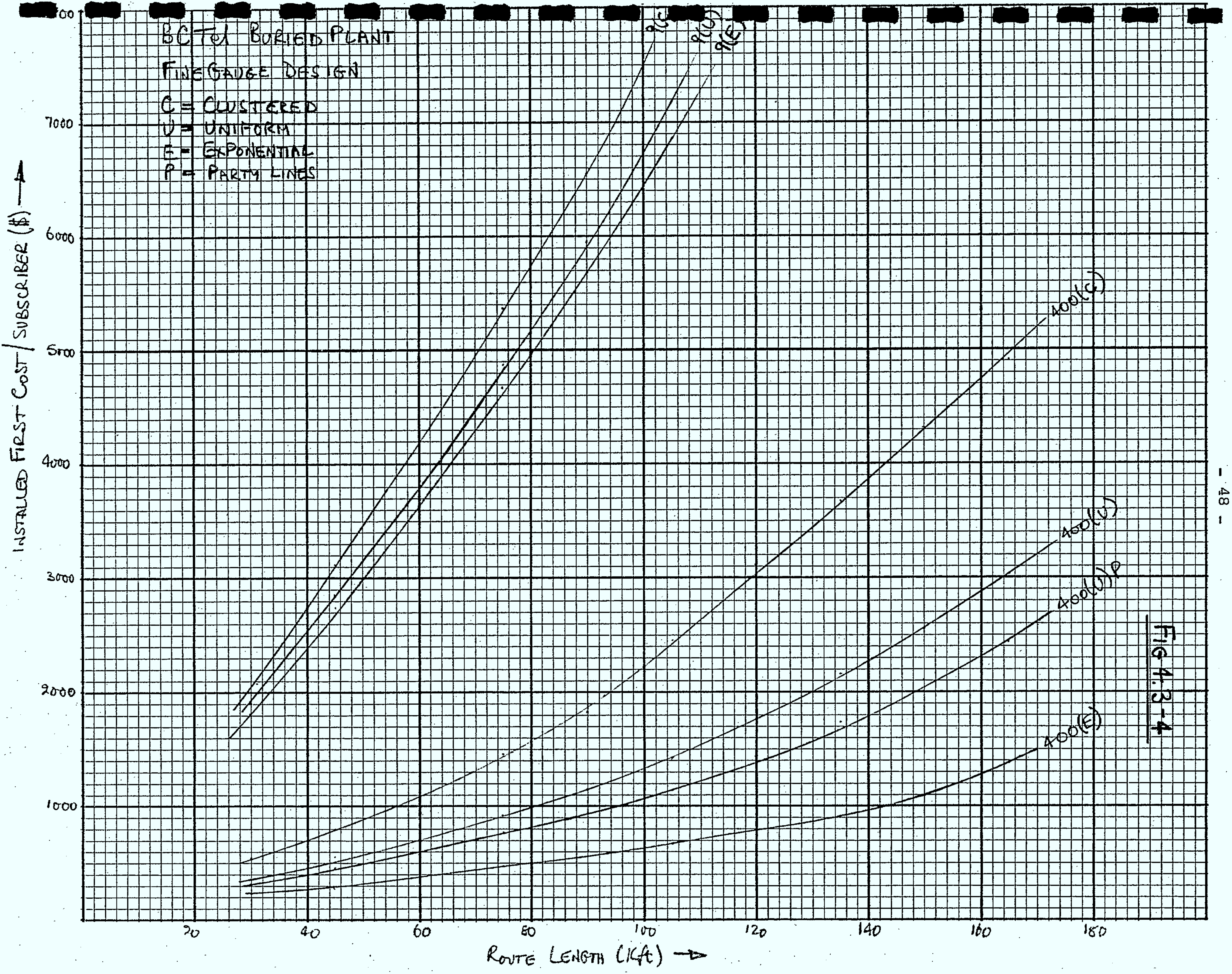

BC TEL BURIED PLANT
UNIFORM SUBSCRIBER DISTRIBUTION
FINE GAUGE DESIGN
COARSE GAUGE DESIGN
INSTALLED FIRST COST / SUBSCRIBER ($)
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
120
140
160
180
ROUTE LENGTH (Kft)
9 SUBS
9 SUBS
24 SUBS
48 SUBS
96 SUBS
400 SUBS
400 SUBS

FIG 4.3-3



BC Tel Buried Plant
Fine Gauge Design
C = Clustered
U = Uniform
E = Exponential
P = Party Lines
Installed First Cost / Subscriber ($)
Route Length (Kft)
7000
6000
5000
4000
3000
2000
1000
20
40
60
80
100
120
140
160
180
9(C)
9(U)
9(E)
400(C)
400(U)
400(U)P
400(E)

