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Edited by Pauline Rigby, Freelance Technology Editor
Foreword

The publications of the FTTH Council Europe play an important part in our mission to accelerate the adoption of fibre to homes and businesses throughout Europe. These documents help to meet the increasing thirst for knowledge about fibre-to-the-home (FTTH) networks, particularly among the new entrants and alternative operators who form an important part of the FTTH scene in Europe.

The FTTH Handbook was the first major publication produced by the FTTH Council Europe. Originally issued in 2007, its purpose was to help operators understand the options available for deployment of optical fibre infrastructure.

Last year the Handbook was expanded to include current and future developments in active equipment for FTTH networks, including both passive optical network and active Ethernet solutions.

For the third edition the entire document has been updated and extensive new sections have been added on FTTH network testing, including qualifying networks during construction, service activation and troubleshooting.

The result is a comprehensive source of information about the methods and equipment for deploying and operating both the passive infrastructure and the active electronic equipment in an FTTH network.

The Handbook remains true to its original purpose – to provide straightforward and impartial information on the range of available options for building and operating an FTTH network.

This document would not be possible without the invaluable contributions of a number of people, and considerable hard work. Therefore, I would like to extend my heartfelt thanks to the Deployment and Operations Committee for co-ordinating and compiling the latest edition of the FTTH Handbook.

Karel Helsen, President of the FTTH Council Europe
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Appendix B: European Standards
1 Introduction

Optical fibre will be the main building block for future high-capacity home broadband networks. The transmission capacity of fibre is almost unlimited and is unconditional compared to existing copper cabling systems.

Numerous financial models have shown little difference between the deployment costs of optical fibre and copper cables systems of equal capacity. However, the advantages of fibre – high bandwidth over long distances, future upgrade potential and significantly lower maintenance and operational costs – make fibre the sensible, long-term choice.

The FTTH Handbook has been written in order to provide a straightforward and impartial description of the important elements and various possible construction methods for a fibre-to-the-home (FTTH) network infrastructure.

In these pages, you will find details of the many different infrastructure deployment options that can be considered when planning and building an FTTH network in Europe. The scope of this document is to provide an overview of existing technologies; it should not be taken as a design guide.

All deployment options discussed in this handbook are based on a complete optical fibre path from the network operator’s active equipment right through to the subscriber premises. Hybrid options involving part fibre and part copper infrastructure networks are not considered.

The FTTH Council Europe accepts that all existing solutions have a place in today’s networks. A key part of designing a network is choosing the most appropriate build methodology. It is up to the network designer to decide which methodology is the most appropriate for the specific circumstances.

All of the equipment, services, and deployment methods described are currently available and have been successfully deployed throughout Europe and elsewhere. They can be used either in isolation or in combination with the other options to form the most efficient overall solution for specific network circumstances.

When designing and building FTTH networks, it is helpful to understand the challenges and tradeoffs facing potential network owners and operators. Some of these challenges may present conflicts between functionality and economic demands.

Key functional requirements for a FTTH network will include:

- provision of high bandwidth services and content to each customer
- a flexible network architecture design that can accommodate future innovations
connection by fibre of each end subscriber directly to the active equipment, to ensure maximum available capacity for future service demands
• support for future network upgrade and expansion
• minimize disruption during network deployment, to help fibre networks gain acceptance from network owners and to benefit FTTH subscribers

At the same time, the FTTH network builder must create a profitable business case, balancing capital expenditure with operating expenditure while ensuring revenue generation. Cost considerations are introduced briefly in Chapter 6 of the Handbook, but for a more detailed investigation into the main influences on the cost of deploying FTTH networks please read the FTTH Business Guide, which is also available from the FTTH Council Europe.

Eric Festraets, Chair of the Deployment and Operations Committee, FTTH Council Europe
2 FTTH Network Description

An FTTH network constitutes a fibre-based access network, connecting a large number of end users to a central point known as an access node or point of presence (POP). Each access node will contain the required active transmission equipment used to provide the applications and services over optical fibre to the subscriber. Each access node is served by a larger metropolitan or urban fibre network, which connect all the access nodes throughout a large municipality or region.

Access networks may connect some of the following:

- fixed wireless network antenna, for example wireless LAN or WiMAX
- mobile network base stations
- subscribers in residential houses, terraces or blocks of flats
- larger buildings such as schools, hospitals and businesses
- key security and monitoring structures like surveillance cameras, security alarms and control devices

An FTTH network may be considered to be part of the wider area or access network.

2.1 FTTH network environment

The deployment of fibre closer to the subscriber may require deployment of fibre infrastructure on public and private land, and also within public and private properties.

The environment can be broadly split into:

- city
- open residential
- rural
- building type and density – single homes or multi-dwelling units (MDUs)
Not only does each environment offer different customer densities (per sq km), but this also varies by country.

The type of site will be a key factor in deciding the most appropriate network design and architecture. Types include:

- **Greenfield** – new build where the network will be introduced at the same time as the buildings
- **Brownfield** – where there are existing buildings and infrastructure but the infrastructure is to a lower standard
- **overbuild** – adding to the existing infrastructure

The main influences for the infrastructure deployment methodology are:

- type of FTTH area:
- size of the FTTH network
- initial deployment cost of the infrastructure elements (CAPEX)
- ongoing costs for network operation and maintenance (OPEX)
- network architecture, for example PON or Active Ethernet
- local conditions, for example, local labour costs, local authority restrictions (traffic control) and others

The fibre deployment technology will determine CAPEX and OPEX, as well as the reliability of the network. These costs can be optimised by choosing the most appropriate active solution combined with the most appropriate infrastructure deployment methodology. These methods, which are described in Section 9, include:

- conventional underground duct and cable
- blown micro-ducts and cable
- direct buried cable
- aerial cable
- “other rights of way” solutions

### 2.2 FTTH architecture

In order to specify the interworking of passive and active infrastructure, it is important to make a clear distinction between the topologies used for the deployment of the fibres (the passive infrastructure) and the technologies used to transport data over the fibres (the active equipment).

The two most widely used topologies are point-to-multipoint, which is often combined with a passive optical network (PON) architecture, and point-to-point, typically using Ethernet transmission technologies.
Point-to-multipoint topologies with passive optical splitters in the field are deployed in order to be operated by one of the standardized PON technologies (GPON is today’s frontrunner in Europe, while EPON has been massively deployed in Asia) using time-sharing protocols to control the access of multiple subscribers to the shared feeder fibre. Active Ethernet technology can also be used to control subscriber access in a point-to-multipoint topology – this requires placing Ethernet switches in the field.

Point-to-point topologies provide dedicated fibres between the POP and the subscriber. Each subscriber is directly connected by a dedicated fibre. Most existing point-to-point FTTH deployments use Ethernet, but this can be mixed with other transmission schemes for business applications (e.g., Fibre Channel, SDH/SONET). This topology can also include PON technologies by placing the passive optical splitters in the access node.

2.3 Different fibre termination points

Various access network architectures can be implemented.

**Fibre to the home (FTTH)** – Each device at the subscriber premise is connected by a dedicated fibre to a port on the equipment in the POP, or to the passive optical splitter, using shared feeder fibre to the POP. It uses 100BASE-BX10 or 1000BASE-BX10 transmission for Ethernet connectivity, mainly GPON (or EPON) in case of point-to-multipoint connectivity.

**Fibre to the building (FTTB)** – each optical termination box in the building (typically in the basement) is connected by a dedicated fibre to a port on the equipment in the POP, or the optical splitter, using shared feeder fibre to the POP. The connections between subscribers and the building switch can be fibre or copper based and use some form of Ethernet transport suited to the medium available in the vertical cabling. In some cases building switches are not individually connected to the POP but are interconnected in a chain or ring structure in order to utilize existing fibres deployed in particular topologies and to save fibres and ports in the POP. The particular case of bringing fibre directly into
the apartment from POP or optical splitter onwards, without any switch in the building, brings us back to the fibre-to-the-home scenario.

**Fibre to the curb (FTTC)** – each switch / DSLAM, typically in a street cabinet, is connected to the POP via a single fibre or a pair of fibres, carrying the aggregated traffic of the neighbourhood via Gigabit Ethernet or 10 Gigabit Ethernet. The connections between subscribers and the switch in the street cabinet can be fibre or copper based, and use either 100BASE-BX10, 1000BASE-BX10, or VDSL2. This architecture sometimes is also called “Active Ethernet” as it requires active network elements in the field.

![Different FTTx networks](image)

Figure 4: Different FTTx networks.

This document will however concentrate on FTTH/B deployments because in the long term they are considered the target architecture due to their virtually unlimited scalability.
3 Active Equipment

Both passive optical network (PON) and Ethernet point-to-point solutions have been deployed worldwide. The choice of equipment depends on many variables including demographics and geographical segmentation, specific deployment parameters, financial calculations, and more. In particular, the choice is highly dependent on the ease of deploying the passive infrastructure. Clearly, in today’s marketplace there is room for both solutions.

In a multi-dwelling unit (MDU), the connections between end-users and the building switch can either be copper or fibre, although fibre is the only solution that will guarantee the ability to manage future bandwidth requirements.

In some situations a second fibre is provided for RF video overlay systems.

![Diagram of different FTTH network architectures](image)

Figure 5: Different FTTH network architectures.

3.1 Passive optical network

The PON equipment comprises an optical line terminal (OLT) in the point of presence (POP) or central office, one fibre to the passive optical splitter and a fan-out towards a maximum of 64 end-users, each having an optical network unit (ONU), where the fibre is terminated. The ONU exists in several versions, including an MDU version that handles many customers for in-building applications, reusing existing in-building cabling (CAT5/Ethernet).

Advantages of PON include reduced fibre usage, the absence of active equipment between the OLT and ONU, and the dynamic bandwidth allocation capabilities, which could lead to capital and operational cost savings.
3.1.1 PON solutions

There have been several generations of PON technology to date. The Full Services Access Network (FSAN) Group develops technical specifications, which are then ratified as standards by the International Telecommunications Union (ITU). These standards include APON, BPON and now GPON, which provides 2.5Gbps of bandwidth downstream and 1.25Gbps upstream for a maximum of 64 users. In the second half 2010, ITU will ratify a new standard, XG-PON, offering 10 Gbps downstream and 2.5 Gbps upstream. Commercial XG-PON products will be released shortly afterwards.

In 2004 the Institute of Electrical and Electronic Engineers (IEEE) introduced an alternative standard called EPON with a capability of 1Gbps in both directions. Proprietary EPON products are also available with 2Gbit/s downstream bit rate. In September 2009 the IEEE ratified a new standard, 10G-EPON, offering 10 Gbps symmetric bit rate. Commercial 10G-EPON products will be released in 2010.

Trends for access technology over the next ten years will be towards more symmetrical bandwidth. Multimedia file sharing, peer-to-peer applications and the more data-intensive applications used by home-workers will drive subscriber upstream bandwidth. Still, it is difficult to envision complete symmetry in residential applications due to the enormous amount of bandwidth required for HDTV and entertainment services in general – although small businesses could benefit from symmetric, broadband connectivity. Nonetheless, it is the high upstream bit rate of the PON that gives FTTH operators their main competitive advantage over DSL or cable providers.

GPON provides a 20 km reach with a 28dB optical budget using class B+ optics. Reach can be extended to 30 km by limiting the splitting factor to a maximum of 1:16, or by the introduction of C+ optics, which add 4 dB to the optical link budget. 10G-EPON can also provide a 20km reach with a 29dB optical budget.

Figure 6: Schematic diagram of a GPON network.
RF video overlay is optional via separate wavelength (1550 nm), and can be useful in stepwise build-up and time-to-market critical situations for digital TV offerings.

3.1.2 Bandwidth management

GPON, EPON, XG-PON and 10G-EPON bandwidth is allocated by TDM (time division multiplexing) based schemes. Downstream, all data is transmitted to all ONUs; incoming data is than filtered based on port ID. In the upstream direction, the OLT controls the upstream channel by assigning a different time slot to each ONU. The OLT provides dynamic bandwidth allocation and prioritisation between services using a MAC (Media Access Control) protocol.

Figure 7: Bandwidth management in PON systems.

3.1.3 PON active equipment

Standard PON equipment consists of an optical line terminal (OLT) and the optical network unit (ONU). The OLT is usually situated at the central office or concentration point. The OLT boards can handle up to approximately 3600 subscribers (based on a maximum of 64 per GPON connection) per shelf.

There are different types of ONU available to suit the location:

- indoor application (I-series)
- outdoor application (O-series)
- business application (B-series)
- FTTB application

Depending on the application, the ONU can offer analogue phone connections (POTS), Ethernet connections, RF connections for video overlay or in the case of FTTB, a number of VDSL2 connections.

3.1.4 Deployment optimisation

When deploying FTTH networks, active and passive infrastructure go hand in hand. It is clear that the timely investment in active equipment (mainly at network side) can be optimised once the correct passive splitting arrangement has been chosen.
Knowing the current and future customer distribution and location is of the utmost importance when planning splitter placement.

With single splitter placement, the splitter can be situated closer to the customers in case of high end-user density such, or can be placed in a more central location to improve the spread of customers in case of less dense end-user locations.

Further optimisation can be achieved by distributing the splitters in more than one level, which reduces the length of fibre required and eases the configuration, but increases the number of locations where splitters are installed.

![Figure 8](image)

3.2 Ethernet point-to-point

For Ethernet architectures, there are two possibilities, one dedicated fibre per customer between the Ethernet switch located at the POP and the home, or one fibre to an aggregation point and dedicated fibre from there onwards. The former possibility is easy and straightforward to implement, the latter limits the fibre usage in the access loop and is therefore suitable for FTTB solutions.

3.2.1 Ethernet point-to-point solutions

From a civil engineering perspective the topologies of the cables for point-to-point fibre deployments can look identical to those for PON. From the POP, individual feeder fibres for each subscriber are laid down towards some distribution point in the field – typically a splice point – either in an underground enclosure or a street cabinet. From this distribution point, fibres are laid towards each individual home.
The higher number of feeder fibres does not pose any major obstacle for from a civil engineering perspective. However, since the fibre densities in the feeder and drop part are very different, it is likely that different cabling techniques will be employed in the two parts of the network.

In the feeder part deployments can be greatly facilitated by existing conventional ducts, and by other rights of way like sewers or tunnels.

Fibres arriving in the POP are terminated on an optical distribution frame (ODF) – this is a flexible fibre management solution that makes it possible to connect any customer to any port on the switches in the POP.

Due to the large number of fibres handled in a POP, the density of the fibre management solution has to be very high in order to reduce space required. This figure shows an example of a high-density ODF that can terminate and connect more than 2300 fibres in a single rack. For illustration purposes it is positioned next to a rack with active equipment that can terminate 1152 fibres on individual ports.

Take rates in FTTH projects typically take some time to ramp up and usually stay below 100%. Fibre management allows a ramp up of the number of active ports in synchrony with the activation of customers. This minimizes the number of unused active network elements in the POP.

Figure 9: High density fibre management.

Figure 10: Ethernet network diagram.
3.2.2 Transmission technologies

Recognizing the need for Ethernet in access networks, IEEE established the IEEE 802.3ah Ethernet in the First Mile (EFM) Working Group in 2001. As well as developing standards for Ethernet over copper and EPON, the group created two standards for Fast Ethernet and Gigabit Ethernet over singlemode fibre.

