

# Cost Reduced Cable Delivery for the 21<sup>st</sup> Century

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This paper addresses the issue of cost effective optical fibre cable delivery within current projections of fibre build. The implications are generally valid for Fibre To The Home (FTTH) but additional considerations will apply. The challenge lies in increasing the penetration of optical fibre for business customers and addressing the impending exhaustion of Core Network fibre.

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## 1. Introduction

To effectively address the cost of cable delivery a wider view must be taken that just the cost of the cable and its installation. These costs, although significant, are often overshadowed by civils costs if new duct or footway boxes are required. For this reason, in the Access Network the main objective is to minimise new duct build, whilst at the same time introducing optical fibre cable into already occupied ducts.

Even when costing the actual cable installation, it is important to include the associated activities, such as preparation of the site, set up of equipment and closing the site. These activities usually take longer than the actual time that the cable is being installed.

Another factor to consider is the cost of the cable itself. Moving away from traditional winched installation of cables should allow reductions in cable cost to be achieved.

## 2. Traffic Forecasts

Traffic in the Inner Core Network (i.e. between Digital Main Switching Units (DMSU) is currently growing by approximately 7% of UK call minutes per annum. Much more significant is the growth in internet which has taken most people within the industry by surprise. The 10,000 Erlang internet traffic over BT's network in 1997 is predicted to grow ten fold in the next 5 years. BT's Inner Core Network can not be evolved fast enough to cope with this massive increase. Therefore, the internet traffic may need to be groomed off at the local exchange or remote concentrator unit and fed via an alternative route to the serving exchange of the called internet user.

## 3. Optical Fibre

The two most important distance limiting properties of a single mode fibre are the attenuation (power reduction by scattering and

absorption) and the chromatic dispersion (pulse broadening as the propagation speed varies with wavelength). The majority of single mode fibre deployed in the world meets the ITU-T recommendation G.652 for use with systems meeting ITU-T G.957. G.652 fibre has a minimum attenuation of about 0.3 dB/km at about 1310 nm, coinciding with a zero value for the chromatic dispersion. Pulses can therefore travel the distances required for long haul inter-office communication. G.652 fibre is also used at 1550 nm, where the attenuation is even lower ( $\sim 0.2$  dB/km), but the chromatic dispersion ( $\sim 20$  ps/nm/km) can limit the useful range.

A means of improving the useful range is to move the chromatic dispersion zero to coincide with the region of least attenuation at 1550 nm. This is incorporated in ITU-T recommendation G.653 for dispersion-shifted single-mode fibre and has been successfully deployed for long haul networks. Problems have been encountered when using high power wavelength division multiplexing (WDM) signals due to non-linear effects. The most successful means of increasing the range has been the commercial development of the Erbium doped fibre amplifier (EDFA) that operates in the 1530-1565 nm range. As the chromatic dispersion in G.652 fibres is large the dispersion compensator, a component with a very large dispersion coefficient opposite that of fibre, has been developed to reset the chromatic dispersion. A parallel development has been the development of a non-zero dispersion shift single-mode fibre described in ITU-T G.655. The operating window is that of the EDFA and the chromatic dispersion values are low but specifically exclude a chromatic dispersion zero in the operating window, in order to avoid the non-linear effects seen with G.653 fibres. As G.655 fibre is a more complicated design there is currently a price premium over other fibre types.

There seems little that G.652 fibre cannot do, now that the EDFA and the dispersion compensator are commercially available and

G.652 fibre is the fibre to meet the bandwidth demands of tomorrow.

Although the cost of fibre has reduced ten-fold in the past decade, this trend has levelled out and further reductions are likely to be small by comparison. Nevertheless it should be noted that the cost of the fibre comprises a large proportion of the cost of optical fibre cables and therefore reductions in the cost of fibre remain the largest single factor in the reduction of the cost of optical fibre cable.

There is little that can be done to fundamentally reduce the cost of optical fibre production. Reductions in the price of optical fibre are now influenced more by market factors than technological advances.

Optimising cable design can lead to some reduction in optical fibre cable cost. However, larger savings to installed cable cost may be achieved by switching to more cost effective cable installation methods (in conjunction with changes to cable design where possible).

#### **4. The Cabling Environment**

Virtually all of the optical fibre cables that have been installed to date in BT's Access Network have been installed in underground ducts. This paper therefore concentrates on this cabling environment.