FIG 4.3-4

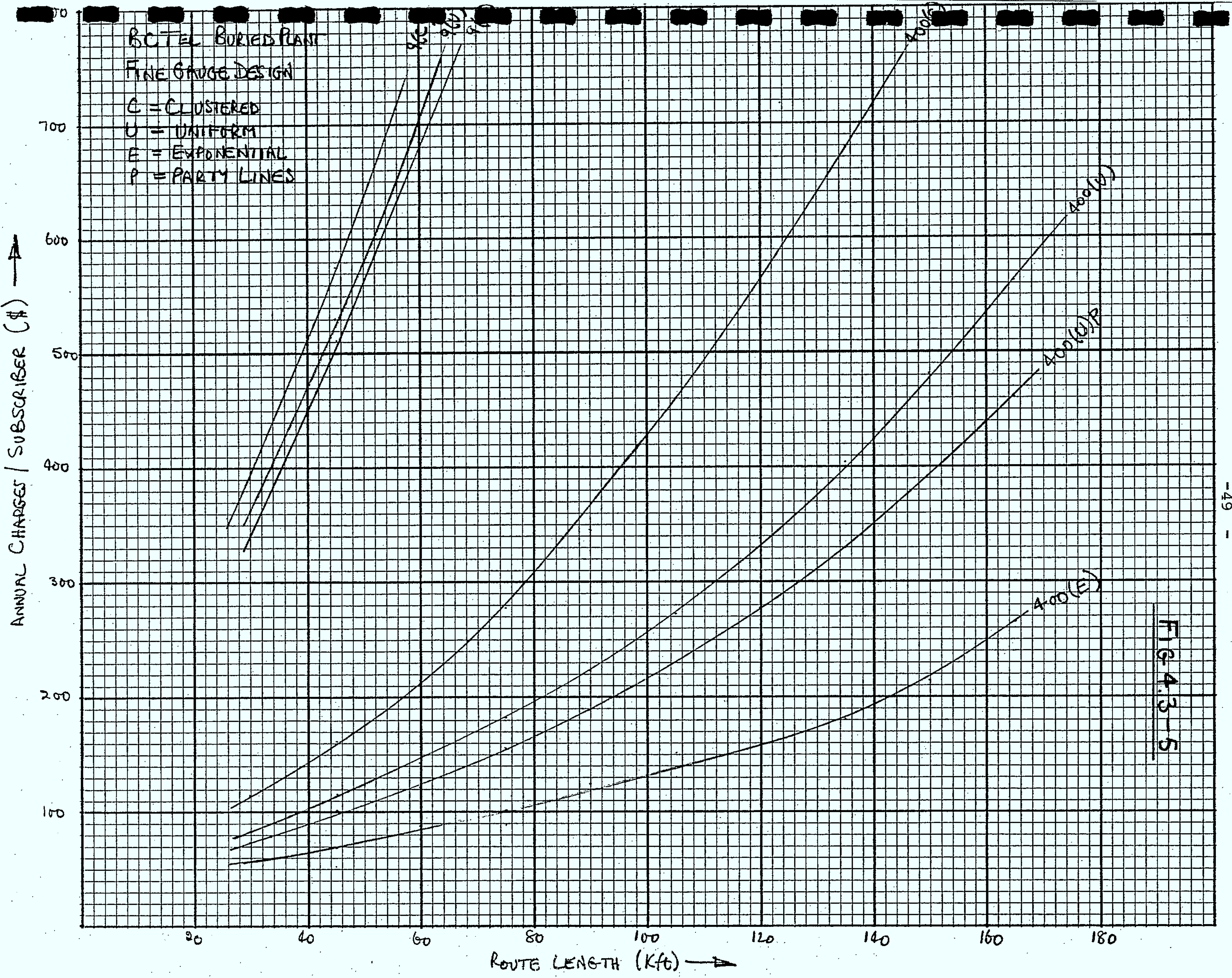
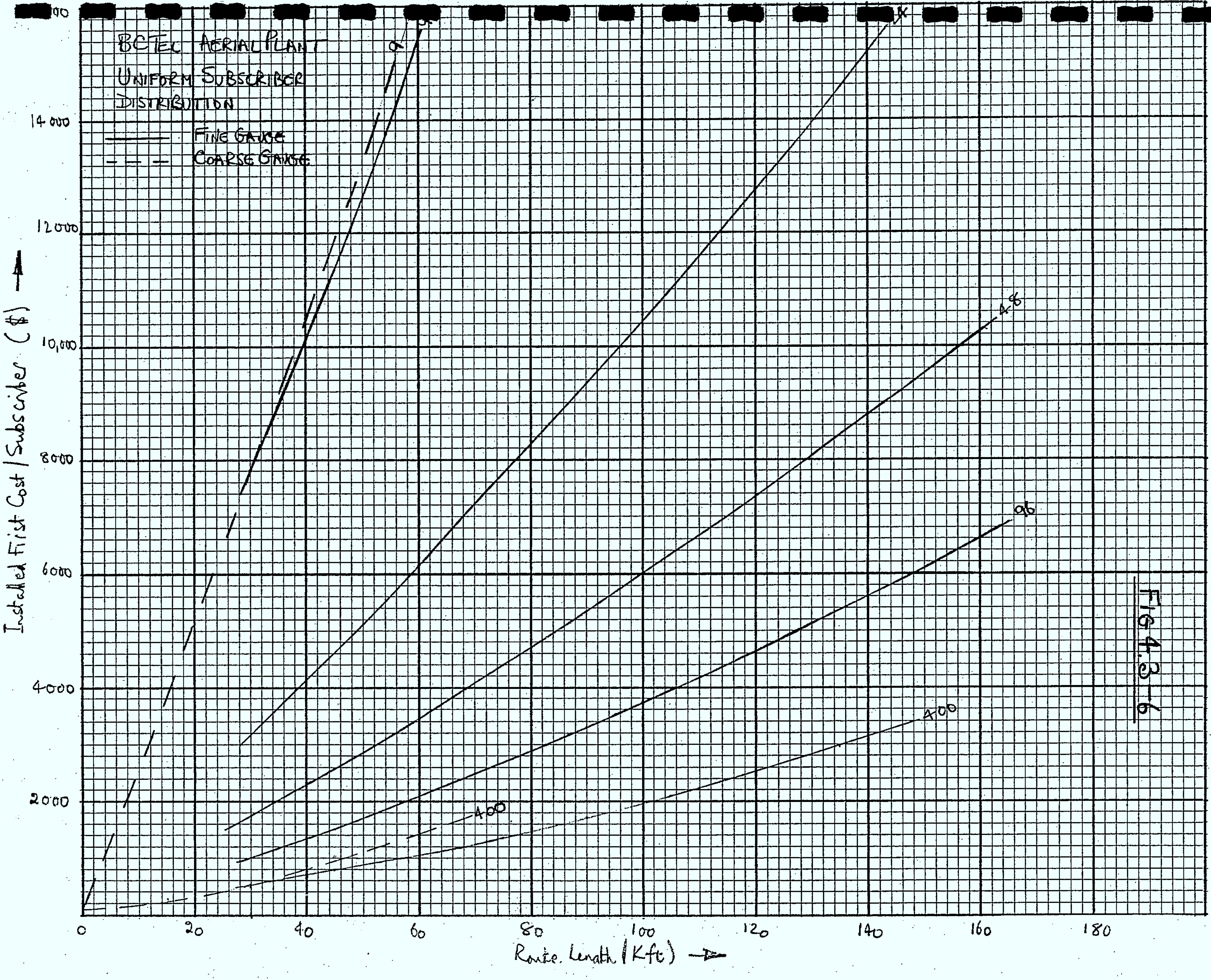

BCTEL BURIED PLANT
FINE GAUGE DESIGN
C = CLUSTERED
U = UNIFORM
E = EXPONENTIAL
P = PARTY LINES
400(C)
400(U)
400(U)P
4.00(E)
700
600
500
400
300
200
100
20
40
60
80
100
120
140
160
180
ANNUAL CHARGES / SUBSCRIBER ($)
ROUTE LENGTH (Kft)

FIG 4.3-5



BCTEL AERIAL PLANT
UNIFORM SUBSCRIBER
DISTRIBUTION
FINE GAUGE
COARSE GAUGE
Installed First Cost / Subscriber ($)
14 000
12 000
10,000
8000
6000
4000
2000
Route Length (Kft)
0
20
40
60
80
100
120
140
160
180
α
β
X
48
96
400
400