The EFM standard was approved and published in 2004, and was included into the base IEEE 802.3 standard in 2005.

The specifications for transmission over singlemode fibre are called 100Base-BX10 for Fast Ethernet and 1000Base-BX10 for Gigabit Ethernet. Both specifications are defined for a nominal maximum reach of 10km.

To separate the directions on the same fibre wavelength-division duplexing is employed, such that for each of the bit rate classes two specifications for transceivers are defined, one for upstream (from the customer towards the POP) and one for downstream (from the POP towards the customer).

The table provides the fundamental optical parameters of these specifications:

<table>
<thead>
<tr>
<th></th>
<th>100Base-BX10-D</th>
<th>100Base-BX10-U</th>
<th>1000Base-BX10-D</th>
<th>1000Base-BX10-U</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit direction</td>
<td>Downstream</td>
<td>Upstream</td>
<td>Downstream</td>
<td>Upstream</td>
</tr>
<tr>
<td>Nominal transmit wavelength</td>
<td>1550nm</td>
<td>1310nm</td>
<td>1490nm</td>
<td>1310nm</td>
</tr>
<tr>
<td>Minimum range</td>
<td>0.5m to 10km</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Minimum channel insertion loss</td>
<td>5.5dB</td>
<td>6.0dB</td>
<td>5.5dB</td>
<td>6.0dB</td>
</tr>
</tbody>
</table>

In order to cope with requirements not considered in the standard, the market offers optical transceivers with non-standard characteristics. Some types can bridge significantly longer distances to suit deployment in rural areas.

Since the nominal transmit wavelength of 100BASE-BX-D (1550nm) is the same as the standard wavelength for video overlays in PON systems, transceivers exist which can transmit at 1490nm. This makes it possible to use off-the-shelf video transmission equipment to insert an additional signal at 1550nm in order to carry the RF video overlay signal on the same fibre.

3.2.3 RF-based video solutions

IPTV-based video solutions provide superior features over simple broadcast solutions and have, therefore, become an indispensable part of any triple-play offering. Quite frequently, however, there is a need to provide RF video broadcast overlays in order to
support existing TV sets in the subscribers’ households. In PON architectures this is typically accomplished by providing an RF video signal, compatible with cable TV solutions, over an additional wavelength at 1550nm. In point-to-point fibre installations this can be achieved by two different approaches, depending on the possibilities for fibre installation:

In the first approach an additional fibre per customer is deployed in a tree structure, which carries only an RF video signal that can be fed into the in-house coaxial distribution network. In this case the split factors (e.g. ≥ 128) exceed those typically used for PONs so that the number of additional feeder fibres is minimized.

In the second approach a video signal is inserted into every point-to-point fibre at 1550nm. The RF video signal carried by a dedicated wavelength from a video-OLT is first split into multiple identical streams by an optical splitter and then fed into each point-to-point fibre by means of triplexers. On the customer side the wavelengths are separated, the 1550nm signal converted into an RF signal for coax distribution, and the 1490nm signal made available on an Ethernet port.

In both cases the CPE/ONU devices comprise two distinct parts:

- a media converter that takes the RF signal on 1550nm and converts it into an electrical signal that drives a coax interface
- an optical Ethernet interface into an Ethernet switch or router

In the single-fibre case the signals are separated by a triplexer built into the CPE, while in the dual fibre case there are individual optical interfaces for each fibre.
4 Customer Equipment

In the early days of broadband, home internet connectivity was delivered by simple, low-cost data modems for PCs, followed by routers and wireless connectivity (Wi-Fi). Today, owing to the proliferation of digital devices inside the home – including but not limited to computers, digital cameras, DVD players, game consoles and PDAs – the environment is changing. The “digital home” has arrived.

We distinguish two functions in the home environment: the ONU, where the fibre is terminated, and the customer premise equipment (CPE), which provides the necessary networking and service support. These functions may be integrated or separate, depending on the demarcation point between service provider and end-user, and how the responsibility is shared, which will be linked to the commercial contract.

As more advanced devices and technologies are adopted, the concept of the residential gateway has emerged. This device is a CPE that combines a broad set of networking and service capabilities, including broadband connectivity on the WAN, routing, wireless LAN (Wi-Fi), Network Address Translation (NAT), security and firewall, as well as capabilities required for the support of VoIP and IPTV service, and quality of service capabilities.

To help address concerns related to home and device management, the Broadband Forum (previously the DSL Forum) created the TR-069 management interface standard, which is now available on most modern residential gateways.

Home connectivity opens up a new competitive landscape in which network operators, internet service providers, IT-vendors, and consumer electronics vendors compete to capture the greatest customer share.
5 Future Technology Development

Access and backbone bandwidth requirements are expected to continue growing exponentially. By that we mean that global peak and average bandwidth will inexorably increase and access bit-rate requirements will soon exceed 100Mbps.

5.1 Evolution of passive optical networks

5.1.1 Evolution of ITU standards

Although GPON is widely perceived to possess sufficient bandwidth for the next few years, a 10G specification is currently being developed, and is expected to be ratified by the ITU in the second half of 2010. But this is not the limit; in future PON parameters will be pushed to even higher values.

XG-PON1, as the proposed standard is called, is a natural continuation in the evolution of PON technologies, increasing bandwidth four times to 10Gbps, reach from 20 to 60 km, and split from 64 to 128 – although reach and split maxima are not obtainable simultaneously. Most importantly, these evolutionary technologies will avoid the need for significant upgrades to the installed outside plant.

The optical budget of 28dB with today’s GPON technology using class B+ optics enables a reach of 30 km when the splitting factor is limited to 1:16. New class C+ optics add another 4dB of link budget, and thus either more distributed splitting capabilities or more reach. GPON extenders increase reach further to 60km or 128 end-users.

Figure 14: Evolution of ITU PON standards.
5.1.2 Evolution of IEEE standards

The 10G-EPON (10-Gigabit Ethernet PON) standard was ratified in September 2009 under the name 802.3av. This latest standard offers a symmetric 10Gbps, and is backward compatible with 802.3ah EPON.

10G-EPON uses separate wavelengths for 10G and 1G downstream, and will continue to use a single wavelength for both 10G and 1G upstream with TDMA separation of customer data.

The 802.3av Task Force has concluded its work, with the 802.3av now being included in the IEEE 802.3 standard. Commercial 10G-EPON equipment is expected to reach the market in 2010.

5.2 WDM-PON

WDM-PONs promises to combine the best of both worlds – sharing feeder fibres while still providing dedicated point-to-point connectivity. These architectures provide dedicated and transparent connectivity on a wavelength per subscriber basis, and thus allow very-high uncontended bit rates for each connected subscriber, and provide the same inherent security as with dedicated fibre.

These architectures use wavelength filters instead of splitters in the field to map each wavelength from the feeder fibre onto a dedicated drop fibre. As a result, there is a logical upgrade path from current TDM-PON deployments to WDM-PON at the level of physical infrastructure.

The key challenge for WDM-PON is to provide diverse upstream wavelengths while having a single ONU type. Communications providers consider it unmanageable to have a different ONU per wavelength, and tunable lasers are so far not affordable.

The technologies required for WDM-PON are available today, but they have to undergo some cost reduction in order to be considered suitable for mass deployment.
6 Cost Considerations

Deployment costs must be considered as part of the build decision criteria. For more information of the main influences on FTTH deployment cost, please read the FTTH Business Guide, available from the FTTH Council Europe website.

6.1 Capital costs

FTTH deployment involves a number of different cost components that can be individually optimized. However, it is important to understand the relative contribution of each component, and thus the relative saving potential. The following graph shows a typical cost distribution for Greenfield FTTH deployments.

![Figure 15: Typical initial CAPEX distribution for Greenfield FTTH deployments.](image)

The graph confirms what could be expected intuitively: civil works comprise over almost half the total initial costs. Obviously, this is the cost component where saving efforts have the largest effect. Therefore, every alternative solution should be considered in order to reduce the start-up costs, including sewers, tunnels, etc.

Active network elements are the second largest component at 26% contribution. Independent of the particular technology employed, this is a component where technological progress will continue to drive costs down on a per-port basis.

6.2 Operation costs

Operation costs are a multi-faceted subject. Although many of these cost items – marketing, subscriber acquisition, and subscriber management to name but a few – are not specific to any particular access technology, the correct installation and, in particular the reliability, of the passive infrastructure will greatly affect the ongoing costs. Therefore network design, simplicity, ease of trouble-shooting and speed to repair are of critical importance.
7 Infrastructure Sharing

Owing to the high costs of FTTH deployment, access to fibre and infrastructure sharing has been a hot topic amongst network builders and owners.

There are various “layered” FTTH business models operating in the market today, which has opened up the market to organisations other than traditional telecom players. New entrants are emerging – utility companies, municipalities, real estate companies, governments – all of them are stepping in and seeking the best approach to bring fibre connectivity to homes.

Please read the *FTTH Business Guide*, available from the FTTH Council Europe website, for more information about the different FTTH operator models.

Four business models can be identified in the market today:

1. **Vertically integrated** – one major player covering passive, active and service layers, who offers services directly to their customers, conveys traffic on their networking equipment and uses their own passive infrastructure (exclusively or with wholesale to other communications providers).
2. **Passive sharing** – in this model, the infrastructure owner deploys the passive infrastructure and provides passive access to other players, who concentrate on the active and service layers.
3. **Active sharing** – the vertical infrastructure provider deploys both active and passive infrastructure, and opens it up to service providers, with each service provider taking care of its base of subscribers.
4. **Fully separated** – in some countries the fully separated model has emerged, featuring an infrastructure owner, a network operator and a series of service providers.

For each of these models, infrastructure must be shared.

Access to fibre can be granted at various points in the network:

- at the central office or POP
- at the basement of a multi-tenant building
- at some place between the building and the central office – typically a street cabinet or an underground enclosure

In all these cases, access to the customer can be provided by dedicated fibres in a point-to-point scenario. In the latter two cases passive optical splitters can be used to share a common fibre towards the optical central office using PON technology.
There are four methods of infrastructure sharing, ranging from passive to active components of the network:

1. **Duct** - multiple retail or wholesale service providers may share the use of a duct network covering a substantial region by drawing or blowing their fibre cables through the shared ducts, and compete to offer their services.

2. **Fibre** - multiple retail or wholesale service providers may use the FTTH network by connecting at the physical layer ("dark" fibre) interface, and compete to offer their services.

3. **Wavelength** - multiple retail or wholesale service providers may use the FTTH network by connecting at a wavelength layer interface, and compete to offer their services.

4. **Packet** - multiple retail service providers may use the FTTH network by connecting at a packet layer interface, and compete to offer their services to end users.
# 8 Infrastructure Network Elements

Expanding outwards from the access node towards the subscriber, the key FTTH infrastructure elements are:

<table>
<thead>
<tr>
<th>Infrastructure Elements</th>
<th>Typical physical form</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access node or POP (point of presence)</td>
<td>Building communications room or separate building.</td>
</tr>
<tr>
<td>Feeder cable</td>
<td>Large size optical cables and supporting infrastructure e.g. ducting or poles</td>
</tr>
<tr>
<td>Primary fibre concentration point (FCP)</td>
<td>Easy access underground or pole-mounted cable closure or external fibre cabinet (passive, no active equipment) with large fibre distribution capacity.</td>
</tr>
<tr>
<td>Distribution cabling</td>
<td>Medium size optical cables and supporting infrastructure, e.g. ducting or poles.</td>
</tr>
<tr>
<td>Secondary fibre concentration point (FCP)</td>
<td>Small easy access underground or pole cable joint closure or external pedestal cabinet (passive, no active equipment) with medium/low fibre capacity and large drop cable capacity.</td>
</tr>
<tr>
<td>Drop cabling</td>
<td>Low fibre-count cables or blown fibre units/ ducting or tubing to connect subscriber premises.</td>
</tr>
<tr>
<td>Internal cabling</td>
<td>Includes external building fibre entry devices, internal fibre cabling and final termination unit, which may be part of the ONU.</td>
</tr>
</tbody>
</table>

![Figure 16: Main elements in a FTTH network infrastructure.](image-url)
8.1 Access node

The access node, often referred to as the point of presence (POP), acts as the starting point for the optical fibre path to the subscribing customer. The function of the access node is to house all active transmission equipment; manage all fibre terminations and facilitate the interconnection between the optical fibres and the active equipment. The physical size of the access node is determined by the size and capacity of the FTTH area in terms of subscribers and future upgrades.

<table>
<thead>
<tr>
<th>Homes connected</th>
<th>Type of access structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-400</td>
<td>in-house, street</td>
</tr>
<tr>
<td>400-2000</td>
<td>in-house, concrete</td>
</tr>
<tr>
<td>2000 or more</td>
<td>building</td>
</tr>
</tbody>
</table>

Figure 17: Size indication for P2P access node.

The access node may form part of an existing or new building structure. The main network cables entering the node will terminate and run to the active equipment. The feeder cables will also connect to the active equipment and run out of the building and onto the FTTH network area. All other physical items are used to manage the optical fibres within the node.

Separate cabinets and termination shelves may be considered for equipment and individual fibre management to simplify fibre circuit maintenance as well as avoid accidental interference to sensitive fibre circuits.

The access node should be classed as a secure area. Therefore, provision for fire and intrusion alarm, managed entry/access and mechanical protection against vandal attack must be considered.

8.2 Feeder cabling

The feeder cabling runs from the access node to the first or primary fibre concentration point (FCP). The feeder cabling may cover a distance up to several kilometres before termination. The number of fibres in the cable will depend on the build type.

For point-to-point deployments, high fibre-count cables containing hundreds of fibres are necessary to provide the necessary fibre capacity to serve the FTTH area.

For PON deployments, the use of passive optical splitters positioned further into the external network may enable smaller fibre counts cables to be used in the feeder portion of the network.
It is advisable to select a passive infrastructure that is capable of handling different network architectures should the need arise in future, and to factor modularity into the fibre count in the feeder cables.

For underground networks, suitably sized ducts will be required to match the cable design, and additional ducts should be considered for network growth and maintenance. If smaller ducts or sub-ducts are used then the feeder capacity is provided by using several smaller cables, for example, 48-72 fibres (Ø 6.0 mm) or up to 216 fibres (Ø 8.4 mm) cables.

For aerial cable deployment, pole structures with sufficient cabling capacity will be required. Existing infrastructures may be available to help balance costs.

8.3 Primary fibre concentration point

The feeder cabling will eventually need to convert to smaller distribution cables. This is achieved at the first point of flexibility within the FTTH network, which is generally termed the primary fibre concentration point (FCP). Here the feeder cable fibres are separated and spliced into smaller groups for further routing via the outgoing distribution cables.

Note: all fibre termination points within the FTTH network should be treated as points of flexibility in terms of providing fibre routing options. The term FCP is used throughout the Handbook as a generic name for all of these points, and classified as “primary” or “secondary” depending on its position within the network.

Ideally, the primary FCP should be positioned as close to subscribers as possible, shortening subsequent distribution cable lengths and hence minimising further construction costs. In principle, the location of the primary FCP may be determined by other factors such as the position of ducts and access points.