##### *4.1 Duct*

For the last 20 years BT has installed 90mm bore PVC (Polyvinyl Chloride) duct as standard for main duct. Other materials have been used extensively in the past and large quantities of some of these remain, particularly earthenware. The majority of these other duct types have a similar bore size to the current PVC duct.

##### *4.2 Subduct*

Subduct is a small diameter duct designed to be installed within a main duct. It is sometimes used within BT's duct network to provide long, continuous, low friction routes into which optical fibre cables can be installed. Longer lengths of cable can generally be installed into a sub-ducted route than would be possible direct into the main duct. Operationally, sub-duct can be installed in short lengths (perhaps a few 100m) and then easily joined. This means that for cable installation only the boxes at each end of the

route need to be open. This is a major advantage given the short average box spacing in BT's existing duct network, particularly in an urban environment. Subduct also protects the cable as it passes through intermediate boxes.

There are however disadvantages associated with the use of sub-duct. There is the additional product cost of the sub-duct. More importantly, though less quantifiable, is the reduced efficiency of duct space usage. This only becomes a factor where the use of sub-duct leads to inherently expensive new duct installation being required. It is important therefore that the external size of the sub-duct is as small as possible whilst maintaining adequate cable installation and protection.

Optical fibre cable should not be installed directly into main duct which contains copper cable because this would sterilise the duct (installation of further cables or recovery of existing copper cable is not permitted due to the possibility of damaging the fibre cable). Therefore subduct should be used in order to install fibre cable into ducts already containing copper cable.

#### **5. Cable Installation**

This section was first published as part of a paper [1] presented at the 1997 Construction and Operation of Underground Utilities Conference.

##### *5.1 Traditional Methods*

In the past, large capacity copper cables were winched into ducts in short lengths, limited by the capacity of cable drum which could be conveniently transported to the installation location.

Modern optical fibre cables are much lighter than the copper cables used in the past for spines. This enables the transport and installation of much longer lengths of cables. However the traditional installation method of winching cable through preinstalled ducts, with 'figure-eighting' where necessary, has also been adopted for optical fibre cables.

Figure-eighting can be performed after a cable has been installed from a drum into a duct in one direction. The cable remaining on the drum is unloaded and laid into a figure-eight configuration on the ground to gain access to the cable end. This cable end can then be installed into the duct in the other direction until the slack in the cable is eliminated.

## 5.2 Alternative Methods

There are a number of alternative approaches that can be used when installing optical fibre cable into a duct environment. This section briefly describes a number of these techniques and discusses their advantages and disadvantages.

### 5.2.1 Cable Blowing

Several systems are commercially available which use compressed air to install a cable into a small duct. The cable is fed into the pressurised duct by powered wheels or a caterpillar mechanism. One system employs a lead carrier attached to the front end of the cable. This provides extra pull force at the front end of the cable and also reduces the compressor capacity required by restricting the air flow. It is claimed that the system enables longer installation in tortuous routes than standard winching can achieve. The capabilities are highly dependant upon the duct and cable sizes and also the cable stiffness. Cable blowing machines can be employed in tandem to increase installation lengths.

Cable blowing imparts much less tensile force on the cable. Therefore much weaker and hence potentially cheaper cables can be installed by this technique. In fact some of the systems perform less well with relatively heavy BT 96 fibre cable (300-400 kg per km).

Cable blowing is not feasible directly into the large bore duct such as used by BT. Therefore sub-duct must first be installed. This is not necessarily a disadvantage since there are other good reasons to promote the use of sub-duct for optical fibre cables. The major disadvantage with this technique is the current high cost of the cable blowing equipment.

### 5.2.2 Blown Fibre

Blown Fibre consists of a small fibre bundle composed of a number of standard fibres held in a resin matrix and a tube assembly composed of a number of polyethylene tubes within a protective sheath. Currently BT uses a four fibre bundle and a seven tube assembly (See Figures 1 and 2).