FIG 4.3-6

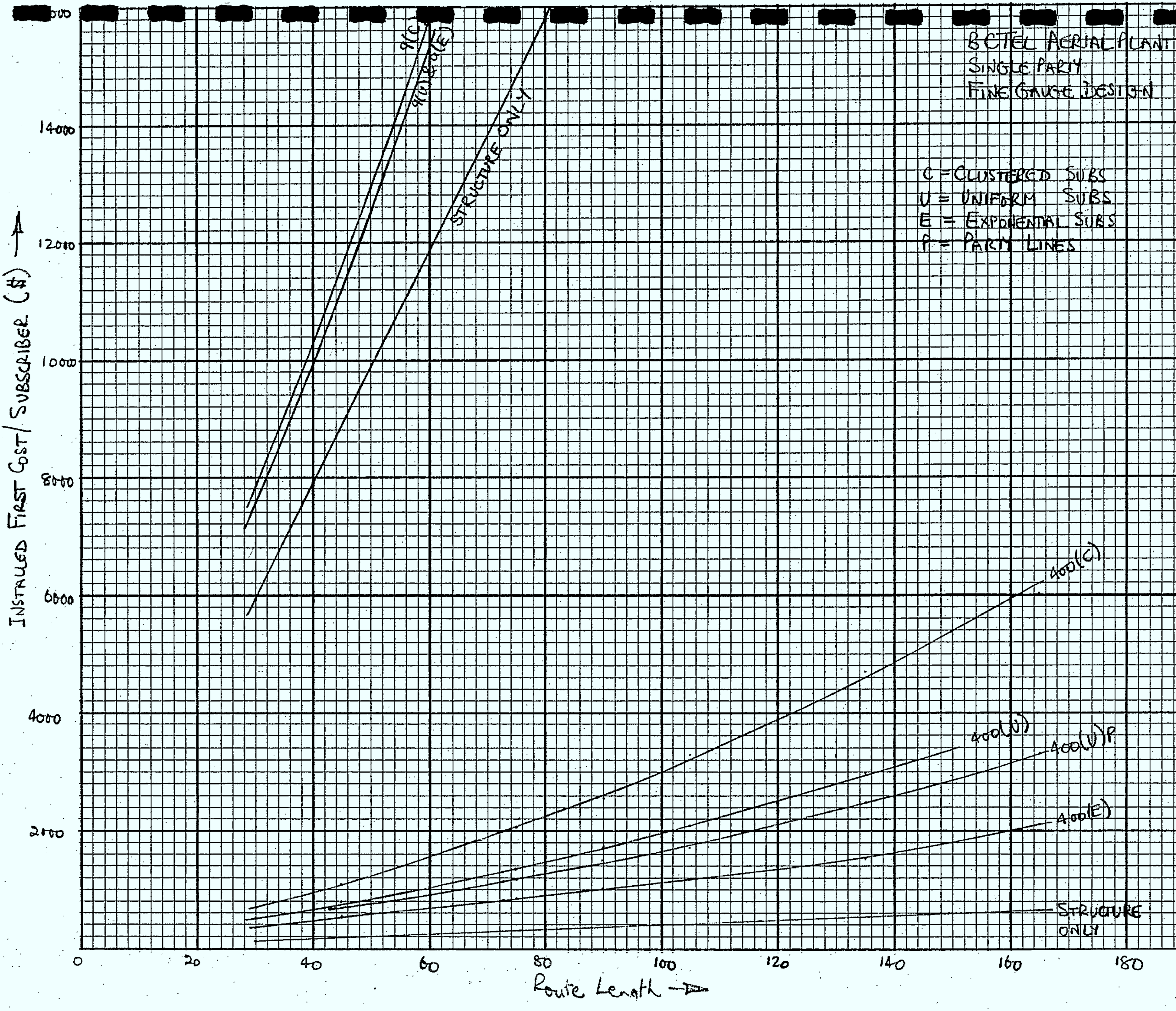

BCTEL AERIAL PLANT
SINGLE PARTY
FINE GAUGE DESIGN
C = CLUSTERED SUBS
U = UNIFORM SUBS
E = EXPONENTIAL SUBS
P = PARTY LINES
9(C)
9(U) & 9(E)
STRUCTURE ONLY
400(C)
400(U)
400(U)P
400(E)
STRUCTURE ONLY
INSTALLED FIRST COST / SUBSCRIBER ($)
14000
12000
10000
8000
6000
4000
2000
0
20
40
60
80
100
120
140
160
180
Route Length

FIG 4.3-7

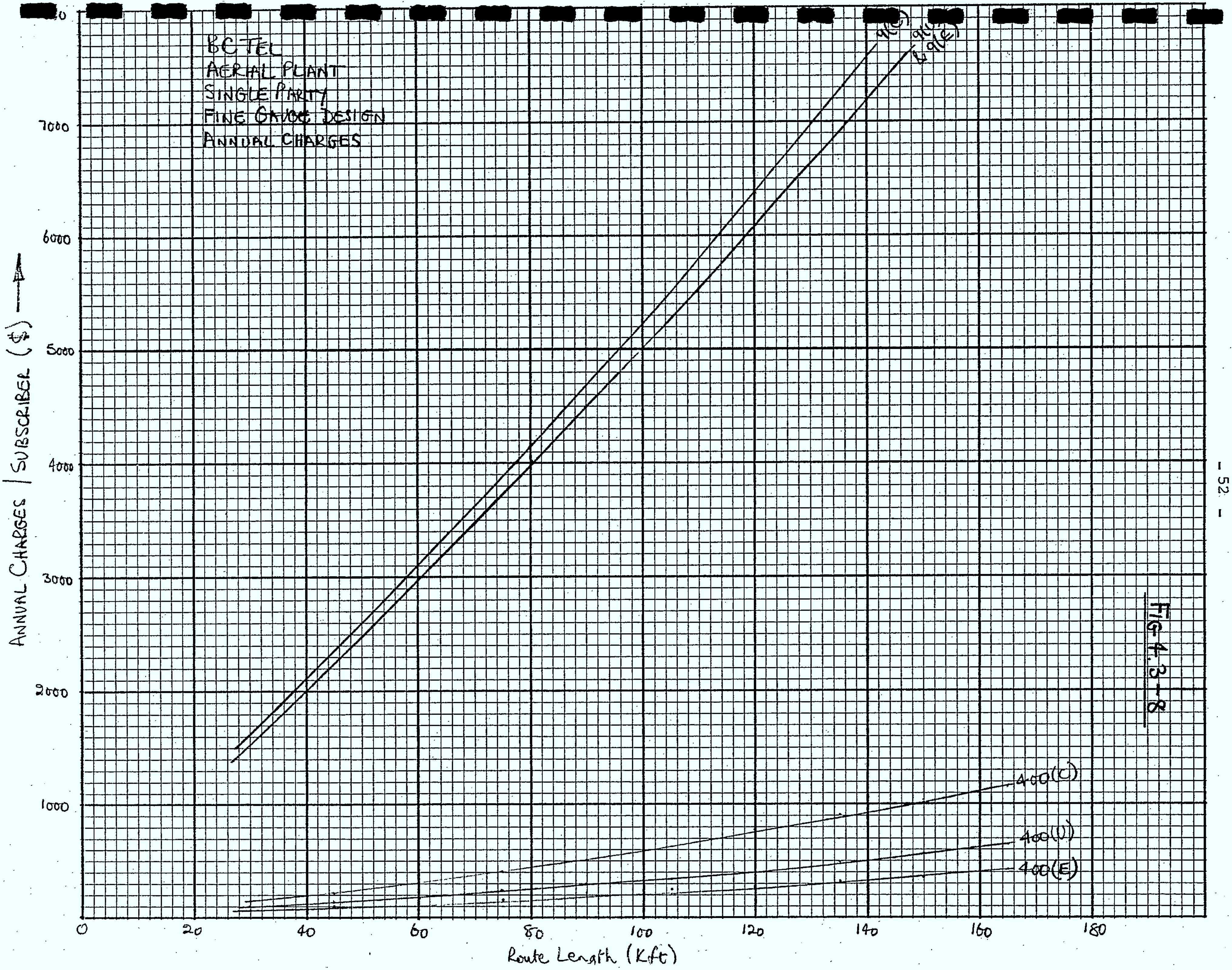
BC TEL
AERIAL PLANT
SINGLE PARTY
FINE GAUGE DESIGN
ANNUAL CHARGES
ANNUAL CHARGES / SUBSCRIBER ($)
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
120
140
160
180
Route Length (Kft)
9(C)
9(U) & 9(E)
400(C)
400(U)
400(E)

FIG 4.3-8

According to the A and B factors we have derived, buried cable has higher fixed costs but lower per pair costs. Excluding the cost of the structure therefore, buried cable is cheaper to install below about 25 pair cable, whereas aerial cable is cheaper to install for cables above this size.