The FCP unit may take the form of an underground or pole-mounted cable joint closure designed to handle a relatively high number of fibres and connecting splices. Alternatively, a street cabinet structure may be used. In either case, entry and further re-entry into a FCP will be required to configure or reconfigure fibres or to carry out maintenance and fibre testing. Where possible this activity should be achieved without
disturbing existing fibre circuits. Although it is not possible to guarantee this, newer preconnectorised plug-and-play solutions are now available that eliminate the need to access closures, which helps to reduce faults and build errors.

Underground and pole-mounted cable joint closures are relatively secure and out of sight, but immediate access may be hindered because special equipment is required for access. Security and protection from vandal attack should be considered for street cabinet based FCPs.

8.4 Distribution cabling

Distribution cabling connects the FCP to the subscriber connection over distances usually less than 1km. Cables will have medium-sized fibre counts targeted to serve a specific number of buildings within the FTTH area.

Cables may be ducted, direct buried or grouped within a common microduct bundle. Microduct bundles allow other cables to be added on a ‘grow as you go’ basis.

For larger MDUs, the distribution cabling may form the last drop to the building and convert to internal cabling to complete the fibre link.

For aerial networks the arrangement will be similar to that of feeder cables.

Distribution cables are smaller in size than the feeder cables. Total fibre counts will generally be between 48 and 216.

Loose tube cables can be installed by blowing or pulling into conventional ducts and subducts, direct burial and by suspension from poles.

Ducting can vary from standard 40mm internal diameter HDPE to microducts.

Cables installed in microducts may be blown to distances in excess of 1km. Microducts offer a means of deferred cable deployment.

8.5 Secondary fibre concentration point

In certain cases, the fibres may need to be separated at a second FCP within the network before final connection to the subscriber. Like the primary FCP, this second point also
needs to be a point of flexibility, allowing fast connection and reconfiguration of the fibre circuits. This is termed the secondary FCP.

At the secondary FCP, distribution cables are spliced to the individual fibres or fibre pairs (circuits) of the drop cables. The secondary FCP is positioned at an optimum or strategic point within the network, enabling the drop cabling to be split out as close as possible to the majority of subscribers. The location of the secondary FCP will be determined by factors such as position of ducts, tubing and access points and, in the case of PON, the location for splitters.

The secondary FCP is typically an underground or pole-mounted cable joint closure designed to handle a relatively small number of fibres and splices. Alternatively, a small street pedestal structure may be used. In either case, entry and further re-entry into the secondary FCP will be required to configure or reconfigure fibres and to carry out maintenance and fibre testing.

In the case of air-blown fibre, the secondary FCP may take the form of a tubing breakout device designed to allow microduct cable or fibre units to be blown directly to the subscriber premises. This reduces the number of splicing operations.

While pole-mounted secondary FCP cable joint closures are relatively secure and out of sight, access may be hindered and special equipment is required for access.

Underground secondary FCP joint closures are also relatively secure and out of sight, and will require a small “handhole” for access. Secondary FCPs based on street cabinets may require security and protection from vandal attack; however, immediate access to fibre circuits should be relatively simple.

8.6 Drop cabling

The drop cabling forms the final external link to the subscriber and runs from the last FCP to the subscriber building with a distance restricted to less than 500m, and often much less in high-density areas. The drop cables can contain up to four fibres for the customer connection, and possibly additional fibres for backup or for other reasons. The drop cable normally provides the only link to the subscriber, with no network diversity.

For underground networks the drop cabling may be deployed within small ducts, within microducts or by direct burial to achieve a single dig and install solution. Overhead drop cables will feed from a nearby pole and terminate on part of the building for routing to the subscriber fibre termination unit. In either case, the cable assembly may be pre-terminated or pre-connectorised for rapid deployment and connection, and to minimize disruption during installation.

Air blown cables and fibre units can enter through the fabric of the building using suitable microduct products and route internally within the building. This will form part
of the internal cabling network with the building entry device acting as the transition point for the microduct (external to internal material grade).

Drop cables come in four main types: direct install, direct buried, facade and aerial.

### 8.7 Direct install cables

Direct install cables are installed into ducts, usually pulled, pushed or blown.

The structure can be non-metallic with external/internal sheath, or a double sheath: one internal LSZH and one external PE.

Cables are available from 1 to 36 fibres (typically 12 fibres).

The fibre elements can be loose tubes, micro sheath, or blown fibre unit.

### 8.8 Direct buried cables

Cables are available in two constructions; non-metal, or with metal protection (corrugated steel).

The advantages of metal-protected cables are their very high crush resistance and high-tension loading.

New non-metal strain-relief and protective sheets have been developed to give non-metal direct buried cables similar performance to metal protected cables. On average, non-metal cables are lower in cost.

Direct buried drop cables are available in fibre counts from 1 to 12 (typically 2-4).

### 8.9 Aerial cables

Cables are available as follows:

- continuation of feeder or distribution networks, e.g. optical ground wire (OPGW) or all-dielectric self-supporting (ADSS)
- short-span drop cables, e.g. Figure 8, flat or circular

Aerial cables are designed to a specific tensile load, which is determined by span length and environmental conditions.
The Figure 8 cable consists of a central tube fixed to a steel wire. Typical fibre counts are 2-48 and cable tensile loading will be ~6000N.

OPGW cables are mainly used in power line connections.

All the above cables can be pre-connectorised which gives an advantage on installation – less installation time in the home and better planning.

The fibre elements can be loose tubes, micro sheath or blown fibre units.

8.10 Facade cables

Facade installation is a suitable installation method for buildings that are connected, such as large blocks of flats or terraced properties. It is useful in Brownfield deployments where the building structure prevents the running of cables. The cables are stapled along the outside of the building with closures, branches or ruggedized connection points providing the drop to customers. There may, however, be appearance issues with owners and authorities, particularly in conservation areas.

Facade cables have a similar structure to direct install cables and also require UV resistance. Because facade drop cables usually feed small buildings, the fibre count is usually low, between 1 to 12 fibres (typically just 1-2 or 4 fibres). The fibre elements can be loose tubes, micro sheath, or blown fibre units.

8.11 Internal cabling

For residential properties, the drop cable can be terminated on the outside structure of the house, or pass through the wall and terminate inside the house.

If termination unit is inside of the building, this will require the fibres to be routed through the building wall fabric via a suitable cable lead-in, and subsequently routed within the building to the ONU. If the ONU is sited externally within a box, the drop cable is simply terminated in a similar manner to a utility feed.

In both case there will be little or no internal optical cabling required, unless the house owner or subscribed decides to add it.

The topic of MDU internal cabling has attracted considerable attention because a large number of FTTH network have been MDU builds. Many suppliers have special riser (vertical) and drop (horizontal) cable solutions. Where installation is challenging, new bend-insensitive fibres can be used, even by non-specialist tradespeople.

For larger MDUs, the internal cabling forms a major part of the infrastructure. Cables may be installed in existing service ducts, or surface mounted. To reduce costs and protect the décor, existing infrastructure should be used when possible.
The following diagram identifies ways in which an MDU can be cabled:

The schematic drawing on the right provides a review of some options for internal cabling of a building.

The drop cables or microducts are run up riser shafts to each floor or branched to a riser cable from an entry basement room where is located a building demarcation box.

Cables or ducts are routed horizontally to each apartment or room using breakout devices or riser boxes as necessary.

Note: internal cables or microducts are graded for internal deployment, i.e. low smoke/zero halogen (LSZH).

The cables or microducts are anchored at regular intervals in the
horizontal and the vertical position.

8.11.1 Building entry point

Most MDUs are fed from the basement with an outside network cable entering the building and terminating at the building entry point. The outside network cable can come from a closure, a street cabinet or from an adjacent building. Once the cable has entered the building either the same cable will feed the apartments in the building (rare unless there are only a few apartments), or a demarcation box installed in the basement acts a flexibility point between the external network and the in-building network.

8.11.2 Flexibility point

A flexibility point provides the ability to incorporate PON splitters and patching for point-to-point networks, and to share the internal cabling when more than one operator has cables feeding the building. This provides local flexibility and reduces the cost of the most expensive part of an MDU build – the internal cabling.

Most of the boxes used for multi-operator activity are modular. Additional boxes can be added depending on the number of operators in the building.

These points can be configured for fibre management with a splice and patch solution, with mechanical optical connectors or only with splices.

8.11.3 Vertical riser

For the vertical cabling section, often also called riser, it is preferable to install cables inside existing structures such as a riser shaft or duct. It is usual to limit MDU builds to a single installation of vertical cabling, and this is not repeated by each operator.

Depending on the number of apartments in the building, the riser cables can have various structures: mono fibre, bundles of mono fibre, or bundles of multiple fibres.

Riser cables can be installed from the basement or the top floor of the building. For high buildings several riser cables may have to be installed to feed all the premises, e.g. one cable for the first 10 floors, then a second cable for the next 10 floors.

Riser cables can be pre-connectorised to save time during installation.
In addition to pre-connectorised solutions, risers are available with extractable fibre elements. This technology allows the installer to extract some fibre elements from the cable sheath to prepare, at the floor level, the horizontal drop to the premises.

Using the latest solutions available on the market enables the use of less skilled labour to deploy the networks, helping to reduce labour costs.

### 8.11.4 Horizontal drop

The horizontal drop is the portion of the network linking the riser cable to the premises with the required number of fibres. The riser and horizontal drop may be one cable. In other designs the riser cable joins to a separate horizontal cable at each floor.

A tube or a cable can be used for the horizontal drop. The cables can be spliced at the riser and floor levels, or can be pre-connectorised at one or both ends of the drop.

Typical issues found with cabling are that there is no existing duct or space available. Since these cables are installed in difficult conditions the use of the new bend-insensitive fibres should be considered – refer to fibre section for details.

Above are some examples of riser to horizontal solutions; there is also the option of a direct cable or blown fibre from basement direct to each apartment.

### 8.11.5 Optical network unit

Inside the customer premises, the optical fibre(s) are usually terminated with a connector inside a customer interface box and then a patch cord used to link to the ONU. These boxes can be integrated, or separate.
9 Deployment Techniques

This section provides a description of available infrastructure deployment techniques. More than one technique may be used in the same network, depending on the specific circumstances of the network build.

9.1 Conventional duct infrastructure

This is the most conventional method of underground cable installation and involves creating a duct network to enable subsequent installation of cables by pulling, blowing or floatation techniques. This may comprise a large main duct that contains smaller sub-ducts (for individual cable installation), a large main duct into which cables are progressively pulled, one over the other as the network grows, or a small sub-duct for the installation of a single cable. Duct installation enables further access and reconfiguration.

As with any civil works, consideration needs to be given to other buried services. Efficiency of cable installation in ducts relies heavily on the quality of the duct placement; this applies to all installation methods.

9.1.1 Product map

Figure 36: Deploying duct infrastructure.

Figure 37: Product map for conventional duct infrastructure.
9.1.2 Duct network

The use of a single duct maximizes the number of cables that can be installed, but it can be difficult to extract older cables from full ducts to create room for new cables – they typically end up at the bottom of the duct. Using subduct may reduce the total number of cables that can be installed, but at least older cables can be removed. This method also allows the use of cable blowing as well as cable pulling, since it is easier to create an airtight connection to the subduct.

![Figure 38: 110mm mains duct.](image1)

![Figure 39: 110mm mains duct with four subducts.](image2)

Typical duct sizes are 110mm, 100mm or 90mm for main duct and 50/43mm, 40/33mm, 33/26mm or 25/20mm for sub-duct (outer diameter/inner diameter). Smaller microducts may also be deployed (see below).

Cables can be installed into the ducts by pulling, blowing or floating. If they are to be pulled, then the duct either needs to contain a pre-installed draw rope or must have one installed by rodding and roping. If cables are to be blown in or floated, then the duct and any connections between sections of duct need to be airtight.

The inner wall of the duct or subduct is manufactured to ensure low friction with the cable sheath. This is typically achieved with a low friction coating. Alternatively, the duct or subduct may have a low-friction extruded profile or special duct lubricants are used.

A number of factors govern the continuous length that can be pulled or blown, including coefficient of friction, bends in the duct route (vertical as well as horizontal), the strength and weight of the cables, and the installation equipment used. Fill ratios should be calculated as part of the planning process. The cable diameter should not be too large compared to the inner diameter of the duct. For existing networks the condition of the ducts should be checked for any potential damage and suitable space and capacity for future cabling.

9.1.3 Type of ducts

Main ducts – underground systems

The feeder ducts run from the access node to the FCP. The number of ducts required will be dictated by the size of feeder cables used. Extra space may be allowed, so that
more than one cable can be installed in a single duct to save vital duct capacity (e.g. using blowing or pulling techniques). Ducts sizes will range from 25mm to 50mm outer diameter. Larger ducts of 110mm may be used and these may contain smaller sub-ducts between 20mm and 40mm outer diameter. The duct material is normally HDPE.

9.1.4 Types of duct cables

There are a wide variety of cables for use in a duct network. If pulled in using a winch, then they may need to be stronger than blown versions, because the tensile force applied may be much higher. Blown cables need to be suitably lightweight with a degree of rigidity to aid the blowing process. The presence of the duct affords a high degree of crush protection, except where the cable emerges into the footway box. Duct cables are normally jacketed and non-metallic – to remove the need for earthing, for lightning protection and for environmental reasons. However, they may contain metallic elements for higher strength (steel central strength members), for remote surface detection (copper elements) or for added moisture protection (longitudinal aluminium tape). Duct environments tend to be benign, but the cables are designed to withstand potential long-term flooding and occasional freezing.

![Diagram of duct cable types](image)

**Figure 40:** Duct cable selection.

There are a wide variety of cable designs, but these are based on a small number of elements. The first and most common building block is a loose tube, comprising a plastic tube containing the required number of fibres (typically 12) together with a tube filling compound that both buffers the fibres and helps them to move within the tube as the cable expands and contracts at environmental and mechanical extremes. Other building blocks include multiple fibres in a ribbon form or in a thin easy-strip tube coating. Fibres may also be laid in narrow slots grooved out of a central cable element.
Tubes containing individual fibres or multiple ribbons are laid around a central cable element that comprises a strength member with plastic jacketing. Water blocking materials such as water-swellable tapes or grease can be included to prevent moisture permeating radially or longitudinally through the cable, which is over-sheathed with polyethylene (or alternative materials) to protect it from the external environment. Fibres, ribbons or bundles (protected by a coloured micro-sheath or identified by a coloured binder) may also be housed within a large central tube. This is then over-sheathed with strength elements included.

9.1.5 Cable installation by pulling

The information below is an outline of the required installation and equipment considerations. Reference should also be made to IEC specification 60794-1-1 Annex C, Guide to the installation of optical fibre cables.

When cables are pulled into a duct, there needs to be either a pre-existing draw-rope or one must be installed prior to cable winching. The cable should be fitted with a swivel, which allows the cable to freely twist as it is installed, and a fuse rated at or below the cable’s tensile strength. Long cable section lengths can be installed if the cable is rated to take the additional tensile pulling load, or by “fleeting” the cable at suitable section mid-points to allow a secondary pull operation, or by using intermediate assist pullers (capstans or cable pushers). Fleeting involves laying loops of fibre on the surface during a pull using figure of 8 loops to prevent twisting in the cable.