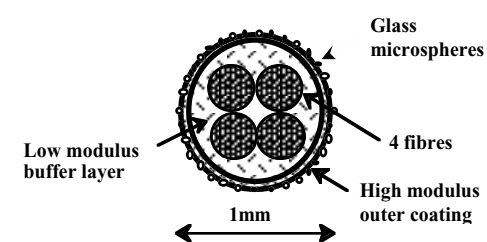


Figure 1 : Blown Fibre Bundle

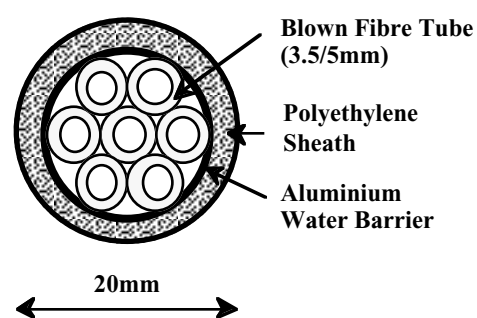


Figure 2 : Blown Fibre Tube Assembly

Compressed air is applied to the Blown Fibre tube and the Blown Fibre bundle is fed into the airflow by a special 'blowing head'. The Blown Fibre principle relies on the viscous drag of air over the Blown Fibre bundle that produces a distributed installation force on the Blown Fibre bundle.

The Blown Fibre technique is patented by BT and used extensively in BT's Access Network. Blown Fibre is also used under licence in a number of overseas countries. The installation method for Blown Fibre is the same as for blowing of traditional optical fibre cable, but on a smaller scale.

#### Positive attributes

- By installing fibre only as required, the up front investment can be minimised whilst still enabling the rapid deployment of further fibre capacity.
- The strain on the fibre during and after installation is negligible.
- Long splice free lengths are possible by using range extending techniques.
- Routes can be reconfigured using push fit connectors.

#### Negative attributes

- Lower potential fibre density than conventional cable, possibly resulting in more new duct build being required for future installations.
- Labour intensive if installing a high fibre count at a single visit.

Labour costs could be reduced by using higher fibre count bundles (e.g. 8, 12, 16 fibres) and by employing simultaneous installation of more than one bundle. Fibre density may also be improved by using higher fibre count bundles and by using higher tube count assemblies (e.g. 19 tube).

Recent work has shown that tube bores as small as 2.5 mm can be used to successfully install up to 300m of standard fibre bundle.

### 5.2.3 Cable Floating

Cable can also be installed into a small duct using pressurised water. As with cable blowing significant increases in installation length are claimed. The strain on the cable is evenly distributed along the length of the cable. This would enable the use of smaller, weaker and potentially cheaper cables to be used, which would in turn enable the use of smaller ducts. The major disadvantages with this technique are the large size of the equipment and the quantity of water required for an installation (5 tonnes when demonstrated to BT in 1992). The water is collected in a second vehicle and reused. Use of smaller ducts would reduce the quantity of water required.

### 5.2.4 Mid-assist Capstan Winch

A large diameter capstan winch (or other device) can be used to eliminate the need to figure-eight and pull a cable in both directions from the mid-point. The capstan winch is used at some point along the route to reduce the tension seen by the end winch. Multiple winches can be used if necessary. This technique enables the whole route to be installed in one pull. A capstan winch can also be used to pull cable through a box for onward installation. This is particularly useful at an exchange manhole to pull through additional cable to feed into the exchange. By eliminating the need to figure eight cable onto the ground, disruption to the public will be reduced.

### 5.2.5 Cable Fleeting Machine

This commercially available device is a direct alternative to figure of eighting. After the initial cable installation the remaining cable is pulled off the cable drum and laid in a controlled circular manner on the purpose made trailer. Once the cable has been removed from the drum, the cable can then be installed into the duct from the cable fleeting trailer. It is claimed that the device will fleet cable at up to 100m/min - an order of magnitude faster than traditional figure of eighting. Additionally a cable fleeting machine is generally more space efficient than figure of eighting, thereby reducing disruption to the public, especially in urban environments.

### 5.2.6 Subduct Rodding

Subduct is usually installed into a duct by winching in a similar manner to cable installation. An alternative method would be to push the sub-duct into the duct. This negates the need to install drawropes. BT Labs has performed an initial hand-rodding experiment into an 85m straight duct route to

verify the feasibility of this approach. In addition, a mechanical sub duct caterpillar pusher has been developed. This is capable of installing 600m of 25/32 mm sub duct into a standard BT main duct. The system includes footway box reaction rods and cabling guides. For tortuous routes a limit of 300m may be expected.

### 5.3 Comparison of Methods

It is important when analysing processes that the entire job is examined. For cable installation, this has been taken to include preparation of the installation environment, installation of ropes and sub-duct (where required), set up of equipment, installing the cable and closing the site. Installations were broken down into their constituent tasks. A man-hour requirement was ascribed to each of the tasks following consultation with the BT training department and three of BT's cable installation contractors. The total number of man-hours required for any installation can then be calculated by determining how many times each of the constituent tasks needed to be performed. To assist analysis the tasks were grouped into categories.