4.4 MARITIME TELEGRAPH AND TELEPHONE COMPANY

4.4.1 Loop Design Practices

The transmission objectives set by MT&T are as follows:

i) The expected measured loss (EML) to the furthest subscriber on any loop should not exceed 8.5 dB at 1Khz including the central office losses.

ii) The average echo return loss for uniform cable gauge should be 25DB or better (500 Hz to 2500 Hz range).
For mixed gauges an average return loss of 20 dB or better is the objective.

iii) The minimum loop current is 23 ma.

Generally all working loops 18 Kft and over are loaded with 88 millihenry loading coils spaced every 6 Kft.

Standard resistance design procedure is used for loops having a resistance of less than the office signalling limit or 1300Ω whichever is less. Long route design is applied to routes having resistances greater than 1300Ω but not more than 3200Ω.

The resistance range from zero at the switching centre to 3200 ohms is divided up into four resistance zones (RZ) 13, 15, 22, 32. The equipment for each zone is as follows:

RZ 13 (0-1300 ohms)	No special equipment.
RZ 15 (1301-1500 ohms)	24 v Loop extender

RZ 22 (1501 - 22 ohms) 24v loop extender 4.6 dB voice frequency repeater (4.1 dB net gain).

RZ 32 (2201 - 32 ohms) 48v loop extender 7.0 dB voice frequency repeater (6.5 dB net gain).

Resistance zones RZ 15, RZ 22 and RZ 32 make up the 'Long Route design' practice. As in the previous cases, for a given route, the most economical alternative design is chosen based on PWAC studies.

At the end of 1976 approximately 60% of the exchange cables operated by MT&T were aerial plant which accounted for 70% of the exchange wire mileage.

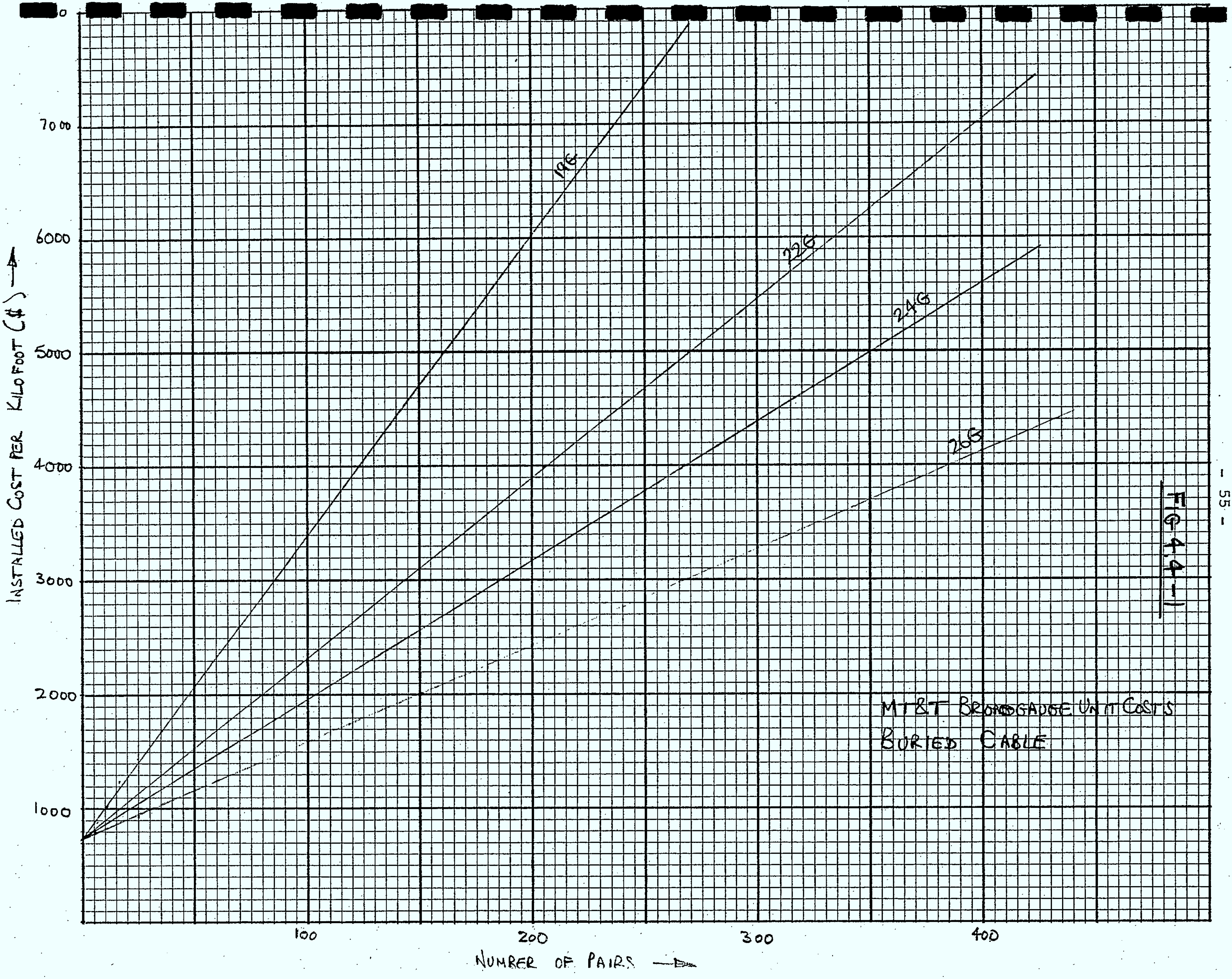
4.4.2 Cost of Service

Broadgauge unit costs for buried and aerial cables are shown in Figures 4.4-1 and 2 respectively. From these figures the input data for CORTS may be computed as follows (all costs are per kilofoot):

Buried plant	A 19	750	B 19	26.28
	A 22	750	B 22	15.73
	A 24	750	B 24	12.15
	A 26	750	B 26	8.45
Aerial plant	A 19	350	B 19	24.45
	A 22	350	B 22	13.98
	A 24	350	B 24	10.00
	A 26	350	B 26	7.95

These figures indicate that buried cables are never cheaper to install than aerial cables (excluding the cost of support structure).