When installing cables, due account should be taken of their given mechanical and environmental performances as indicated on the supplier’s datasheets, which should not be exceeded. The tensile load represents the maximum tension that should be applied to a cable during the installation process and ensures that any strain imparted to the fibres is within a safe working limit. The use of a swivel and mechanical fuse will protect the cable if the pulling force is exceeded. Cable lubricants can be used to reduce the friction between the cable and the sub-duct, hence reducing the tensile load. The minimum bend diameter represents the smallest coil for cable storage within a cable chamber. Suitable pulleys and guidance devices should be used to ensure that the minimum dynamic bend radius is maintained during installation. If the cable outer diameter exceeds 75% of the duct inner diameter the pulling length may be reduced.

Figure 41: Pulling cable swivel.  Figure 42: Cable guide pulley.
9.1.6 Cable installation by air blowing

Traditionally, cables were pulled into ducts. More recently, particularly with the growth of lightweight non-metallic designs, a considerable proportion of cables are now installed by blowing. This can be quicker than pulling, and may allow longer continuous lengths to be installed, thus reducing the amount of cable jointing. If spare ducts are installed, then subsequent cables can be installed as the need arises (“just in time”).

When cables are blown into a duct, it is important that the duct network is airtight along its length. This should be the case for new-build, but may need to be checked for existing ducts, particularly if they belong to a legacy network.

A balance must be struck between the inner diameter of the duct and the outer diameter of the cable. If the cable’s outer diameter exceeds 75% of the duct’s inner diameter, air pressures higher than those provided by conventional compressors are required or the blow length may be reduced. Nevertheless, good results have also been obtained for between 40 – 85% fill ratios. If the cable is too small then this can lead to installation difficulties, particularly if the cable is too flexible. In such cases, a semi-open shuttle attached to the cable end can resolve this difficulty.

A cable blowing head is required to both blow and push the cable into the duct. The pushing overcomes the friction between the cable and duct in the first few hundred metres, and hauls the cable from the drum. A suitable air compressor is connected to the blowing head. The ducts and connections must be sufficiently air tight to ensure an appropriate flow of air through the duct. Hydraulic pressure at the blowing head must be strictly controlled to ensure no damage to the cable.

9.1.7 Cable installation by floating

Considering that most outside plant underground cables are exposed to water over a major part of their life, floating is an alternative method to blowing. Floating can be done with machinery originally designed for blowing: air is simply replaced by water. Compared to blowing, floating makes it possible to place considerably longer cables in ducts without an intermediate access point.

Floating can prove very efficient for over-laying cable in many situations. The performance of the process decreases when placing cables with an outer diameter exceeding 75% of the duct inner diameter. Nevertheless good results have also been obtained for higher fill factors; for example, a 38mm cable was floated over 1.9km in a duct with inner diameter of 41 mm (fill factor 93%).

Floating is also a safe method for removing cables from the duct, thus making possible the re-use of such cable. Blowing out cable is, by comparison, a hazardous operation.
9.1.8  Cable de-coring

New techniques have been developed to successfully de-core cables. With this method, the core of copper cables can be replaced cost-effectively and speedily with fibre-optics.

Instead of digging up the entire cable length, the cable is now only accessed at two points 50 to 400 metres apart. A special fluid is pumped under pressure into the space between cable sheath and cable core wrapping, detaching the core from the sheath.

Next, the old cable core is extracted mechanically and treated for clean, environmentally friendly disposal or recycling. Simultaneously, an empty, accurately fitted sheathing for the new fibre-optic cable is drawn into the old cable sheath.

Afterwards these so-called “microducts” are connected, the pits are closed and, finally, the empty cable sheath is refilled with fibre optics.

Apart from the positive environmental aspects – old cables can be recycled homogenously, and the fluid is biodegradable – this technique can be 40 to 90% cheaper than installing a new cable, especially due to the much faster completion time and the reduction in planning and building costs.

9.1.9  Access and jointing chambers

Suitable sized access chambers should be positioned at regular intervals along the duct route. These can be located to provide the best position for connection to the customer drop cables. The duct chambers must be large enough to enable all duct cable installation operations, storage of slack cable loops for jointing and maintenance, cable hangers and bearers, and the storage of the cable splice closure. The chambers may be constructed on site or be provided as pre-fabricated units to minimise construction costs and site disruption. On site constructed modular chamber units are also available. Where existing legacy access chambers are insufficient due to size or over population of cables/closures then an ‘off-track or spur’ chamber should be considered.

9.1.10  Cable joint closures

Cable joint closures may act as a track or straight-through joint, to join sequential cable and fibre lengths together, or provide a function for distribution of smaller drop cables. Closures will usually be sited in the manhole or underground chambers. Occasionally the cable joint may take place within an off-track chamber or above ground cabinet.
Closures may be placed as regularly as every 500m in medium-density areas and as frequently as every 250m in high-density areas. Certain networks may require the use of mid-span joints, which enable fibres to be continued through the joint un-spliced; only the required fibres are intercepted for splicing.

The closure must be resistant to long term flooding and any future need to re-open for adding or changing customer fibre circuits.

### 9.2 Blown microducts and microcable

This option utilises compressed air to blow fibre unit and small diameter cables quickly through a network of tubes to the customer/ premises. Fibre deployment can be deferred until the customer requirement has been confirmed, hence deferring costs compared to speculative up-front build programmes. Also, the number of splices can be minimised by blowing long lengths of fibre through the network of tubes (which themselves are easily joined via push-fit connectors).

This option may be used in combination with duct, direct buried and aerial infrastructure and the tubes may be housed in constructions designed for any of these three methods.

#### 9.2.1 Product Map

Figure 44: Product map for blown microducts and microcable.

#### 9.2.2 Microduct solutions

Microduct cabling uses small, flexible, lightweight tubes. These could be a small conventional duct typically less than 16mm in diameter (e.g. 10 mm outer diameter, 8 mm inner diameter) that is pre-installed or blown into a larger subduct. They can be used to further segment a subduct (for example using five 10mm microducts). The microducts may be blown directly into the subducts.
They could also be small tubes (e.g. 5mm outer diameter, 3.5 mm inner diameter) manufactured as a single or multi-tube cable assembly, known as a “protected microduct”. Protected microduct assemblies (typically containing from one to twenty-four microducts) may be constructed in a similar fashion to the aerial, direct buried or duct cables described previously, and would be installed in a similar fashion.

**Figure 45:** Sub-divided subduct.  
**Figure 46:** Post-installed microduct.  
**Figure 47:** Protected microduct.

**Thick-walled microducts** do not need to be placed or blown inside another duct or tube. Bundles of thick-walled microducts offer the most user-friendly connector solution. From a technical perspective, this is the best solution for near-surface needs where temperatures may vary significantly. These products can be direct buried over long distances in bundles of 2, 4, 6, 7, 12, or 24, or they can be buried individually over shorter distances. In addition, microducts offer the easiest solution for branching – just cut the thin outer coating and snap on a connector.

**Figure 48:** Thick walled microduct bundle  
**Figure 49:** Branching of thick walled microduct.

**Tight-bundled microducts** offer a larger number of microducts pre-installed in a standard duct. They consist of a standard HDPE duct pre-sheathed around a bundle of microducts. Both the main duct and the microducts come in a variety of sizes to accommodate different types of fibre cables. Tight-bundled microducts are sheathed in a manner that they do not have space to buckle, which makes them less susceptible to temperature changes.

**Loose bundled microducts** are notable for their high crush resistance and record-breaking distances over which fibre can be blown. Loose bundled microducts can be implemented in two ways:
- Pre-installed in various size HDPE ducts and so ready to be laid in trenches and branched where necessary.
- Blown in after the HDPE ducts have been buried, for the ultimate in network expansion flexibility.

### 9.2.3 Microduct tube connectors and closures

Sections of microduct can be joined with specialist connectors, which are available in water and gas-sealed versions.

Thick-walled microduct connectors have a simple design that allows the installer to snap together the ends of two microducts – there is no need for a closure, Y-branch, or tube management box. Gas-tight connectors or terminations must be used at network access points to protect the integrity and safety of the design.

Tight-bundled microducts need a watertight closure for branching. Watertight Y-branch and wraparound connector products make it possible to access and branch microducts at any point in a network. Tube management boxes can also be used when several microducts branch in different directions. Straight connectors, reducers, and branching components for connecting and branching the ducting layout are widely used. Gas-tight connectors or terminations must be used at network access points to ensure the integrity and safety of the design.

![Branching components](image1.png)

**Figure 50:** Branching components.

![Push-fittings](image2.png)

**Figure 51:** Push-fittings (left to right): gasblock tube connectors, straight tube connectors, and end-tube connectors.
9.2.4 Microduct cable and fibre units

Microducts tubes house microduct cables (e.g. 96 fibre 6.4mm diameter for use in a 10mm/8mm microduct) or very small blown-fibre unit cables 1 to 3mm in diameter containing up to 12 fibres (e.g. 4 fibres in a 1mm cable for use in 5mm/3.5mm tubes). The cables used in these tubes are small lightweight designs that require the tube for protection. In other words, the tube and cable act together as a system. The cables are installed by blowing, and may have special outer coatings to assist with blowing.

The microduct size must be chosen to suit the cable and required fibre count. Typical combinations of cable size and duct size are given in the table. Other sizes and combinations can be used.

<table>
<thead>
<tr>
<th>Microduct outer diameter (mm)</th>
<th>Microduct inner diameter (mm)</th>
<th>Typical fibre counts</th>
<th>Typical cable diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>12</td>
<td>24-216</td>
<td>9.2</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>96-216</td>
<td>6.5-8.4</td>
</tr>
<tr>
<td>10</td>
<td>8</td>
<td>72-96</td>
<td>6-6.5</td>
</tr>
<tr>
<td>7</td>
<td>5.5</td>
<td>48-72</td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>3.5</td>
<td>6-24</td>
<td>1.8-2</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>22-12</td>
<td>1-1.6</td>
</tr>
</tbody>
</table>

Figure 52 Microduct cables. Figure 53: Microduct cable with 4 fibres.

Figure 54: Examples of Fibre units.
Figure 55: Protected cable microduct with tight integral outer duct (not to scale).

Figure 56: Microduct optical fibre cables (not to scale).

Figure 57: Protected microducts with loose package.
The distance achieved by blowing will depend on the microduct, cable and installation equipment used plus route difficulty, particularly turns in the route and vertical deviations. As the fibre reaches its final drop to the home, it may be possible to use even smaller tubes (e.g. 4mm/3mm or 3mm/2.1mm), since the blowing distance will be quite short.

9.2.5 Microcable/blown fibre unit installation

The installation method will be very similar to the equipment for full-size cables, but with smaller blowing equipment and using smaller, lighter and more flexible cabling payoff devices – reels instead of drums and cages and pans. Under certain conditions, microcables can be floated using smaller floating equipment.

9.2.6 Access and jointing chambers

The same principles apply as for microduct cable normal cable. Additionally, it is possible to branch microduct tubes at hand-hole locations using a suitable swept branch closure, rather than requiring a full-size chamber.

9.2.7 Microcable joint closures

Microcable joint closures have the same basic features as duct joint closures. There are different types, depending on whether the joint is being used to join or branch fibres, or whether it is the tubes themselves that are to be branched or jointed. These closures allow considerable flexibility with the routing of the ducts whilst minimising the number of installation steps, because the cables or fibres may be blown through the whole route once the tubes are connected, and may be facilitated using simple joints rather than full-scale joint closures.

External tubing can be joined directly to suitable indoor tubing, hence avoiding the need for a joint splice at the building entry point. Additional safety features may be required, particularly with respect to pressure relief. If a fully jointed airtight closure is required, then dangers may occur when fibre is blown through a joint if there happens to be an air-leak within the tubes housed in the joint. To prevent pressure build-up in the joint that could cause it to blow apart, the fitting of a reliable safety valve or other pressure relief mechanism is strongly recommended.

9.3 Direct buried cable

Direct burial offers a safe, protected and hidden environment for cables, but requires careful survey to avoid damaging other buried services. A narrow trench must be excavated in order to effectively bury and protect the cable. Excavation techniques include mole ploughing, open trenching, slotting and directional boring. A combination of these options can be used in a deployment area.
9.3.1 Product map

Figure 58: Product map for direct buried cable.

9.3.2 Installation options

A number of excavation techniques are possible including open trenching, mole ploughing, slotting and directional boring – more than one method may be used.

9.3.3 Types of direct buried cable

Direct buried cables are designed in a similar fashion to duct cables, employing similar elements, such as filled loose tubes. The cables may have additional armouring to protect them, although this depends on the burial technique. Pre-trenching and surrounding the buried cable with a layer of sand can permit the use of quite lightweight designs, whereas direct mole-ploughing or backfilling with stone-filled soil may require a more robust design. Crush protection is a major feature and could consist of a corrugated steel tape or the application of a thick sheath of suitably hard polyethylene.

Figure 59: cable with corrugated steel protection.  
Figure 60: non-metal direct buried cable.

9.3.4 Lightning protection

Non-metallic designs may be favoured in areas of high lightning activity, but have less crush protection than a cable with a corrugated steel tape. The steel tape can survive being struck by lightning, particularly if the cable contains no other metallic components, since it can absorb a direct strike, and offers excellent crush protection.
9.3.5 Rodent protection

Corrugated steel tape has proven to be one of the best protections against rodent damage or other burrowing animals. If the cable needs to be non-metallic, then a complete covering of glass yarns may deter rodents to some degree.

9.3.6 Termite protection

Nylon sheaths, though expensive, offer excellent protection against termites. Nylon resists bite damage, and is chemically resistant to the substances excreted by termites.

9.3.7 Access and jointing chambers

Depending on the actual application, buried joints are typically used in lieu of the access and jointing chambers used in duct installation.

9.3.8 Direct buried cable joint closures

Basic joint closures for direct buried cable are similar to those used for duct cables, but may require additional mechanical protection. The closure may also need to facilitate the distribution of smaller drop cables.

9.4 Aerial cable

Aerial cables are supported on poles or other tower infrastructure, and represent one of the more cost-effective methods of deploying drop cables in the final link to customer. The main benefits are the use of existing pole infrastructure to link customers, avoiding the need to dig roads to bury cables or new ducts. Aerial cables are relatively quick and easy to install, using hardware and practices already familiar to local installers.

9.4.1 Product map

Figure 61: Product map for aerial cable.
9.4.2 Condition of the pole infrastructure

The poles to which the optical cable is going to be attached may already exist and have other cables already attached to them. Indeed, the pre-existence of the pole route could be a key reason for the choice of this type of infrastructure. Adding cables will add to the loading on the poles, so it is important to check the condition of the poles and their total load capacity. In some countries, such as the UK, the cable design for aerial cables has to be designed to break if it comes into contact with high vehicles to prevent damage to poles.

9.4.3 Types of aerial cable

Types of aerial cable include circular self-supporting (ADSS or similar), Figure 8, wrapped or lashed.