In order to produce realistic labour comparisons, two representative routes (urban and rural) were devised in conjunction with three of BT's cable installation contractors. The breakdown of time into task group for a traditional winched subduct and cable installation of the rural route is demonstrated in Figure 3.

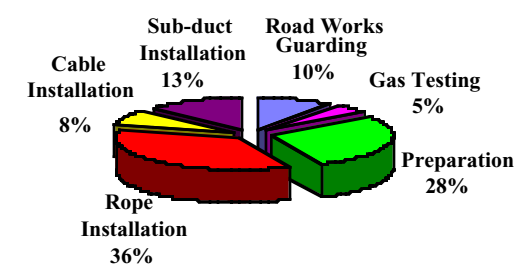


Figure 3 : Analysis of Traditional Winched Subduct and Cable Installation (Rural Route)

This section presents results of a comparison of installation time between the following installation methods for the standard routes :-

1. No sub-duct, cable winched in using a mid-point 'figure-eight'.
2. No sub-duct, cable winched in using a mid-point capstan winch.
3. No sub-duct, cable winched in using a mid-point cable fleeter.
4. Sub-duct winched in, cable winched in.
5. Sub-duct winched in, cable blown in.

6. Sub-duct self-rodged in, cable winched in.
7. Sub duct self-rodged in, cable blown in.

For cases 1-6, standard optical fibre cable is assumed. In case 7 micro sheath cable at 13.5mm diameter for 100 fibres is used (see Section 6).

Figure 4 presents results for the rural route. It can be seen that the capstan or fleeter offers very little time saving over the standard 'figure-eight' technique. Considering the extra plant costs of these alternative techniques, they are not likely to be financially attractive. Their associated operational benefits may temper this view.

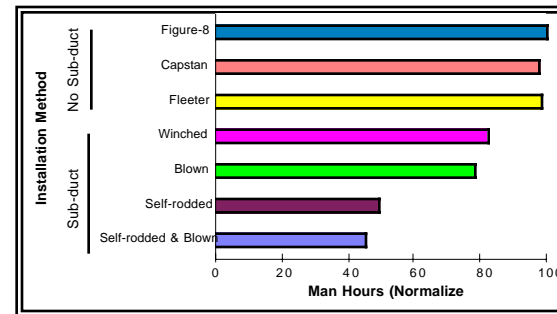


Figure 4 : Comparison of Installation Techniques (Rural)

The sub-ducted methods offer considerable time savings. It should be remembered that the sub-duct itself constitutes a considerable additional stores cost. Cable blowing offers a small, but appreciable, reduction in installation time. Self-rodged sub-duct, in contrast, offers a sizeable time saving (approximately 40% on the standard, winched sub-duct method).

Results for the urban route are also presented (Figure 5). This mirrors the results for the rural route but with greater time savings when using sub-duct. Self-rodged sub-duct offers less time savings over standard winched subduct installation than for the rural route.

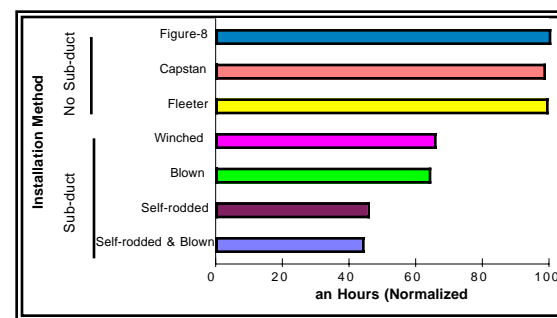


Figure 5 : Comparison of Installation Techniques (Urban)

Use of capstan, fleeter or cable blowing techniques only tackle the 'cable installation' tasks. Since this accounts for only a small part

of the total installation time (For the rural route : 16% if unsub-ducted, 8% if sub-ducted), only small savings are possible. Self rodged sub-duct addresses the largest task grouping (rope installation) and in fact eliminates it completely (See Figure 6). This explains the large time savings that this technique indicates.