Installed first costs and annual charges have been calculated for the same subscriber distributions and routes as were considered previously for MTS and BC Tel. Results for the buried plant case are shown in Figures 4.4-3 to 4.4-5. For the uniform subscriber distribution case shown in Fig 4.4-3 the break point between coarse and fine gauge design occurs at 30Kft. In this figure (at 100 Kft) we have a 7:1 spread between costs per subscriber



MT&T BROADGAUGE UNIT COSTS
BURIED CABLE

FIG 4.4-1

MT&T BROADGAUGE UNIT COSTS

AERIAL CABLE

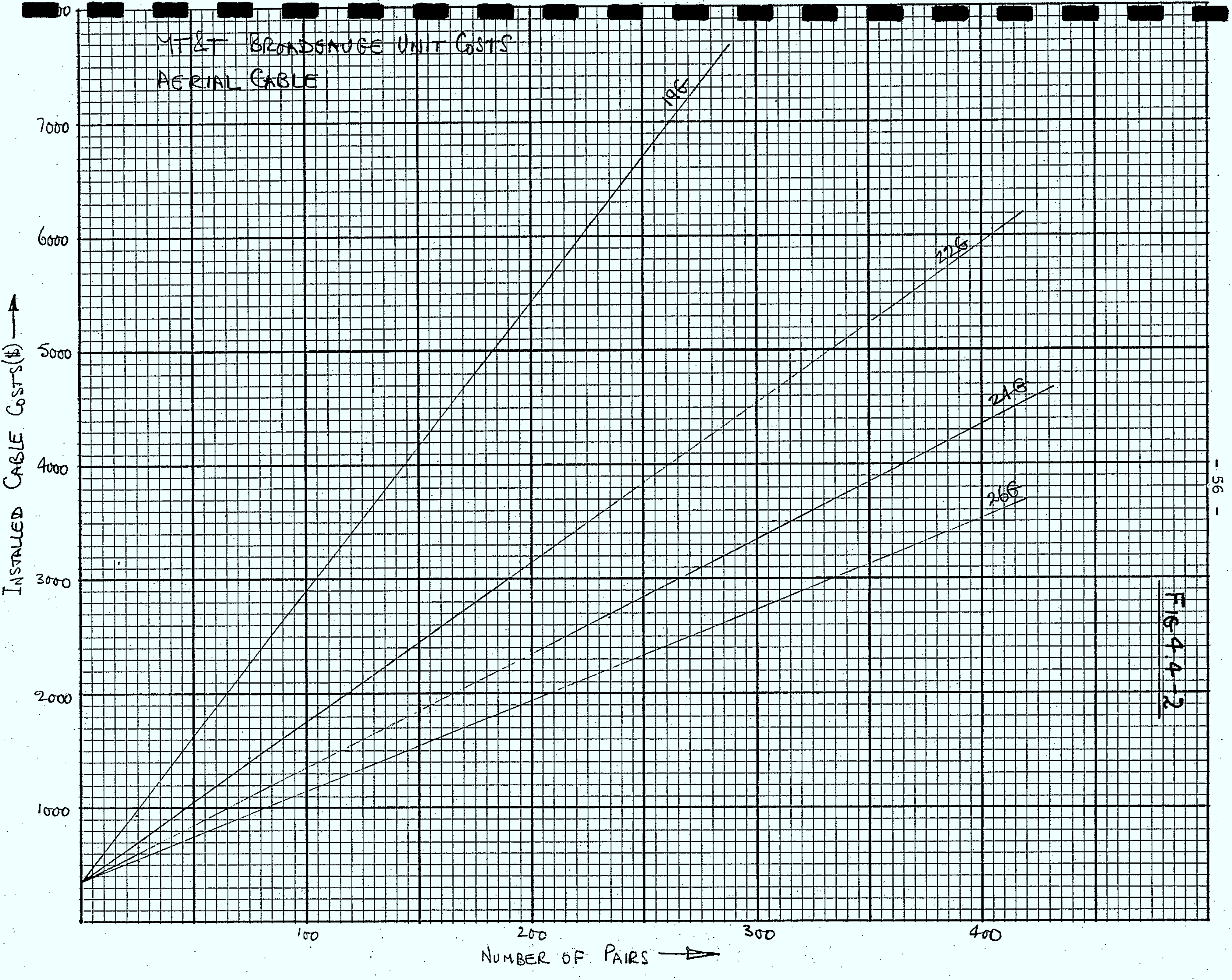


FIG 4.4-2

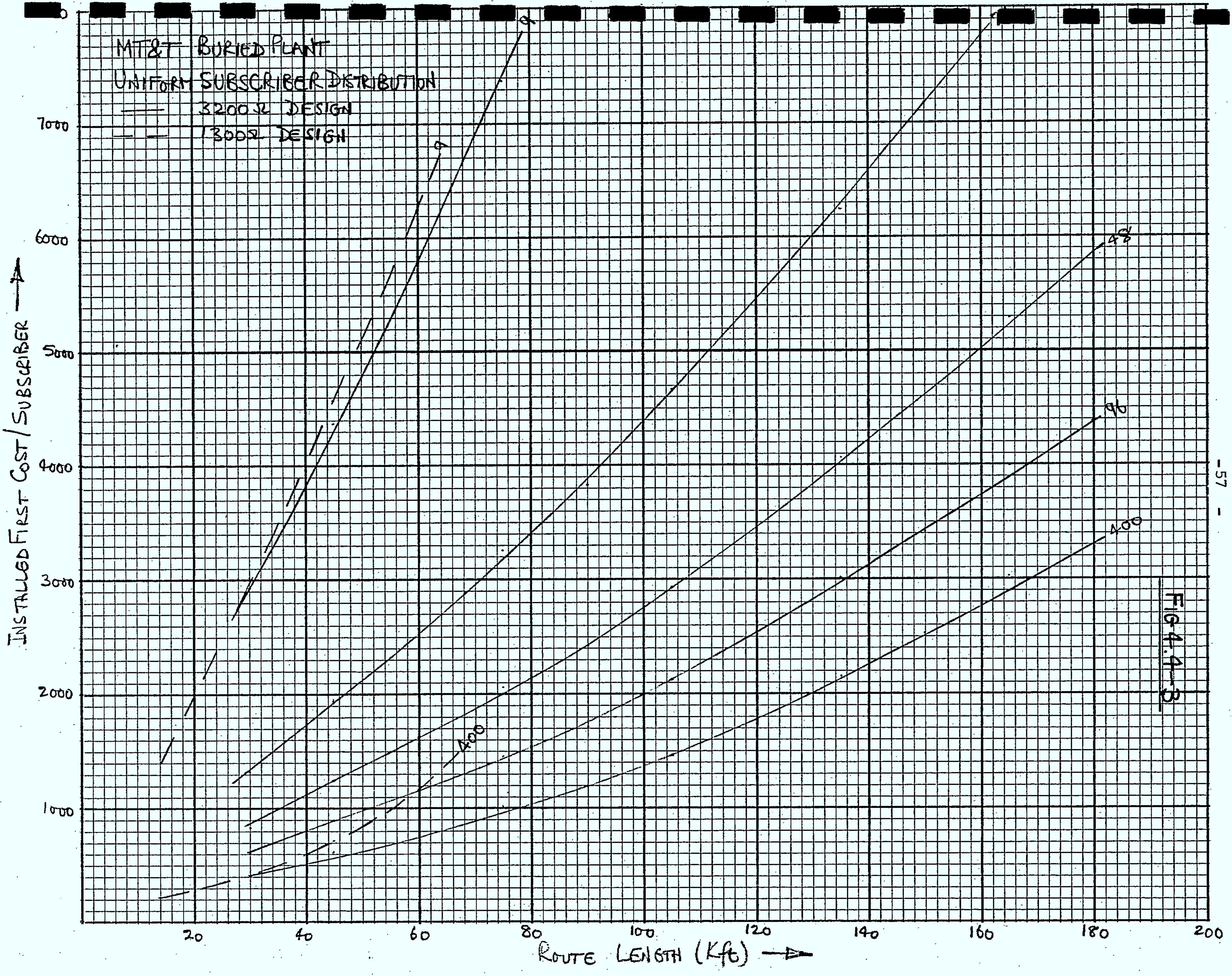

MT&T BURIED PLANT
UNIFORM SUBSCRIBER DISTRIBUTION
3200Ω DESIGN
1300Ω DESIGN
INSTALLED FIRST COST/SUBSCRIBER
ROUTE LENGTH (Kft)
1000
2000
3000
4000
5000
6000
7000
20
40
60
80
100
120
140
160
180
200
9
9
48
96
400
400