ADSS is useful where electrical isolation is important, for example, on a pole shared with power or data cables, and when a high degree of mechanical protection is required. The Figure 8 design allows easy separation of the optical package away from the strength member, while in the ADSS cable the strength member bracket is part of the cable. ADSS cable may be favoured by companies used to handling copper cables, since similar hardware and installation techniques can be used.

Lashed or wrapped cable is created by attaching conventional cable to a separate catenary member using specialist equipment; this can simplify the choice of cable.

Aerial cables can have similar cable elements and construction to those of duct and buried optical fibre cables described previously.

Circular designs, whether self-supporting, wrapped or lashed, may include additional peripheral strength members plus a sheath of polyethylene or special anti-tracking material (when used in high electrical fields). Figure 8 designs combine a circular cable with a high modulus catenary strength member.

If the feeder cable is fed by an aerial route then the cable fibre counts will be similar to the underground version.

It should be noted that all of the above considerations are valid for blown fibre systems deployed on poles or other overhead infrastructure.

Extra consideration needs to be taken for the environmental extremes that aerial cables may experience, such as ice and wind loading. Cable sheath material should also be...
suitably stabilised against solar radiation. Installation medium also need to be properly considered (e.g. poles, power lines, short or long spans, loading capabilities).

In addition cables are also available with a “unitube” structure.

9.4.4 Cable pole support hardware

Support hardware can include tension clamps to anchor a span of cable to a pole or to control a change of pole direction, and intermediate suspension clamps to support the cable between the tensioning points. The cable may be anchored with bolts or with preformed helical accessories, which provide a radial and uniform gripping force on the area of application. Both types of solutions should be carefully selected for the particular diameter and construction of the cable. The cable may need protection if it is routed down the pole, for example by covering with a narrow metal plate.

Where there are very long spans or when snow or ice accretion has modified the conductor profile, right angle winds of moderate or high speed may cause aerodynamic lift conditions which can lead to low frequency oscillation of several metres amplitude known as "galloping". Vibration dampers fitted to the line, either close to the supporting structure or incorporated in the bundle spacers are used to reduce the threat of metal fatigue at suspension and tension fittings.

9.4.5 Cable tensioning

Aerial cables are installed by pulling them over pre-attached pulleys, and then securing them with tension and suspension clamps or preformed helical dead-ends and suspension sets to the poles. The installation is usually carried out in reasonably benign weather conditions and the installation loading is often referred to as the everyday stress (EDS). As the weather changes, temperature extremes, ice and wind can all affect
the stress on the cable. The cable needs to be strong enough to withstand the extra loading.

Care also needs to be taken that the installation sag and subsequent additional sagging, due to ice loading for example, does not compromise the cable’s ground clearance (local authority regulations on road clearance need to be taken into account) or lead to interference with other pole-mounted cables with different coefficients of thermal expansion.

9.4.6 Aerial cable joint closures

Closures may be mounted on the pole or tower, or located in a footway box at the base. In addition to duct closure practice, consideration should be given to UV and possible shotgun protection, particular for closures mounted on the pole. The closure may require a function for the distribution of smaller drop cables.

9.4.7 Other deployment considerations

If a power line is being exploited to deploy the fibre, then this may involve OPGW (optical ground wire), earth or phase-wrap cables or ADSS designs. OPGW protects the fibres within a single or double layer of steel armour wires. The grade of armour wire and the cable diameters are normally selected to be compatible with the existing powerline infrastructure. OPGW offers excellent reliability but is normally only an option when the ground wires also need to be installed or refurbished. Wrap cables use specialised wrapping machines to deploy cables around the earth or phase conductors. ADSS cables have the advantage of being independent of the power conductors. ADSS and phase-wrap cables use special anti-tracking sheath materials when used in high electrical fields.

Aerial products may be more accessible to vandalism than ducted or buried products. Cables could, for example, be subject to shotgun damage. This is more likely to be low energy impact, due to the large distance from gun to target. If this is a concern, however, then corrugated steel tape armouring within a Figure 8 construction has been shown to be very effective. For non-metallic designs, thick coverings of aramid yarn, preferably in tape form, can also be effective. OPGW cable probably has the best protection, given that it has steel armour.
9.5 Pre-terminated network builds

Both cables and hardware can be terminated with fibre-optic connectors in the factory. This enables factory testing and hence improved reliability, while reducing the time and the skills needed in the field.

Pre-terminated products are typically used from the primary fibre concentration point in cabinets through to the final customer drop. In this way the network can be built out quickly, passing homes, but when a customer requests service the final drop is made with a simple plug-and-play cable assembly.

There are several pre-connectorised solution methods that allow termination either inside or outside the product closures, some examples are shown below.

Figure 65: First row: fully ruggedized, environmentally sealed connectors. Second row: cable assembly with rugged covers, conventional connector with rugged cover, standard connectors in thin closure. Third row: Rugged closures that take conventional connectors.
Street cabinets can also be provided pre-stubbed and terminated. These cabinets are assembled in the factory and tested prior to delivery. The cabinets have a cable stub that is run back to the next closure and offer a patch panel for simple plug-and-play connectivity. This provides faster installation, and greatly reduces the incidence of installation faults on site.

Compact pedestals and cabinets that are designed to be the last premises distribution/termination point can be placed directly in front of residents’ property or along the street. These cabinets are also used as an easy repair and access point in the fibre optical network.

9.6 Other deployments options using rights of way

In addition to the traditional cabling routes discussed above, it can also be advantageous to exploit other rights of way (RoW) that already exist within towns and cities. Deployment costs and time may be reduced by deploying cables within water and sewer networks (sanitary and stormy), gas pipe systems, canals and waterways, and other transport tunnels.

Cable installations in existing pipe-networks must not impair their original function. Restrictions during repair and maintenance work have to be reduced to a minimum and coordinated with the network operators.

9.6.1 Fibre-optic cables in sewer systems

Sewers may be used for access networks, since they reach almost every corner of the city and pass all potential customers. Utilising sewers avoids the need to gain digging approvals and reduces the cost of installation.

Tunnel sizes in the public sewer range from 200mm in diameter to those that can be entered by boat. The majority of public sewer tunnels are between 200mm and 350mm in diameter – sufficient cross-section for installation of one or more microduct cables.

Various installation schemes are possible, depending on the sewer cross-section. One scheme uses steel bracings to fix corrugated steel tubes (that will carry the cable) to the inner wall of the smaller sewer tube without drilling, milling or cutting. This is done by a special robot based on a module used for sewer repairs.

9.6.2 Fibre-optic cables in gas pipes

Gas pipelines can also be used for deploying optical fibre networks without major disruption and destruction of the streets and sidewalks normally caused by conventional cut and fill techniques. The fibre network is deployed using a specially developed I/O port, which guides the cable into and out of the gas pipe, bypassing the gas valves.
The cable is blown into the gas pipes by means of a stabilized parachute either by using the natural gas flow itself or by using compressed air, depending on the local requirements.

The gas pipeline system provides good protection for the optical fibre cable, being situated well below the street surface and other infrastructure.

9.6.3 Fibre-optic cables in drinking water pipes

Drinking water pipes can be used for the deployment of fibre optical cables in a similar manner as in the case of gas pipes.

9.6.4 Canals and waterways

To cross waterways and canals, hardened fibre optic cables can be deployed without any risk as fibre is insensitive to moisture.

9.6.5 Underground and transport tunnels

Underground tunnels can be used to install fibre-optic cable, often alongside power and other data cabling. Typically, they are installed on hangers fixed to the wall of the tunnel. They may be fixed in a similar manner to cables used in sewers.

Two key issues to consider are fire performance and rodent protection.
Should a fire occur in a transport tunnel, then the need to evacuate personnel is critical. IEC TR62222 gives guidance on “Fire performance of communication cables in buildings”, which may also be applied to transport tunnels if the fire scenarios are similar. This lists potential hazards such as smoke emission, fire propagation, toxic gas and fumes, which can all be detrimental to evacuation.

Figure 68: Cable installation in a train tunnel.

Potential users of underground and transport tunnels should ensure that all local regulations for fire safety are considered prior to installation. This would include fixings, connectivity and any other equipment used.

Cables in tunnels can also be subject to rodent attack which could require the cable to have extra protection, such as a corrugated steel tape.

### 9.7 Internal cabling

#### 9.7.1 Indoor cables

Indoor cables start may extend for short runs within a house or long runs through a building. The cable designs may from single fibre cables, possibly pre-connectorised, through to multi-fibre designs using tight-buffered or loose tube cable. There is also blown fibre and microduct for indoor application.

Whilst the designs may vary, they are all used in customer premises, therefore they should all typically offer some form of fire protection. This would typically include the use of a low smoke zero halogen (LSZH) sheath. The cable would be constructed in such a way as to afford some degree of protection from flame propagation (for example IEC60332-1 and IEC 60332-3-24 category C) and smoke emission (IEC61034). The materials may be characterized for halogen content in line with IEC60754-1 and for conductivity and pH in accordance with IEC60754-2.
Other criteria may apply, depending on the user’s exact requirements, but attention to public safety is paramount. Typical cable performance requirements are given in the IEC60794-2 series of specifications (see Appendix A).

The simplest cable type is the patch cord or pigtail. This comprises a single 250µm diameter, acrylate-coated fibre jacketed with nylon with an outer diameter of 0.8-1mm. The jacket improves the handling properties of the fibre and the robustness of the connector. It may be applied as a tight buffer for optimum robustness, or as a semi-tight layer to enable easy-strip (for example where 1m or more is stripped for ease of tray storage). Strength is given by a layer of aramid yarns. The cable is covered with a low-smoke sheath material.

For distribution of fibres through a building, one popular construction is the ‘multi-tight’ design. This is similar to the cable above, except that it would typically house up to 24 fibres.

Fibres may be housed within loose tubes, either central loose tube (for up to 24 fibres) or multi-loose tube for up to 144 fibres; or bundles inside a central tube for all fibre counts up to 144 fibres. These types of cable are typically used for connection to racks in exchange buildings.

Microduct cables are also constructed with low smoke zero halogen (LSZH) materials for indoor application.

There are a number of tubing distribution and breakout devices available that connect and distribute the in-building tubes.

From small (slim) boxes up to large distribution boxes for high-count tubes, these boxes are available in watertight, open and vandal proof construction.
9.7.2 Building entry point

There are many ways to enter the customer building and this depends on factors such as local rules, aesthetics and how the network changes at the interface.

The above examples show typical solutions for:

- where the internal and external ducts are joined and the cable continues into the building
- where the duct stops a gas block is provided and only the cable continues into the building
- where the cable simply passes through the wall
- where a ruggedized optical connection is made at the interface to an internal cable in this case a plug and play connection point

9.7.3 Customer premises equipment

This is the point where the passive network ends and the active equipment is installed. The fibre is terminated inside the CPE with connectors, usually SC/APC or LC/APC.

The position of the CPE depends on the operator. Some networks have the CPE mounted outside to the premise to aid access and maintenance. Other operators choose to position the equipment inside the premises, to ensure the active equipment is retained close to the equipment it will feed. For MDUs the CPE may be positioned in a basement or at a floor level.

In this example of an external fibre termination unit, the fibre network terminates in a wall unit that also contains the CPE equipment. From this position the feed will be with a copper cable.

One downside with an external CPE is the need to get power to the unit; also it is exposed to potential vandalism.

Figure 73: External fibre termination box.
10 Fibre and Fibre Management

10.1 Choice of optical fibre for FTTH

Several types of optical fibre are available. FTTH schemes are usually based on singlemode fibre, but multimode fibre may also be used in specific situations. The choice of fibre will depend on a number of considerations. Those listed below are not exhaustive; other factors may need to be considered on a case-by-case basis.

1. **Network architecture** – The choice of network architecture will affect the data rate that must be delivered by the fibre, and the available optical power budget of the network. Both factors affect the choice of fibre.

2. **Size of the network** – Network size can refer to the numbers of properties served by the network. However, in this context we mean the physical distance across the network. The available power budget will determine how far away the POP can be from the customer. Power budgets are affected by all components in the optical path including the fibre.

3. **The existing network fibre type** – If linking into an existing network, then the optical fibre in the new network must be compatible with the fibre in the existing network.

4. **Expected lifetime** – FTTH networks are designed with a lifetime of at least 30 years. Therefore, it is imperative that any investment made in the FTTH infrastructure is able to serve future needs as well as those of today. Changing the fibre type halfway through the expected lifetime of the FTTH network is not a desirable option.

10.1.1 What is optical fibre?

Optical fibre is effectively a “light pipe” carrying pulses of light generated by lasers or other optical sources to a receiving sensor (detector). Transmission of light in an optical fibre can be achieved over considerable distances, supporting high-speed applications unsustainable by today’s copper based networks. Conceived in the 1960s, optical fibre has been highly developed and standardised to form a reliable, proven backbone of today’s modern telecommunication transmission systems.

10.1.2 Optical fibre basics

Fibre is manufactured from high purity silica glass-like rods drawn into fine hair-like strands and covered with a thin protective plastic coating. Fibres are subsequently packaged in various cable configurations before installation in the external and/or internal networks. Whilst there are many different fibre types, this document concentrates on fibre for FTTH applications.
Fibre is made up of a core, cladding and outer coating. Light pulses are launched into the core region. The surrounding cladding layer keeps the light travelling down the core and prevents light from leaking out. An outer coating, usually made of a polymer, is applied during the drawing process.

The fibre core can be designed in varying geometrical sizes. These impact how the light pulse travels, thus producing differing optical performance.

A number of parameters determine how efficiently light pulses are transmitted down the fibre. The two main parameters are attenuation and dispersion.

Attenuation is the reduction of optical power over distance. Even with the highly pure materials used to manufacture the fibre core and cladding, power is lost over distance by scattering and absorption within the fibre. Fibre attenuation limits the distance light pulses can travel and still remain detectable. Attenuation is expressed in decibels per kilometre (dB/km) at a given wavelength or range of wavelengths.

Dispersion can be broadly described as the amount of distortion or spreading of a pulse during transmission. If pulses spread out too far, the detector at the other end of the fibre is not able to distinguish one pulse from the next, causing loss of information. Chromatic dispersion occurs in all fibres and is caused by the various colours of light (components of a light pulse) travelling at slightly different speeds along the fibre. Dispersion is inversely related to bandwidth, which is the information carrying capacity.

There are many other parameters, which affect fibre transmission performance. Further information can be found in IEC 60793 series of specifications.

10.1.3 Singlemode fibre

Singlemode fibre has a small core size (<10μm) which supports only one mode (ray pattern) of light. Most of the world’s fibre systems are based on this type of fibre.

Single-mode fibre provides the lowest optical attenuation loss and highest bandwidth transmission carrying capacity of all the fibre types. Singlemode fibre incurs higher equipment cost than multimode fibre systems.

For FTTH applications, the ITUT G.652 recommendations for singlemode fibre should adequately cover most users’ needs.
More recently, a newer type of singlemode fibre was introduced to the market that has reduced optical losses at tight fibre bends. This fibre is standardized in ITU-T G.657 and is available from several fibre suppliers. This type of fibre is most beneficial when optical fibre needs to be installed in environments where cables need to be installed in tight bends, inside buildings, for example.