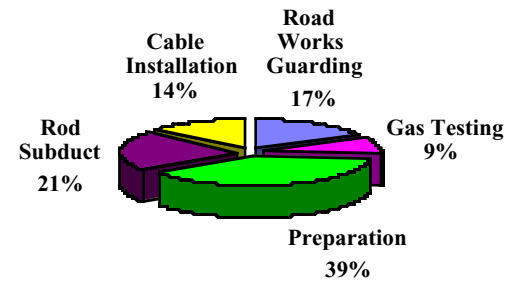


Figure 6 : Analysis of a Self-rodged Sub-duct and Traditional Cable Installation (Rural Route)

Table 1 summarises a basic comparison of labour, cable and equipment costs. Self-rodging of subduct offers a large reduction in overall installation time compared to the standard winched subduct method. Blown and floated cable require a high investment in equipment, but offer considerable savings in installed cost by enabling cheaper cables. The most cost effective approach would be to combine self-rodging of subduct with blown (or floated) cable installation.

Technique	Time Saving	Cheaper Cable	Equipment Cost
Mid-point Capstan	Very Low	No	Medium
Fleeting Machine	Very Low	No	Medium
Blown Cable	Low	Yes	High
Floated Cable	Low	Yes	High
Rodded Sub-duct	High	No	Low

Table 1 : Installed Cost Comparison Summary

## 6. Optimisation of Optical Fibre Cables

For successful fibre cable blowing the cable needs to have a diameter ~50% that of the duct bore. Most sub ducts have an internal diameter of 25 to 29 mm so that loose tube cables of 15-20mm for 100 fibres are not ideal. The majority of free space inside a loose tube cable is that within and interstitially disposed around the loose tubes. Fibre ribbons enable more of the internal space to be used and micro sheath designs [2] lessen both internal and interstitial voids.

Moreover, to the user with a large equipment base the basic units are jointable with single fibre splicing machines.

The microsheat cable concept was created by France Telecom and SAT in 1991. The fibre bundles are enclosed in a thin, easily removable sheath to produce fibre element. A number of these fibre elements are then enclosed in a protective cable sheath.

Figure 7 illustrates such a cable which has a fibre packing density of  $0.38 \text{ fibres/mm}^2$  compared to  $0.67 \text{ fibres/mm}^2$  for the traditional loose tube alternative. Reduction in cable size make this cable more optimal for blowing into current subducts. The approach also enables larger fibre count cables to be developed whose diameters permit blowing into current subduct. The possibility of smaller subducts also exists, especially for low fibre count cables. By reducing subduct size or installing higher fibre count cables, best use can be made of existing duct, thereby minimising the amount of new duct required.

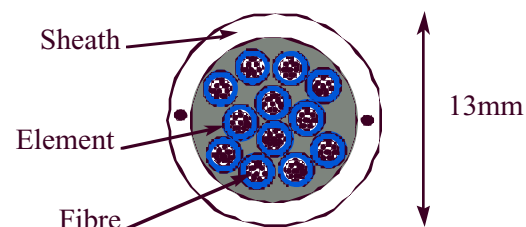


Figure 7 : Microsheath Cable

Such cables are also intrinsically more blowable due to the absence of a tensile steel strength member and consequent weight reduction. The cable illustrated could be installed in excess of 1000m with current blowing equipment.

## 7. Installation Methods for Optical Fibre Customer Drops

Several techniques exist that are particularly relevant for the installation of optical fibre customer drops. This part of the network is particularly expensive on a per customer connected basis since the costs are fully attributed to a single customer connection. Cost savings in customer drops have a correspondingly large effect on the cost per customer connected. The cost per metre of traditional duct installation (including trench excavation, duct laying and surface reinstatement) can be as much as ten times the cost of cable installation and the reinstatement is often unsightly and unacceptable to

customers. Therefore alternative methods which avoid surface disruption, such as described in this section, are preferred.

It should be noted that knowledge of the location of existing underground plant must be obtained before underground construction is undertaken. Although information can be obtained from local authorities and utility companies, an on site survey is often performed to give exact positions of the utility plant. Able locator technology is well established and permits accurate location of buried metallic plant. Ground Probing Radar is a popular technique for locating buried non-metallic objects, which has received increased attention in recent years [3]. The technique allows rapid location of plant, but does not operate well in water logged soils such as clay.

### 7.1 Impact Moling

Impact Moles operate using a compressed air driven hammer within an enclosure. The percussion action of the hammer impacts the soil ahead of it and drives the mole forward.