FIG 4.4-3


MT&T BURIED PLANT
INSTALLED FIRST COST / SUBSCRIBER ($)
8000
7000
6000
5000
4000
3000
2000
1000
20
40
60
80
100
120
140
160
180
ROUTE LENGTH (Kft)
9(C)
9(U)
9(E)
400(C)
400(U)
400(E)

FIG 1.4-4


MT&T BURIED PLANT
ANNUAL CHARGES / SUBSCRIBER ($)
ROUTE LENGTH (Kft)
800
700
600
500
400
300
200
100
20
40
60
80
100
120
140
160
180
%
%
%
400
400(V)
400(E)

FIG 4.4-5

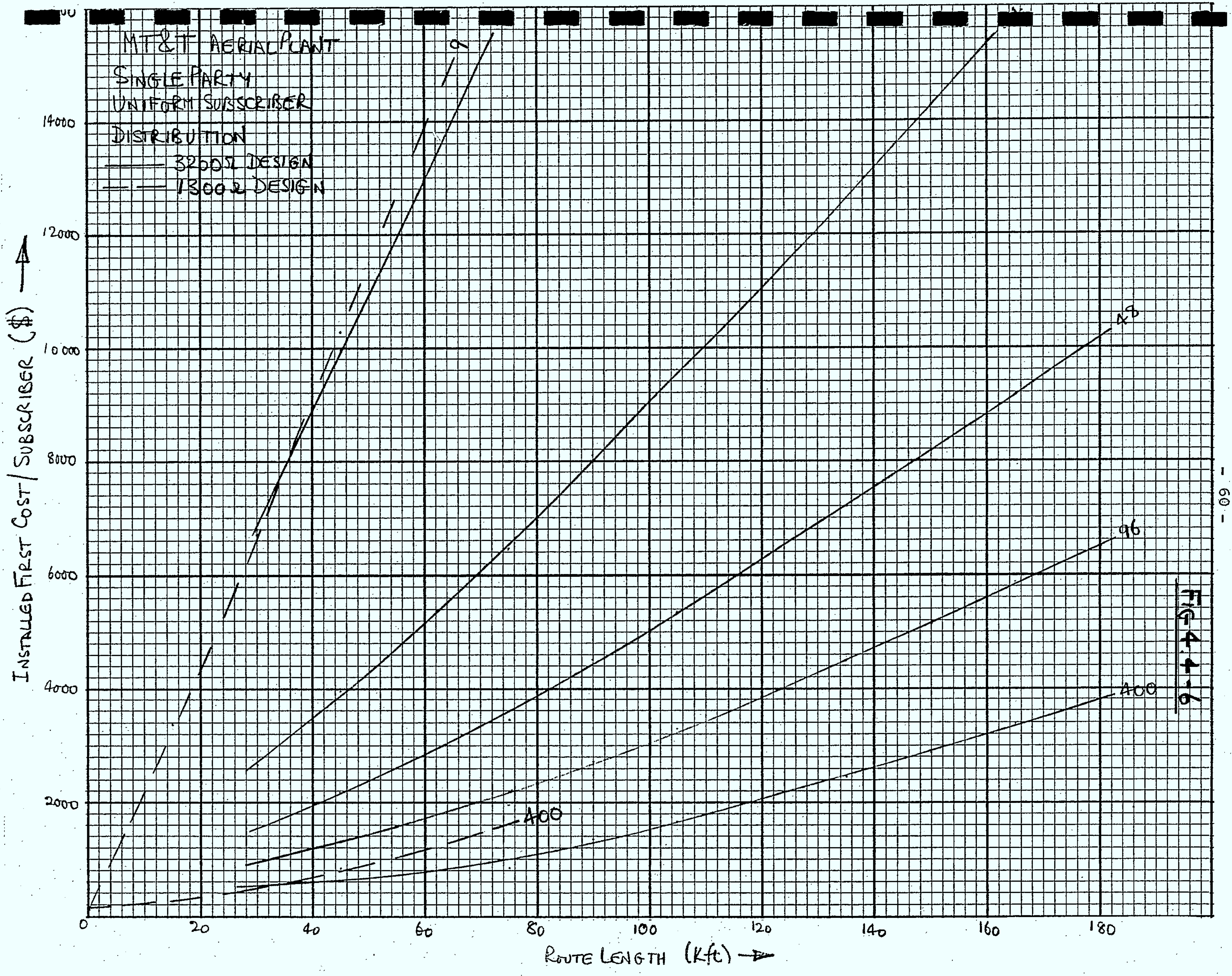

MT&T AERIAL PLANT
SINGLE PARTY
UNIFORM SUBSCRIBER DISTRIBUTION
——— 3200Ω DESIGN
— — 1300Ω DESIGN
9
48
96
400
400
INSTALLED FIRST COST / SUBSCRIBER ($)
14000
12000
10 000
8000
6000
4000
2000
0
20
40
60
80
100
120
140
160
180
ROUTE LENGTH (Kft)