10.1.4 Graded-index multimode fibres

Multimode fibres have a larger core size (50 or 62.5μm), which supports many modes (different light paths through the core). Depending on the launch characteristics, the input pulse power is divided over all or some of the modes. The different propagation speed of individual modes (modal dispersion) can be minimised by adequate fibre design.

Multimode fibre can operate with cheaper light sources and connectors, but the fibre itself is more expensive than singlemode. Multimode fibre is used extensively in data centres and sometimes used in campus networks and for in-building applications. It has lower bandwidth capability and restricted fibre length.

The ISO/IEC11801 specification describes the data rate and reach of multimode fibre grades, referred to as OM1, OM2, OM3 and OM4.

10.1.5 Bend insensitive fibre

When cabling inside buildings there are many areas that would provide difficulties for conventional fibres resulting in poor optical performance or the need for very careful and skilled installation practice or special fibre protection with ducts and cable designs. However, new fibre types described by the ITU-T G.657 standard are now available, which enable fibre-optic cables to be installed just as easily as conventional copper cables. The fibres inside these cables, which are termed “bend-insensitive”, are capable of operating at a bend radius down to 7.5mm, with some fibres fully compliant down to 5mm.

10.2 Optical distribution frames

An optical distribution frame (ODF) is the interface between the outside plant cables and the active transmission equipment. ODFs are usually situated in the POP, bringing together several hundred to several thousand fibres. A single ODF cabinet can connect up to 1400 fibres; large POPs will use multiple ODF cabinets.

Outdoor cables are terminated within an ODF using an optical connector. To terminate the cable, a connectorised fibre pigtail is spliced to each individual fibre.

The POP is an access node and should be classified as a secure area. Therefore provision for fire, intrusion alarm, managed entry/access and mechanical protection against vandal attacked must be considered.
In most cases, the ODF offers flexible patching between active equipment ports and the field fibre connectors. Fibres are identified and stored in physically separated housings or shelves to simplify fibre circuit maintenance and prevent accidental interference to.

For a compact ODF system, climate controlled street cabinets can provide a flexible solution. The cabinets can be equipped with the same security measures and un-interrupted power supply as in large scale access nodes.

Internal optical cables are run between the ODFs and active equipment. A fibre-guiding platform is built between the active equipment and the ODF cabinets. This provides a protected path for the internal cables to run between the two locations.

An uninterruptible power supply (UPS) provides emergency power back up in case of external power supply failure. The access node may also require a second diverse external power supply, which may form part of local & statutory requirement (provision of emergency services). Available UPS modules vary in size and depend upon the power requirement to be backed up.
Suitable air conditioning equipment is required to keep the active equipment within environmental operation limits. The size and capacity of the unit will depend on the size of the equipment room to be served.

Figure 82: Uninterruptible power supply.  
Figure 83: Air-conditioning unit.

10.3 Patchcords and pigtails

Patchcords are fibre-optic cables fitted with a connector at one end (pigtail) or both ends (jumper). The cables are generally available in two different constructions:

- 900 µm (typical) tube or buffer without any strength member
- 1.7 -3.0 mm ruggedized cable with construction based on 900µm tubing with aramid yarns as strength members and a plastic jacket over the sheath

The optical loss of a connector is the measured loss of two mated connectors fitted within an adapter housing. The typical loss of a connector is 0.5dB when randomly mated, and 0.2dB when mated with a reference connector (an "ideal connector").

Some connector types are also available in low loss versions with typical insertion loss of 0.15dB when randomly mated. Power budget considerations will determine the class of connector to be used. Where low loss connector performance is required, many vendors are able, through design, to achieve lower loss by tuning connectors to minimise the lateral fibre offset between a mated pair.

Connectors are also characterised with a return loss value. When light is transmitted into a connector, a portion of the light is reflected back from the fibre end face. For PC connectors this gives rise to attenuation of 45dB; for UPC types this value is 50dB; and for APC it is 60dB (non-mated versions). It is desirable for this figure to be as high as possible to avoid problems with transmission lasers.

Pigtails can be deployed in OSP conditions in temperatures ranging from −40 to +70°C. Connectors should be protected from high amounts of dust and humidity.
Cable regulation in Europe usually requires that polymers for indoor wiring are LSZH-rated (low smoke, zero halogen) to minimise toxic gases when burned.

There is a mix of connector styles in use in today’s networks. The complete range is shown in the following diagram:

More common standards are the SC and LC. Standard size connector styles include: SC, FC, E2000, ST, and DIN. Small form factor connector styles (half size) include: LC, MU, and F3000.

Connectors are supplied either:
- without angle polishing (PC or UPC) or
- with angle polishing (APC)
10.4 Splicing of fibres

Two technologies are common for splicing fibre to fibre: fusion and mechanical.

10.4.1 Fusion splicing

Fusion splicing requires the creation of an electric arc between two electrodes. The two cleaved fibres are brought together in the arc, so that both ends melt together.

The optical losses of the splice can vary from splicer to splicer, depending on the alignment mechanism. Splicing machines with core alignment match up the light-guiding channel of the fibre (9µm core) one to the other. These machines produce splices with losses typically <0.05dB.

Some splice machines (smaller handheld versions for example) align the cladding (125 µm) of a fibre instead of the cores that transport the light. This is a cheaper technology, but can cause more error because of the larger dimensional tolerances of the cladding. Typical insertion loss values for these splice machines are <0.1dB.
10.4.2 Mechanical splicing

Mechanical splicing is based on the mechanical alignment of two cleaved fibre ends so that light is coupled from one fibre into the other. This also applies to terminating fibres onto connectors. To facilitate the light coupling between the fibres, an index matching gel is often used. Different manufacturers have various tooling to terminate the fibres in the mechanical splice.

Mechanical splices can be angle cleaved or non angle cleaved, but the angled cleave has higher return loss. The insertion loss of a mechanical splice is typically <0.5 dB.

![Figure 87: Mechanical splicers.](image)

10.5 Cable joint closures

Since cables are not endless in length and need to be branched off at several locations, intermediate splice closures are needed. These are environmental and mechanically protected housings for outdoor use that offer a small compact means of managing fibres for storage within underground chambers and on overhead poles. Security risks are low and easy access is possible if the underground chamber in which the enclosure is stored is well managed.

Closures are available in many different sizes and shapes. The typical splice capacity exceeds 500 fibre circuits per joint closure. Fibre management systems allow fibre identification, and protect against and avoid accidental interference of fibre circuits when specific fibres are accessed.

Some closures offer the opportunity to access selected fibres out of a complete cable for splicing, while the other fibres in the cable are left untouched. This is mostly referred to as mid-span cable access. This capability drastically reduces the installation time of a branch, and the required down time of a link.

The environmental protection level depends on the application and deployment area, whether underground, pedestal, or aerial mount. For overhead applications specialist equipment may be required to access the closure for configuration.
A differentiation between closures can also be made on the cable sealing features. Today most joint closures seal the cables using heat shrinkable tubing, or are cold sealable using gel or rubber sealing elements.

![Figure 88: Typical examples of underground closures.](image)

The fibre deployment technology used will also influence the joint closure features. For example, deployments in sewer systems require closures that are suitable to deal with very harsh chemical environments. Blown fibre closures need to handle the blown fibre tubes and allow for access of the blowing equipment. For this reason, each application might require a different closure solution.

![Figure 89: Examples of blown fibre closures.](image)

### 10.6 Access and jointing chambers (handholes and manholes)

Handholes in FTTH networks are used for easy access to splice closures, duct distribution points and cable slack storage. There are basically four types/materials available: concrete, HDPE, polyester and polycarbonate.

Different sizes and shapes are available in all types of materials, and most of the plastic types are also available in modular versions.

The choice of a type of handhole is based on the following criteria:
- Where will it be installed? (mainly security reasons)
- What is the maximum load that it has to take?
- How much space is required?
- What are local regulations?
- Is it at underground or ground level?

Figure 90: Access chambers.

In situations where there is a possibility of damage, it is sometimes wise to place the handhole completely underground. The disadvantage of this is difficult access when repeated access is required. Alternatively you can use a handhole with a cover that can be locked with special keys – several types are available.

The load that the handhole has to take is regulated by European Standard: EN 124. All required tests are also described in this standard.

<table>
<thead>
<tr>
<th>Cover load</th>
<th>Field of Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>A 15 [15 kN test load]</td>
<td>Traffic areas utilised by pedestrians and bicycles only and similar areas (i.e. park areas) – can be crossed by cars in restricted extension.</td>
</tr>
<tr>
<td>B 125 [125 kN test load]</td>
<td>Foot-walks, pedestrian areas, parking areas – can be crossed by cars in restricted extension.</td>
</tr>
<tr>
<td>D 400 [400 kN test load]</td>
<td>All traffic ways (except landing runways).</td>
</tr>
</tbody>
</table>

If the handhole is used for cable slack or splice closures, it is important to respect the maximum bend radius that the installed cable will allow.
Handholes are expensive to install and should be chosen with care, ensuring sufficient space is available and that local regulations are incorporated in the design such as load profile, and type of pavement topping, whether tiles, concrete, etc.

10.7 Street cabinets

A buried FTTH network contains communication equipment that can either reside below or above ground level. Street cabinets can be provided both above and below ground although the recognised convention is above ground.

With the different sizes, lower profiles and smaller above-ground footprint, modern street cabinets are less of an eyesore than the larger cabinets required for a copper or VDSL network. Although visibility is an important consideration, it is not the only one. Other considerations include:

- **Cost** – In FTTH deployments the labour costs of installation often dwarf the material cost of the network components. Cabinets can be a cost-effective method of providing a network access point, if the build specification and methodology allows. A scalable or modular cabinet solution can help to control project costs because the size of the cabinet can easily be extended if the need arises.

- **Network accessibility** – Depending on the geographical location, the cleanliness of the splice closure installed will normally be better in an above ground installation. Wet conditions can turn a traditional hand and manhole into miniature mud pools, increasing the installation time. In cold winters, underground access can sometimes be impossible due to ice.

Street cabinets are metal or plastic enclosures, which serve as a distribution/access point between the distribution fibre and the drop fibre to the subscriber. They are usually placed for relatively easy and rapid access to fibre circuits, and can handle larger capacities than fibre joint closures. Access/distribution points often serve from 24 to 96 subscribers, whilst compact pedestal types of cabinet typically serve from 1 to 24 subscribers.

Cabinets can also be used as above-ground access points for fibre closures. Where these are mounted inside the street cabinet, an easy-to-remove solution is required to allow clean and efficient access when required.

Figure 91: Typical street cabinet.
Street cabinets are often used to store PON splitters, which also require flexible connectivity to customer-dedicated fibres. Street cabinets are also used in point-to-point network architectures.

The biggest concern in terms of above ground installation is the relative vulnerability of cabinets to uncontrolled damage, for example car accidents and vandalism. Distances from sidewalks and positioning on streets with heavy traffic must be taken into consideration. Positioning may also be restricted by local authority rules, for example, in historic city centres or secure public places.

When the advantages of a cabinet are required but there are issues with location, an underground solution is also available that allows the cabinet can be raised out of the ground for access; when stored no more than a manhole cover is seen.

A typical street cabinet has three functions:

1. **Duct management** is made in the root compartment to connect, separate and store ducts and cables. The same area can be used as point of access to facilitate blowing in (also midpoint blowing) of fibre units, ducts or cables.

2. **Base management** is where ducts, modular cables and fibre-optic cables can be fixed and managed, usually on a mounting rail.

3. **Fibre management** is where the fibres of the different cable types can be spliced. This construction facilitates easy and fault-free connection of different fibre types.

![Figure 92: Duct management.](image1)

![Figure 93: Fibre management.](image2)

![Figure 94: Base management.](image3)
An important factor in the roll-out of new networks is speed. Cabinets are now being provided pre-stubbed and terminated. These cabinets are assembled in the factory and tested prior to delivery. They have a cable stub that is run back to the next closure, and offer a patch panel for simple plug-and-play connectivity. This provides faster installation, and reduces the incidence of installation faults. This can be combined with plug-and-play PON splitters, which can be installed as and when required without the need for further field splicing.

When protecting active components which are sensitive to extremes of temperature and/or humidity, a controlled environment is required and this can be provided by climate-controlled outdoor cabinets.

![Pre-stubbed and terminated cabinet.](image)

**Figure 95:** Pre-stubbed and terminated cabinet.

**Figure 96:** Examples of street cabinets in a range of sizes.

### 10.8 Optical splitters

Two technologies are common in the world of passive splitters: fused biconic taper and planar waveguide splitters.

#### 10.8.1 Fused biconic taper

- FBT splitters are made by fusing two wrapped fibres.
- Well known production process.
- Proven technology for OSP environments.
- Monolithic devices are available up to 1x4 split ratio.
- Split ratios greater than 1x4 are built by cascading 1x2, 1x3 or 1x4 splitters.
- Split ratios from 1x2 up to 1x32 and higher (dual input possible as well).
- Higher split ratios have typically higher IL (Insertion Loss) and lower uniformity compared to planar technology.

**10.8.2 Planar splitter**

- optical paths are buried inside the silica chip
- exist from 1x4 to 1x32 split ratios and higher become available, dual input possible as well
- only symmetrical splitters available as standard devices
- compact compared to FBT at higher split ratios (no cascading)
- better insertion loss and uniformity at higher wavelengths compared to FBT over all bands
- better for longer wavelength, broader spectrum
11 Operations and Maintenance

This section provides a brief overview of the planning, operational and maintenance aspects of an FTTH network infrastructure. While each FTTH network design will differ and operate in different environments and conditions, the planning, operation and maintenance remains a common requirement.

During network construction, the builder will need to ensure minimum disruption to the general public and surrounding environment. This will most likely be a requirement through a contract to ensure that installation and build processes cause little or no disturbance within the FTTH area. This can only be achieved by careful planning and execution. This will also drive the need for efficient build methods to be deployed that will ultimately benefit the FTTH business case. Poor planning will have the opposite effect and potentially lead to poor network performance and a failing build programme.

Whilst fibre is a reliable medium whose reliability has been proven in service over tens of years, it is still vulnerable to unexpected breakdown that will require mobilisation and rapid and efficient repair. During such times immediate access to the networks records by those tasked with repair is essential. It is vital from the onset of the network build that records and documentation are collated and centralised to support all subsequent network analysis.

Maintenance procedures must be planned in advance and contractual arrangement put in place to ensure the appropriate manpower is on hand when needed.

11.1 Network planning guidelines

11.1.1 Site control and installation operation planning

Work with underground duct systems or installations on sidewalks or poles, will require careful planning and in many cases cause disruption to traffic. Liaison with local authorities will be required and suitable controls must be put in place. The following sections briefly list the main installation considerations that need to be taken into account when embarking upon a duct type installation.

11.1.2 General management considerations

Familiarity and experience working with underground or aerial duct and cable systems, practices and working operations is essential.

Careful planning of the installation will lead to an efficient and safe operation. Liaison with the local authorities prior to installation is recommended, where appropriate.
A full appreciation of nearby utility services must be obtained both from the local authorities and by on site confirmation using suitable detection equipment.

11.1.3 Safety

Proper safety zones using marker cones and traffic signals should be organised.

Disruption of traffic should be coordinated with local officials.

All manholes and cable chambers should be identified and those intended for access should be tested for flammable and toxic gases before entry.