Moles are available in a number of diameters and can operate at a rate of approximately 1 m per minute over short runs. Either a duct is pulled in behind the mole, or the mole makes the hole into which the duct is then installed. Moles require a starting pit from which the tool is launched and a reception pit where the tool is received. In some cases the mole may deviate from the chosen straight course, or may breakdown, both eventualities requiring the surface to be excavated to find the tool. Moles can be fitted with radio sondes so that their progress can be tracked from the surface using a cable locator.

#### Positive attributes

- Relatively easy to operate.
- Requires small launch and reception pits.
- Surface disruption is minimised.
- Installation of duct up to 100 mm diameter.

#### Negative attributes

- Moles can hit hard buried objects causing them to deviate from the intended course.
- Recommended for short, straight line operation only (maximum distance ~30 m).
- Severe deviations from course or breakdowns necessitate expensive excavation to retrieve the tool.
- Buried plant can be hit, sometimes without an obvious indication.
- Damage can occur to the surface (heave) if moles are used at too shallow a depth. This will occur, dependent upon surface type, when the mole depth is less than 1 metre.

### 7.2 Rod Pushing

As the name implies, a machine is used to drive a number of connecting rods into the soil. When the rods reach the destination a duct can be pulled back through the hole. Rod pushers are available in many sizes, and this is significant when the size of the start pit is considered. To install a 100 mm diameter duct a typical rod pushing machine requires a launch pit measuring 2 m by 1 m so that the whole machine can be lowered to the depth required.

Some machines can apply a certain amount of steering to the rods, although it would seem that the majority of installations are performed in a straight line.

#### Positive attributes

- Relatively easy to operate.
- Surface disruption is minimised.
- Installation of duct up to 100 mm diameter.

#### Negative attributes

- Recommended mainly for short straight line operation (maximum distance ~30 m).
- Buried plant can be hit, sometimes without an obvious indication.
- Damage can occur to the surface (heave) if the rods are used at too shallow a depth. This will occur, dependent upon surface type, when the depth is less than 1 metre.
- A large launch pit is required so that the machine can be lowered to the required depth.

### 7.3 Directional Drilling

Directional drilling refers to a family of machines that operate using a steerable drill string based upon oil rig drill design. The drill string consists of a number of connecting rods similar to those used by the rod pusher. These machines are able to launch into a small aperture cut in the surface. The drill head can be either a cutting head, possibly water lubricated, or in the form of an impact mole, both with a slanted cutting face.

Steering is achieved by careful rotation of the drill string. For straight-line installation the drill head is rotated continuously and the drill string driven forward. The progress of the machine relies upon the cutting head and the addition of more drill rods to lengthen the drill string. To steer the rods the drilling head is rotated to a set angle and then the drill string is driven forward. The bias caused by the slanted face of the cutting head is sufficient to cause a deviation from the straight-line path.

The drill head is fitted with a sonde which transmits both depth and rotation status to a hand-held locator.

#### Positive attributes

- Drill head can be steered.
- Drill head can be located from the surface enabling progress to be monitored.
- Suitable for long routes (typically >100 m dependent upon soil conditions).
- Surface disruption is minimised.

#### Negative attributes

- Buried plant can be hit, sometimes without an obvious indication.
- Lubricated drilling head systems may require the use of regular small venting points along the route to avoid uncontrolled fluid release.

### 7.4 Guided Water Jetting

About 20% of BT's residential customers are currently fed by a direct buried copper dropcables. Guided water jetting is a novel approach which uses these dropcables as guides for the installation of a Blown Fibre tube (or lightweight cable).

The apparatus consists of a jetting head (see Figure 8) which is held by a slip ring over the exposed end of the existing cable. A tube is attached to the jetting head down which water is pumped at high pressure. With the application of water the head is forced through the soil to create a pathway alongside the copper cable. The Blown Fibre tube (or cable) to be installed is connected to the jetting head tube, which is then retracted drawing the Blown Fibre tube (or cable) into the pathway that has been produced.

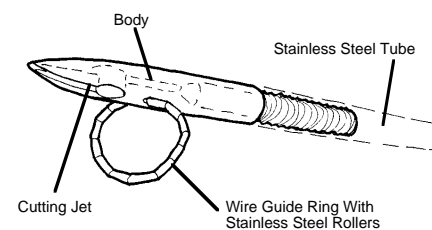


Figure 8 : Guided Water Jetting Head

The guided water jetting installation technique has demonstrated the following performance :

- a distance of 20 m.
- an installation time of 1 hour including setting up and breaking down the equipment.
- the use of a single installer.
- the space required is consistent with that available at the customers curtilage.
- the equipment can be fitted in a 5 cwt van.