FIG 4.4-6

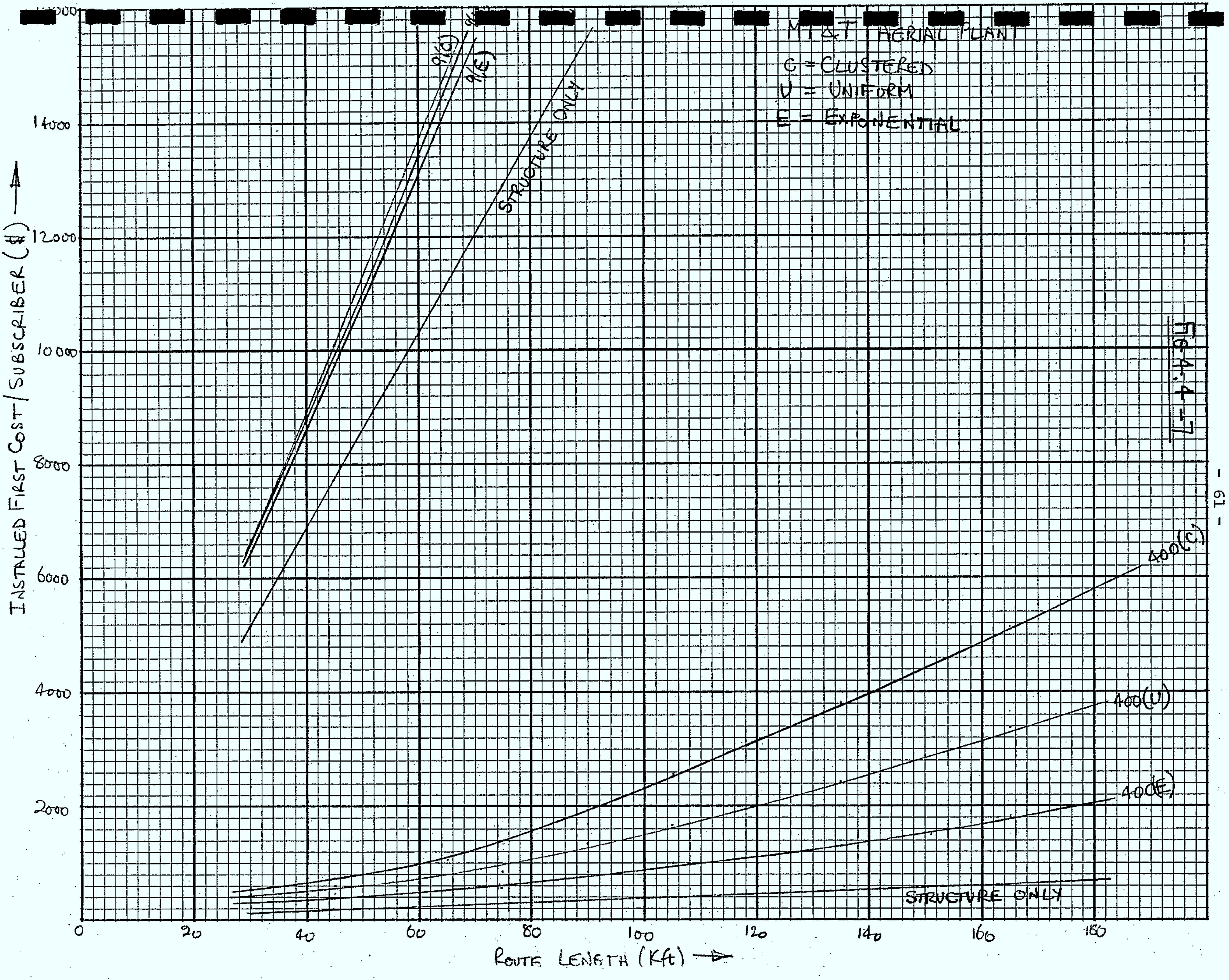

MT&T AERIAL PLANT
C = CLUSTERED
U = UNIFORM
E = EXPONENTIAL
9(C)
9(E)
STRUCTURE ONLY
400(C)
400(U)
400(E)
STRUCTURE ONLY
INSTALLED FIRST COST / SUBSCRIBER ($) →
14000
12000
10000
8000
6000
4000
2000
0
20
40
60
80
100
120
140
160
180
ROUTE LENGTH (Kft) →

FIG 4.4-7


ANNUAL CHARGES | SUBSCRIBER →
7000
6000
5000
4000
3000
2000
1000
0
20
40
60
80
100
120
140
160
180
ROUTE LENGTH (Kft) →
9(C)
9(U)
9(E)
STRUCTURE ONLY
400(C)
400(U)
400(E)
STRUCTURE ONLY

FIG 4.4-8

for 9 to 400 subscribers. Figures 4.4-4 and 4.4-5 show the effect of subscriber distribution on first cost and annual charges. At the 400 subscriber level we have a greater than 3:1 spread in costs from the lowest (exponential distribution) to the highest cost case (clustered).

Corresponding results for aerial plant are shown in Figures 4.4-6 to 4.4-8. Here we have allowed $1375 per kilofoot for the poles and a further $175 for the supporting strand. The structure alone accounts for 77% of the total cost at the 9-subscriber level but only 12% to 33% of the total cost at the 400 subscriber level, depending on how they are distributed. The pattern of variation of costs with numbers of subscribers and distribution functions noted previously is repeated in Figures 4.4-6 to 4.4-8. There is a 16:1 variation in cost per subscriber between 9 and 400 ultimate subscribers.

5. CONCLUDING OBSERVATIONS

We have examined a range of routes representative of the rural situation using data from various telephone companies and have observed a very large spread of costs. The major factors influencing costs may be summarized as follows:

- Size of serving company (influences economies of scale)
- Surface geography (influences type of plant)

- Climate (influences installation and maintenance costs)
- Subscriber distribution and growth (influences route length and cable sizing).

The telephone companies we have examined represent a good cross-section of the Canadian situation in terms of ownership, size, and serving area factors. The range of these factors are given in the table below.

Telco	Size	Cost of Plant		Subscriber Density
		Buried	Aerial	
BC Tel	Large	Medium	High	Low
MTS	Medium	Low	-	Low
MT&T	Medium	High	Low	High

Thus MTS represents a company where almost all cables can be buried (84% of cable sheath miles were buried in 1976) in relatively benign terrain where ploughing costs and also subscriber density are low. As far as buried plant is concerned MT&T is at the other extreme; conditions in the province are such that only40% of plant can be buried in relatively difficult terrain which results in high installation costs. However, subscriber densities are high in Nova Scotia and aerial plant construction relatively inexpensive (but still twice as expensive as buried plant). BC Tel serves rural areas of relatively low subscriber density; costs of burying cables in those parts of the province where it is practicable are slightly higher than in the Prairies. Aerial plant on the other hand is more expensive to construct in B.C. than in the Maritimes, and can be over three times more expensive than buried plant in the Province.

With such wide variations in costs noted in Section 4 it is difficult to generalize about the cost of rural telephone service. If we have to choose one representative range of costs, then those for the 24 subscriber uniform distribution case would be close to the median of the range we have examined. For this case the following table indicates the relative cost per subscriber for aerial and buried plant in the telephone companies we have examined. With buried plant the cost/subscriber for MT&T is 52% higher than for the lowest cost company, MTS. However, it should be realized that on average MT&T routes will be shorter than for MTS so that the average cost/subscriber for MTS will likely be higher. Aerial plant for the two companies examined is 2 to 3 times more expensive than buried.

Telco	Installed First Cost/Subscriber at 100 Kft for 24 subscribers uniformly distributed ($)		Cost per Route Mile per Subscriber ($)	
	Buried	Aerial	Buried	Aerial
BC Tel	3,200	10,400	170	550
MTS	2,900	-	150	-
MT&T	4,400	9,200	230	490

As a general observation increasing the number of subscribers on the route from 9 to 400 (approximately 40:1 increase) reduces the cost per subscriber by a factor of 4 to 7 for buried plant, and by a factor of 16 for aerial plant. The greater reduction for aerial plant is due to the fixed cost of the structure being spread over a larger number of subscribers. For a small number of subscribers how they are distributed has little effect on costs because of the small tapering that can be effectively used on the cables (for 9 subscribers the variation from clustered to exponential distribution does not affect the cost/subscriber by more than 5%). With large numbers of subscribers, however, subscriber distribution can have a 300% to 400% effect on the cost/subscriber for buried plant and 200% to 300% effect for aerial.

Two other factors have important influences on the cost per subscriber, both of which can effectively act as multipliers on the costs shown in the table above. The first of these is the "fill factor" which is a measure of the utilization of the plant (or a measure of the allowance which must be made for growth). For a fill factor of 65%, which might be considered typical of a rural route, the cost per subscriber will be increased by 50% for buried plant, with a somewhat smaller increase for aerial plant depending on how many subscribers share the supporting structure.

The second factor is the route/airline ratio. Depending on the length of route considered and the number of subscribers it serves even a modest increase in route/airline ratio can, because of the steepness of the cost/distance curves, double the cost per subscriber.