For confined spaces, full air and oxygen tests should be carried out before entry and forced ventilation provided as necessary. Whilst working underground, all personnel must have continuous monitoring gas warning equipment in operation at all times – flammable, toxic, carbon dioxide and oxygen levels.

In cases where flammable gas is detected, the local Fire Service should be contacted immediately.

All existing electrical cables should be inspected for any possibility of damage and exposed conductors.

11.1.4 Construction, equipment and planning

A full survey of the complete underground duct system or aerial plant should be carried out prior to installation.

Manhole and cable chambers with excess levels of water should be pumped out.

Ducts should be checked for damage and potential obstructions. Rodding of the duct sections using a test mandrel or brush is recommended prior to installation.

Manholes should be checked to ensure suitable space for coiling slack cables, provision of cable supports and space for mounting splice joint closures.

A plan should be established to optimally position the cable payoff, mid-point fleeting and cable take-up/ winching equipment. The same also applies if the cables are to be blown into the duct, which will require a blowing head and compressor equipment.

Allowances for elevation changes should be taken into account accordingly.

Fleeting the cable at mid sections using a “figure of 8” technique can greatly increase the pulled installation section distance using long cable lengths. Preparation is needed to make sure these locations are suitable for cable fleeting.
The duct or inner duct manufacturer should be contacted for established cable installation guidelines.

Ribbed, corrugated ducts and ducts with a low-friction liner are designed to reduce cable/duct friction during installation. Smooth non lined ducts may require a suitable compatible cable lubricant.

Pulling grips are used to attach the pulling rope to the end of the cable. These are often mesh/weave based or mechanically attached to the cable end minimising the diameter and thus space of duct used. A fused swivel device should also be applied between the cable-pulling grip and pulling rope.

The swivels are designed to release any pulling generated torque and thus protect the cable. A mechanical fuse protects the cable from excess pulling forces by breaking a sacrificial shear pin. Pins are available in different tensile values.

A pulling winch with a suitable capacity should be used. These should be fitted with a dynamometer to monitor tension during pulling.

Sheaves, capstans and quadrant blocks should be used to guide the cable under tension from the payoff, to and from the duct entry and to the take-up equipment to ensure that the cable’s minimum bend diameter is maintained.

Communication radios, mobile phones or similar should be available at all locations in the operation.

Use of midpoint or assist winches may be recommended in cases where the cable tensile load is approaching its limit and could expedite a longer pull section.

Use of a cable payoff device – a reel or drum trailer – is also recommended.

For aerial applications, appropriate equipment such as bucket trucks should be foreseen. Specific safety instructions for working at height need to be respected. Specific hardware is available for cable and closure fixture.

11.1.5 Cabling considerations

Duct and microduct cabling

Duct installation and maintenance is relatively straightforward. Occasionally cables may be dug up inadvertently; hence maintenance lengths should be available at all times.

Duct and buried cables can have similar constructions, with the latter having more protection from the environment in which it is to be installed.

When calculating the route length, make allowance for jointing: typically 3-5m per joint will suffice.
Space cable spare/slack loops at chamber positions of typically 20m. This will allow for mid-span access joints to be added at a later date.

Minimum bend radii (MBR) and maximum tensile load values for the cables must not be exceeded.

MBR is usually expressed as a multiplier of the cable diameter (e.g. 20xD) and is normally defined as a maximum value for static and dynamic situations.

Static MBR is the minimum allowable bend value for the cable in operation, i.e. coiled within a manhole or chamber. The dynamic MBR value is the minimum allowable bend value for the cable under installation pulling conditions.

Pulling load (or pulling tension, N; or force, Kgf) values are normally specified for short and long-term conditions. Short-term load values represent the maximum tension that can be applied to the cable during the installation process and long-term values represent the maximum tension that can be applied to the cable for the lifetime of the cable in service.

In cases where cables are to be installed by blowing, the cable and duct must be compatible for a blowing operation. The cable and duct supplier/s must be contacted for installation guidelines.

**Direct buried cable**

Installation techniques for burying cables can include trenching, ploughing, directional drilling and thrust boring. Reference should also be made to IEC specification 60794-1-1 Annex C.3.6 *Installation of buried cables*.

Confirm minimum bend radii of cable and maximum pulling tensions for installation and long-term service conditions.

Ensure cable tension is monitored during burial and cable maximum limits are not exceeded.

A full survey of the buried section will ensure an efficient installation operation.

Cross over points with other services and utilities must be identified.

All buried cables must be identified and marked for any future location.

Backfilling must ensure the cables are suitably protected from damage from large rocks e.g. sand. All back filling must be tamped to prevent future ground movement and settlement.

All surfaces must be restored to local standards.
**Aerial cable**

Reference should be made to IEC specification 60794-1-1 Annex C.3.5 *Installation of aerial optical cables*.

Cables used in aerial installations are different in design to those for underground applications, and are designed to handle wind and snow/ice loads. Requirements may differ according to geographic area, for example, a hurricane region will experience higher winds.

Cables need a defined amount of slack between poles to reduce the cable loading due to its own weight.

On-pole slack needs to be stored for cable access or closure installation.

Sharing of poles between operators or service providers (CATV, electricity, POTS, etc.) is common practice and will require specific organisation as well.

**11.2 Operation and maintenance guidelines**

Consideration should be given to:

- measurements
- fibre cable and duct records
- marking of key infrastructure items
- complete documentation
- identification of infrastructure elements subject to maintenance operations
- minor maintenance list
- plan for catastrophic network failure from external factors, such as accidental digging of cable or duct
- spare infrastructure items to be kept on hand in case of accident
- location and availability of network records for the above provision of maintenance agreement(s)
12 FTTH Test Guidelines

12.1 Connector care

12.1.1 Why is it important to clean connectors?

One of the first tasks to perform when designing fibre-optic networks is to evaluate the acceptable budget loss in order to create a product that will meet the design requirements. To adequately characterize the budget loss, the following key parameters are generally considered:

- transmitter – launch power, temperature and aging
- fibre connections – connectors and splices
- cable – fibre loss and temperature effects
- receiver – detector sensitivity
- others – safety margin and repairs

When one of the above variables fails to meet specifications, network performance can be affected; in the worst case, the degradation can lead to network failure. Unfortunately, not all variables can be controlled with ease during the deployment of the network or the maintenance stage; however, there exists one component—the connector—that is too-often overlooked, sometimes overused (test jumpers), but which can be controlled using the proper procedure.

A single particle mated into the core of a fibre can cause significant back reflection (also known as return loss), insertion loss, and equipment damage. Visual inspection is the only way to determine if fibre connectors are truly clean.

By following a simple practice of proactive visual inspection and cleaning, poor optical performance and potential equipment damage can be avoided.

Since many of the contaminants are too small to be seen with the naked eye, it is important that every fibre connector is inspected with a microscope before a connection is made. These fibre inspection scopes are designed to magnify and display the critical portion of the ferrule where the connection will occur.
12.1.2 What are the possible contaminants?

Connector design and production techniques have eliminated most of the difficulties in achieving core alignment and physical contact. However, maintaining a clean connector interface still remains a challenge.

Dirt is everywhere; a typical dust particle just 2–15μm in diameter can significantly affect signal performance and cause permanent damage to the fibre end face. Most field-test failures can be attributed to dirty connectors; the majority are not inspected until they fail, when permanent damage may have already occurred.

If dirt particles get on the core surface the light becomes blocked, creating unacceptable insertion loss and back reflection (return loss). Furthermore, those particles can permanently damage the glass interface, digging into the glass and leaving pits that create further back reflection if mated. Also, large particles of dirt on the cladding layer and/or the ferrule can introduce a physical barrier that prevents physical contact and creates an air gap between the fibres. To further complicate matters, loose particles have a tendency to migrate into the air gap.

![Figure 97: Increased insertion loss and back reflection due to dirty fibre connection.](image)

A 1μm dust particle on a singlemode fibre core can block up to 1% (0.05 dB loss) of the light—imagine what a 9μm dust particle can do. Another important reason for keeping end-faces free of contaminants is the effect of high-intensity light on the connector end-face—some telecommunication components can produce optical signals with a power up to +30dBm (1W), which can have catastrophic results when combined with a dirty or damaged connector end face (e.g. fibre fuse).

Inspection zones are a series of concentric circles that identify areas of interest on the connector end face (see figure). The inner-most zones are more sensitive to contamination than the outer zones.
Dust, isopropyl alcohol, oil from hands, mineral oils, index matching gel, epoxy resin, oil-based black ink and gypsum are among the contaminants that can affect a connector end-face. These contaminants can occur on their own or in combinations. Note that each contaminant has a different appearance, but regardless of appearance, the most critical areas to inspect are the core and cladding regions—as contamination in these regions can greatly affect the quality of the signal. Figure 3 illustrates the end-face of different connectors that have been inspected with a video-inspection probe.

Figure 98: Appearance of various contaminants on a connector end-face.
12.1.3 Where do we need to inspect and clean?

Inspection and cleaning is recommended for the following network components:

- patch panel
- test jumper
- cable connectors

12.1.4 When should a connector be inspected and cleaned?

Connectors should be checked as part of an inspection routine to prevent costly and time consuming fault finding later. These stages include:

- on delivery
- before installation
- before testing

12.1.5 How to check connectors

To inspect the connector end-face properly, the use of a microscope designed for the fibre-optic connector end-face is recommended. There are many types of inspection tools on the market, but they all fall into two main categories: fibre inspection probes (also called video fibrescopes) and optical microscopes.

The table below lists the main characteristics of these inspection tools:

<table>
<thead>
<tr>
<th>Inspection tool</th>
<th>Main characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fibre inspection probes/video fibrescopes</td>
<td>Image display on an external video screen, PC or test instrument. Eye protection from direct contact with a live signal. Image-capture capability for report documentation. Ease of use in crowded patch panels. Ideal for checking patchcords, patch panels, and multi-fibre connectors (e.g. MTP). Different degrees of magnification available (100X/200X/400X). Adapter tips for all connector types available.</td>
</tr>
<tr>
<td>Optical microscopes</td>
<td>Safety filter* protects eyes from direct contact with a live fibre. Two different types of microscopes needed: one to inspect patchcords and a different one to inspect connectors in bulkhead-patch panels.</td>
</tr>
</tbody>
</table>

* Never use a direct magnifying device (optical microscope) to inspect live optical fibre.

A fibre inspection probe comes with different tips to match the connector type: angle-polished connectors (APC) or flat-polished connectors (PC, SPC or UPC).
12.1.6 Inspection instructions

Visual Inspection of fibre interconnects is the only way to determine if connectors are clean prior to mating them. A video microscope magnifies an image of a connector end face for viewing on either a laptop or portable display depending on the product used.

**INSPECT**
1. Select the appropriate tip for the connector/adaptor you are inspecting.
2. Inspect both connector end faces (patchcord/bulkhead/pluggable interface) using the microscope.

**IS IT CLEAN?**

<table>
<thead>
<tr>
<th>Clean</th>
<th>No – upon inspection, if defects are found on the end-face, clean the connector using a designed-for optics cleaning tool.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect</td>
<td>Yes – if non-removable non-linear features and scratches are within acceptance criteria limits according to operator’s thresholds or standards, the fibre interfaces can be connected.</td>
</tr>
</tbody>
</table>

12.1.7 Tools needed for inspection

There are two methods for fibre end-face inspection. If the cable assembly is accessible, you can insert the connector ferrule into the microscope to do an inspection; this is generally known as patchcord inspection. If the connector is within a mating adaptor on the device or patch panel, you can insert a probe microscope into the open end of the adaptor and view the connector inside; this is known as bulkhead or through adaptor connector inspection.

**Patchcord inspection**

1. Select the appropriate tip that corresponds to the connector type under inspection and fit it on to the microscope.
2. Insert the connector into the tip and adjust focus to inspect.
**Bulkhead/through adaptor connector inspection**

1. Select the appropriate tip/probe that corresponds to the connector type under inspection and fit it to the probe microscope.
2. Insert the probe into the bulkhead and adjust focus to inspect.

**12.1.8 Cleaning wipes and tools**

**Dry Cleaning**

Simple dry cleaning wipes including many types of lint free wipes and other purpose built wipes are available. This category also includes purpose built fibre-optic connector cleaning cassettes and reels, e.g. Cletop cartridges.

**WARNING! EXPOSED WIPES CAN EASILY BECOME CONTAMINATED IN THE FIELD.**

Cleaning materials must be protected from contamination until just prior to use.

Wipes should be used in the hand or on a soft surface or resilient pad. Use on a hard surface can cause damage to the fibre. Do not use the surface of the wipe that you handled as this can contain finger grease residue.

Figure 99: Examples of dry cleaning wipes and tools for fibre-optic connectors.
Damp cleaning

Cleaning fluids or solvents are generally used in combination with wipes to provide a combination of chemical and mechanical action to clean the fibre end-face. Also available are pre-soaked wipes supplied in sealed sachets, e.g. IPA mediswabs. Caution: some cleaning fluids, particularly IPA, can leave a residue that is difficult to remove.

- Cleaning fluid is only effective when used with the mechanical action provided by a wipe.
- The solvent type must be fast drying.
- Do not saturate as this will over-wet the end-face. Lightly moisten the wipe.
- The ferrule must be cleaned immediately with a clean dry wipe.
- Do not to leave solvent on the side walls of the ferrule as this will transfer onto the optical alignment sleeve during connection.
- Wipes must be used in the hand or on a soft surface or resilient pad.
- Use on a hard surface can cause damage to the fibre.

![Cleaning Fluid and Wipes](image.png)

Figure 100: Examples of cleaning fluid and wipes.

Bulkhead / through adaptor connector cleaning tools

Not all connectors can be readily removed from a bulkhead/through adaptor, and are, therefore, more difficult to access for cleaning. This category includes ferrule interface (or fibre stubs) and physical contact lenses within an optical transceiver, but does not include non-contact lens elements within such devices.

Sticks and bulkhead cleaners are designed to reach into alignment sleeves and other cavities to reach the end face or lens, and aid in removal of debris. These tools make it possible to clean the end face or lens in-situ, within the adaptor or without removing the bulkhead connector. When cleaning transceiver or receptacles care must be taken to identify what is within the port prior to cleaning. Take care when cleaning transceiver flat lenses due to possible damage.
Recommendations when manipulating fibre-optic cables:

- When testing in a patch panel, only the port corresponding to the fibre under test should be uncapped—protective caps should be replaced immediately after testing.
- Unused caps should be kept in a small plastic bag.
- The life expectancy of a connector is typically rated at 500 matings.
- The test jumpers used in conjunction with the test instruments should be replaced after a maximum of 500 matings (refer to EIA-455-21A).
- If a launch cord is used for OTDR testing, do not use a test jumper in between the OTDR and launch cord or in between the launch cord and the patch panel. Launch cords should be replaced or sent back to manufacturers for re-polishing after 500 matings.
- Unmated connectors should never be allowed to touch any surface, and a connector ferrule should never be touched for any reason other than cleaning.
- Each connector should be cleaned and inspected using a fiberscope or, better yet a videoscope, after cleaning or prior to mating.
- Test equipment connectors should be cleaned and inspected (preferably with a videoscope) every time the instrument is used.