#### Positive attributes

- Economical solution for underground installation of blown fibre tubing.
- Minimum disturbance of the ground surface.

#### Negative attributes

- The technique does not work if surplus buried lead-in copper cable is laid in a coil.

#### 7.5 Blown Fibre Drop Tube

Over half of BT's residential customers are currently fed by aerial copper dropwires. The most cost effective FTTH upgrade strategy for these customers is likely to be the replacement of the copper dropwire with a Blown Fibre drop tube. The requirements for a Blown Fibre drop tube have been analysed and a product that meets these requirements has been developed and successfully trialled [4].

Figure 9 shows the droptube design that when manufactured with the chosen materials and processing conditions, meets the requirements.

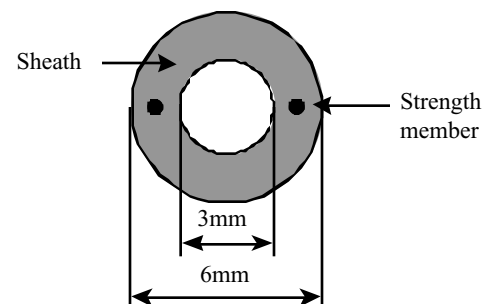


Figure 9 : Blown Fibre Drop Tube

### 8. Cost Effective Alternatives to Traditional Footway Boxes

Traditionally BT has used concrete or brick footway boxes constructed in situ. Although inexpensive in terms of materials, labour costs are high. More importantly these boxes must be left to set, causing prolonged disruption to the public as well as often resulting in poor productivity.

#### 8.1 Prefabricated Boxes

Prefabricated Glass Reinforced Plastic boxes have been used by BT for several years where a small box is required (e.g. some new housing developments). Although prefabricated footway boxes have a significant materials cost, this is far outweighed by the cost savings achieved by faster installation and improved productivity of the workforce.

A trial of pre-cast segmented large plastic footway boxes is currently being performed by BT. Assuming this is successful, it is envisaged that these will be used instead of concrete for larger boxes in the Access Network, resulting in all new footway boxes in the Access Network being prefabricated plastic.

#### 8.2 High Capacity Footway Box

Large cost savings can be achieved by replacing existing footway boxes and ducting that can only serve 4 or 5 houses with a footway box designed to serve 32 houses using blown fibre tube (5 mm O.D.). Blown fibre tube from each customer is terminated on a blown fibre bulkhead at the base of the footway box. Internally a smaller lighter tube is used to spiral up to the joint housing (see Figure 9) which contains OTIAN® splice only sub-assemblies (SOSAs) for point-to-point applications as required. OTIAN® splitter array sub-assemblies (SASAs) can also be accommodated allowing up to four 8-way SOSAs/SASAs to serve up to 32 houses.

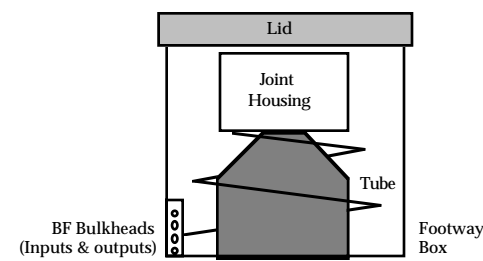


Figure 9 : High Capacity Footway Box

The outer can of the footway box can be provided as glass reinforced plastic (GRP) which is a preferred option. Alternatively it can be constructed using concrete formed in-situ around a removable plug. The blown fibre tubes can be brought in through the sides or the base of the plug.

#### Positive attributes

- The new footway box provides greater capacity to accommodate customers.

#### Negative attributes

- The new designs of footway box may collapse under the load of vehicles traversing the footpaths

### 9. Conclusions

At the Access Network Construction and Installation Techniques workshop in March 1998 a target of £50Bn was proposed for the roll out of FTTH in the European Union.

Infrastructure was estimated as making up 70% of this cost.

Therefore we conclude that :

- The cost of optical fibre cable delivery is an important area for Research and Development and cost analysis.
- Innovative new approaches for Access Network fibre build should be sought, analysed and incorporated into BT practice where cost advantageous.
- BT's alliance partner networks share this problem, although with a different emphasis since they have no legacy networks.

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