All of the telephone company loop design practices we have examined are essentially equivalent differing only in detail. It is interesting to note that MT&T, the company with the highest subscriber density and hence shortest routes, uses design techniques capable of serving longer routes than the other companies. Because of other factors the effect of differences in loop practices tend to be masked in the cost curves developed in Section 4.

Perhaps the only valid observation which can be made is that the introduction of fine gauge design techniques, which essentially entail the use of approximately $200 worth of electronic equipment in the C.O., results in a net saving of about $500 (or 15%) over the cost of coarse gauge (resistance design) techniques at 70Kft route lengths.

Evidently providing telephone service in rural areas is a very expensive proposition. The cost curves we have derived rapidly increase with distance from the central office. However, before any alternative means of providing service are considered it is necessary to ensure that we are comparing apples and apples. The flexibility and reliability of cable plant makes it uniquely suitable for providing high grade service under many different operating conditions. Even if the transmission medium (cable) costs nothing it is worth remembering that installation and other hardware costs would still be incurred, particularly for aerial plant where pole lines can account for 75% of the total cost/subscriber.

APPENDIX 1

Glossary Table

Variable	Description of the Variable
ACC	Annual charges for the cable
ACDRW	Annual charges due to the dropwire
ACE	Annual charges for the electronics
ACFC	Annual charge factor for the cable
ACFDRW	Annual charge factor for the dropwire
ACFE	Annual charge factor for the electronics
ACFSS	Annual charge factor for the support structure
ACSS	Annual charges for the support structure
AICPP	Average installed cost per pole + guys
ALDRW	Average length of dropwire (in kft.)
A1	Fixed cable cost component per kft. of the finer gauge
A2	Fixed cable cost component per kft. of the coarser gauge
A26	Fixed cable cost component per kft. of 26 gauge
A24	Fixed cable cost component per kft. of 24 gauge
A22	Fixed cable cost component per kft. of 22 gauge
A19	Fixed cable cost component per kft. of 19 gauge
B1	Incremental cable cost component per kft. of the finer gauge
B2	Incremental cable cost component per kft. of coarser gauge
B26	Incremental cable cost component per kft. of 26 gauge
B24	Incremental cable cost component per kft. of 24 gauge
B22	Incremental cable cost component per kft. of 22 gauge
B19	Incremental cable cost component per kft. of 19 gauge
CDRW	Installed cost per kft. of dropwire
CIC	Installed cable cost
CIE	Installed cost of electronics
CIDRW	Average installed cost of dropwire per subscriber
CISS	Installed cost of support structure

Variable	Description of the Variable	
CLLE2	Installed cost of loop extender 2	(see Fig. 3.3-1)
CLLE3	Installed cost of loop extender 3	
CLLE4	Installed cost of loop extender 4	
CVFR3	Installed cost of voice frequency repeater 3	
CVFR4	Installed cost of voice frequency repeater 4	
DL	Loading coil spacing in kft.	
LOAD(K)	Distance of the Kth loading point from the C.O.	
MARLT	Maximum feeder length in kft. (maximum value of 150.0)	
MIRLT	Minimum feeder route length in kft.	
NEFF(x)	Cable size required at a point x kft. from the C.O.	
NFP	Fill period in years	
NLP	Number of loading points on the route	
NOCS	Number of cable sizes available	
NP(x), NPAIR(x)	Number of working pairs at x kft. from the C.O.	
NPOLE	Number of poles required for the route	
NRDL	Number of signalling limits used by the telephone company	
NSI	Initial number of subscribers on the route	
NSF	Final (ultimate) number of subscribers	
PAI	Cable size at a given point on the route	
PI1P	Percentage of subscribers with single party service	
PI2P	Percentage of subscribers with two party service	
PI4P	Percentage of subscribers with four party service	
PI8P	Percentage of subscribers with eight party service	
PF1P	Percentage of subscribers with 1-party service at the end of the route	
PF2P	Percentage of subscribers with 2-party service at the end of the route	

Variable	Description of the Variable	
PF4P	Percentage of subscribers with 4-party service at the end of the route	
PF8P	Percentage of subscribers with 8-party service at the end of the route	
PNCO	Number of working pairs required at the central office	
POSP	Pole spacing in kft.	
RDL(J)	Jth signalling limit	
RLT	Feeder route length in kft.	
RL1	Length of that part of the route which uses the finer gauge	See Fig. 3.2-1
RL2	Length of the part of the route which uses the coarser gauge	
RL26	Length of the portion of the route consisting of 26 gauge	
RL24	Length of the portion of the route consisting of 24 gauge	
RL22	Length of the portion of the route consisting of 22 gauge	
RL19	Length of the portion of the route consisting of 19 gauge	
ROLC	Resistance per kft. due to loading	
RTAD	Average value of route distance to airline distance	
R1	Resistance per kft. of the finer gauge	
R2	Resistance per kft. of the coarser gauge	
R26	Resistance per kft. of 26 gauge cable	
R24	Resistance per kft. of 24 gauge cable	
R22	Resistance per kft. of 22 gauge cable	
R19	Resistance per kft. of 19 gauge cable	
SDFC	Subscriber distribution function code: clustered ⟶ SDFC = 1.0 uniform ⟶ SDFC = 2.0 exponential ⟶ SDFC = 3.0	
SGR	Subscriber growth rate per year (in percentage of initial subscribers)	

Variable	Description of the Variable
SIZE(I)	Ith cable size available
SSIZ	Step size (in kft.) between route lengths.
TAC	Total annual charges
TCIC	Total installed capital cost
TRR	Maximum loop resistance on the route
X	Distance (in kft.) of a particular point from the C.O.

In addition to the above variables, there are some other variables of form ****ISUB and ****FSUB used in the program.

****ISUB refers to **** per initial subscriber and **** FSUB refers to **** per final subscriber. For example, ACEISUB refers to electronics annual charges per initial subscriber, and CISSFSUB refers to installed cost of support structure per final subscriber.

Glossary Table for Subroutine PAIR

Variable	Description of the Variable
AD	Average route distance to airline distance
CR	Feeder route length in kft.
C1	Percentage of subscribers with 1-party service
C2	Percentage of subscribers with 2-party service
C4	Percentage of subscribers with 4-party service
C8	Percentage of subscribers with 8-party service
CP	Number of working pairs required at the C.O.
D1	Percentage of subscribers with 1-party service at the end of the route.
D2	Percentage of subscribers with 2-party service at the end of the route.
D4	Percentage of subscribers with 4-party service at the end of the route.
D8	Percentage of subscribers with 8-party service at the end of the route.
FC	Subscriber distribution function code: clustered ⟶ FC = 1.0 uniform ⟶ FC = 2.0 exponential ⟶ FC = 3.0
F1(M)	Number of subscribers with 1-party service beyond a given point
F2(M)	Number of subscribers with 2-party service beyond a given point
F4(M)	Number of subscribers with 4-party service beyond a given point
F8(M)	Number of subscribers with 8-party service beyond a given point
LS	Ultimate number of subscribers on the route
NS(M)	Number of working pairs required at a given point on the route
V	Distance (in kft.) of a given point from the C.O.

RICHARDSON, K.

--Cost of rural telephone service.