12.2 Qualifying FTTH networks during construction

During network construction, part of testing occurs at the outside-plant level. When laying down fibre, new splices must be made, and therefore splicing qualification is performed using an OTDR. For accurate measurements, bidirectional OTDR measurements should be performed.

For acceptance testing, it is important to test each segment of the construction. There are several methods of testing — some of which are presented here — and each has specific advantages and disadvantages. You should select the most appropriate method, depending on the constraints you are facing: labour costs, loss budget, testing time combined with service activation time, maximum acceptable measurement uncertainty, and so on.
Another factor that needs taking into account when determining how much testing is necessary is the skill level of your technicians. Do not make the mistake of trying to use technicians that lack fibre-optic skills. Mistakes made during construction are extremely expensive to rectify both before and after service is added, resulting in a huge increase of your cost per-customer-passed. When it comes to testing during the construction phase, there should be no shortcuts.

12.2.1 Method #1: Use of optical loss test sets

This first method involves using an optical loss test set (OLTS), comprising two test sets that share data to measure insertion loss (IL) and optical return loss (ORL). First, the two units should be referenced prior to measuring IL.

Next, ORL sensitivity is set by calibrating the minimum ORL that the units can measure. The limitation comes from the weakest part of your test setup, which is most likely to be the connector between the units and reference test jumper. You should set ORL sensitivity on both units – follow the manufacturer’s instructions to set the ORL sensitivity and to reference the source and the power meter.

Now you are ready to perform measurements on the end-to-end network or any individual installed segment, such as the fibres between the FCP and the drop terminal. The purpose of the test is to identify whether there are any transposed fibres, and measure the IL and ORL to make sure that the loss budget has been met.

The following table illustrates the expected ORL values for the network:

<table>
<thead>
<tr>
<th>Length (metres)</th>
<th>1310nm (dB)</th>
<th>1490nm (dB)</th>
<th>1550nm (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>53</td>
<td>56</td>
<td>57</td>
</tr>
<tr>
<td>300</td>
<td>46</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>500</td>
<td>44</td>
<td>47</td>
<td>48</td>
</tr>
<tr>
<td>1000</td>
<td>41</td>
<td>45</td>
<td>46</td>
</tr>
</tbody>
</table>

These values only take two connections into account. In FTTH networks there are often multiple connection points and, with reflectance values being very sensitive to dust and scratches, these values can easily be blown away by bad connections. For example a single connector may generate an ORL of 40dB, which would exceed the expected value for the entire network. For point-to-multipoint network, the ORL contribution of each fibre is attenuated by 30 to 32 dB because of the splitter’s bidirectional loss.
Figure 102: Measuring distribution fibre IL and ORL using a pair of OLTS.

<table>
<thead>
<tr>
<th>Advantage of Method #1: OLTS</th>
<th>Disadvantages of Method #1: OLTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accurate IL and ORL measurement</td>
<td>Two technicians required (however with point-to-multipoint network, a single OLTS close to the OLT can be used for all customers within the same network)</td>
</tr>
<tr>
<td>Bidirectional IL and ORL values</td>
<td>Communication required between technicians (when switching fibres)</td>
</tr>
<tr>
<td>Possibility to test every distribution fibre</td>
<td>With point-to-multipoint network, one technician needs to move from drop terminal to drop terminal</td>
</tr>
<tr>
<td>Macrobend identification during testing is performed at 1550 and 1310 nm or at another combination of wavelengths involving the 1625 nm wavelength</td>
<td>In case of a cut fibre or macrobend, an OTDR is required to locate the fault</td>
</tr>
<tr>
<td>Transposed fibre identification on point-to-point networks</td>
<td>Impossible to detect transposed fibre on point-to-multipoint network</td>
</tr>
<tr>
<td>Fast testing</td>
<td></td>
</tr>
</tbody>
</table>

Results table for IL and ORL (Pr = premises, CO = central office):

<table>
<thead>
<tr>
<th>Fibre</th>
<th>λ (nm)</th>
<th>Loss (Pr → CO)</th>
<th>Loss (CO → Pr)</th>
<th>Average</th>
<th>ORL (Pr → CO)</th>
<th>ORL (CO → Pr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td>1310</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1490</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>002</td>
<td>1310</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1490</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1550</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
12.2.2 Method #2: Use of an OTDR

This method uses an optical time-domain reflectometer (OTDR). The main difference between the OLTS and the OTDR is the identification and location of each component in the network. The OTDR will reveal splices loss, connector loss and reflectance, and the total end-to-end loss and ORL.

![Figure 103: Measurement with an OTDR.](image)

All fibres between the OLT and before the first splitter (transport side) may be tested to characterize the loss of each splice and find macrobends. The test could be done in both directions. Post-processing of the results will be required to calculate the real loss of each splice (averaged between each direction).

The engineer can measure the loss of the splitter and the cumulative link loss, as well as identifying whether any unexpected physical event has occurred before, or after, the splitter. Construction testing can significantly reduce the number of problems that occur after customer activation by certifying end-to-end link integrity.

![Figure 104: PON optimised OTDR test from the ONT to the OLT.](image)
Figure 105: Using a launch fibre makes it possible to characterize the first connector on any segment of your network. A pulse width of 300-500m will be sufficient for this test.

<table>
<thead>
<tr>
<th>Advantages of Method #2: OTDR</th>
<th>Disadvantages of Method #2: OTDR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measures both IL and ORL values.</td>
<td>When testing after the splitter on the ONT side, the ORL is not measured in the right direction (opposite from the video signal).</td>
</tr>
<tr>
<td>Possible to test every distribution fibre.</td>
<td>The technician needs to move from drop terminal to drop terminal.</td>
</tr>
<tr>
<td>Macrobend identification during testing is performed at 1550 and 1310nm or at another combination of wavelengths involving the 1625nm wavelength.</td>
<td>It requires a skilled technician to interpret the trace.</td>
</tr>
<tr>
<td>In case of a cut fibre or macrobend, the fault can be located.</td>
<td></td>
</tr>
<tr>
<td>Only one technician required.</td>
<td></td>
</tr>
<tr>
<td>Fast testing</td>
<td></td>
</tr>
</tbody>
</table>
**Service activation**

The service-activation phase may seem very straightforward at first glance, but this task should not be taken lightly because this is the moment at which the customer experience begins. The service-activation scheme can be different, depending on topology of the fibre network. There is also a trend towards pre-engineered plug-and-play components with multiple connection points, rather than an all-spliced approach, particularly for deployments in MDUs.

Another thing to keep in mind is that FTTH networks are point-to-multipoint networks linking one location to multiple end-users, in contrast with legacy fibre networks, where a fibre typically links one location to another.

In terms of data storage, PON service activation brings about two new dimensions:

1. Results should be linked to customers or ONUs instead of fibres.
2. More than one test location may be required, typically two or three.

Since the service-activation phase is often performed by subcontractors, reporting and data authenticity protection are important, especially in PON deployments where hundreds of results may be generated for a single PON activation. Following the right steps in daily activity ensures a smooth workflow and high productivity.

![Figure 106: Activation testing using a PON power meter.](image-url)
Multiple testing locations

Verifying optical levels at various locations along the same fibre path helps test engineers pinpoint problems and/or defective components before activating a customer’s service. Since FTTH network problems are often caused by dirty or damaged connectors, component inspection greatly reduces the need for troubleshooting, as power levels are verified for each network section. It is also highly recommended to inspect each connection point using a fibre inspection probe before each power measurement.

![Diagram of FTTH network](image)

Testing points

1. By performing a power-level certification at the splitter—more specifically at the output—users can verify if the splitter branch is working properly. This simple assessment makes it possible to confirm that all network components from the CO (including the feeder fibre, F1) to the splitter output are in good condition. Typically, the FDH includes SC/APC or LC/APC connectors but may also include fusion splices.

2. By performing a power-level certification at the drop terminal, engineers can characterize the distribution fibre and the drop terminal ports. Usually, a splice tray is included within the drop terminal, which can cause macrobend problems.

3. The fibre connecting the drop terminal to the customer premises, also called the last mile or drop cable, is generally installed during service activation. To ensure reliable services to the customer, the network and the customer ONU must meet their specifications. The best way to guarantee this is to perform a pass-through connection to fully characterize all operating wavelengths (upstream and downstream) in the PON. The only way to achieve this at the service-activation phase is to use a dual-port PON power meter with a pass-through connection; a normal power meter can only certify downstream signals from the CO.
12.3 Service activation reporting

Back at the office, engineers will have to generate reports to keep track of test results at the service activation phase. These results can be used later to pinpoint problems such as power degradation. Operators dealing with subcontractors may also use this information to keep track of customers being activated.

A service activation report will typically include:

1. customer name and/or phone number
2. power level for each wavelength and each location
3. time stamp for each measurement
4. pass/warning/fail status compliant to standards such BPON, GPON or EPON
5. thresholds used to perform the pass/warning/fail assessment

Once the service activation report has been received from the installer, the operator can activate and validate the services.
13 FTTH Network Troubleshooting

Troubleshooting on an out-of-service network (i.e. on a point-to-point network or when the entire PON network is down) can be carried out easily with a power meter or OTDR.

On a live PON network, a PON power meter must be used to investigate when signals are out of tolerance. To pinpoint any fibre breaks, macro-bending, faulty splices or connectors, an OTDR with a live testing port must be used from the customer’s location.

Figure 109: Screen shot from FTTx Service Activation reporting tool.

![Diagram of FTTx Network](image)

The test engineer will connect an OTDR at the output of the drop cable and perform an upstream test using a short pulse width (i.e. 3/5ns). Due to the high loss observed at the splitter location and the relatively low measurement dynamic range provided by a short pulse, the end of the fibre link will be identified at the splitter location.

Make sure the fibre length corresponds to the length in between the drop cable output and the splitter location. If not, it indicates that a problem (break or macrobending) is present at this location.

If the length measurement is correct, check that every splice point doesn't exceed the normal splice values. Any point exhibiting an excessive loss value will indicate the presence of a macrobend, kink on the fibre or a bad splice.

The fibre is terminated at the home by an ONU that provides interfaces to serve analogue and digital video over coaxial cable; video, VoIP, or data over Ethernet; and phone service over twisted pair wiring. Service providers may wish to provide digital video through quadrature amplitude modulation (QAM) or IPTV or a combination.

For the premises architecture that uses both QAM for broadcast video and IPTV for on-demand, the IPTV video shares the coaxial cable with the QAM digital video and is
typically delivered using the Multimedia over Coax Alliance (MoCA) standard. The HPNAv3 protocol can also be used to deliver IPTV and data since it can run on existing twisted pair telephone lines or coaxial cable.

13.1 In-home wiring issues

In addition to loss, latency, and jitter emanating from the fibre network, a number of in-home issues, including phone line problems, Ethernet wiring mis-configuration or faulty termination, poor coaxial cabling integrity, and noise impairments, can combine to degrade the customers’ quality of experience.

Phone line issues

Phone lines (twisted pair) in the premises often carry both voice service and data services using HomePNA (HPNA) standards. The ONU emulates the POTS network by providing all of the battery voltages, ring tones, and dial tones that were provided by the central office in the past. Consequently, troubleshooting VoIP carried over the phone wiring is very similar to troubleshooting POTS.

Common errors affecting in-home wiring installations include:

- opens
- shorts
- crossed wires
- broken wires

Identifying Ethernet wiring issues

Many homes are now pre-wired with twisted-pair wiring suitable for Ethernet data services. Verification of proper termination is very important. Between 75% and 85% of the time in-home technicians spend troubleshooting can be attributed to improper terminations. The most common termination faults can be found by a wiring verifier.

Continuity tests include:

- verification of pin-to-pin connections
- ability of the wire to carry a signal
- shields
- voltage on line

This is a basic connectivity test, not a stress test.

Locating and resolving coax problems

Existing coaxial home networks present a variety of challenges. Constructed by the home builder, the owner, or perhaps a previous service provider, the quality and routing
of the network is rarely known. A high-quality coaxial installation should provide at least 30dB of noise isolation to the outside world (noise immunity).

However, these networks often contain:

- splitters
- pinches
- breaks
- bad cables
- un-terminated ends
- bad connections
- amplifiers

Any of these may lead to network problems and quality of service issues. Proper grooming of the network to repair or replace portions of the network to meet the triple-play service provider standards is critical to providing reliable services.

13.2 High-speed data over FTTx

To validate data service over an FTTx network the technician must:

- establish connectivity to the ISP
- provision necessary network elements for increased data flow and class of service treatment

To complete the installation process, field personnel must verify physical layer performance, ISP connectivity and data throughout. Technicians should use a test instrument in IP ping mode to verify the routing connectivity across the network to an IP host or server, while assessing packet-loss rates and packet delay to and from the ping destination.

The instrument should check the IP layer by verifying whether another host device is alive and able to echo back; use a flood mode to gauge network congestion; and determine the minimum, maximum, and average packet delay time of IP packets.

Tracking packet delay and loss helps determine whether delays and slow service are due to service provider error or CPE problems. Since users can only reach the ISP end of the service with the correct username, password and encapsulation, test tools must support the appropriate IP encapsulations and authentication protocols.

FTP throughput testing with selectable file sizes in both upload and download direction can be used to establish the performance of the link in a way that more closely matches actual usage than a simple download test. HTTP testing must also be completed to ensure the end-users’ ISP access/connectivity is working properly.
IPTV

Video service quality is ultimately determined by the end-user or subscriber. The quality of experience is a subjective concept with components that are nearly impossible to measure in a practical, operational manner. However, a service provider needs to make objective measurements on a set of parameters that can be used to judge the performance of the network.

A model for mapping objective measurements to quality of experience is the basis for good installation and troubleshooting procedures. Mapping of objective measures of quality for video services—video quality of service parameters—cannot be made in a one-to-one, direct correlation manner, nor can all subjective issues be measured directly. This is true especially of certain video artefacts which may be present in the video payload.

In order to help with this correlation and add structure to measurement approaches, quality in this context can be organized into a logical model:

- content quality – the actual video and audio payload
- video stream quality – the video transport stream packet flows
- transport quality – the IP packet flows
- transactional quality – the interaction between the user and the service

VoIP

Prior to completing service turn-up, field technicians must verify connectivity to signalling gateways, service provisioning, and call quality. Terminal adapters or VoIP phones are installed and applications are tested in this phase. Field technicians rely heavily on handheld testing devices to troubleshoot problems. Terminal adapters or IP phones are set up and plugged in to the LAN and their IP addresses are provisioned. Handheld test sets are normally used because they can assume unique aliases to mimic an end device on the network.

Handheld test sets can also be plugged in at any point in the network to help isolate problems. For instance, a handheld device can be used to determine if a specific end device’s alias has been provisioned correctly. It can help identify errors in provisioning network equipment during installation. It can also be used to verify the installation of specific equipment in the VoIP network.

Voice quality issues are resolved at this stage. The technician must place and receive calls through the network to ensure that the link is properly provisioned with the correct signalling protocol. Calls should be placed within the VoIP cloud and from the VoIP cloud to the PSTN. Local and long distance calls should be placed to multiple exchanges. Case-by-case trouble shooting is used to resolve any issues before service turn-over. By
confirming that all of the possible calls can be placed, a technician can confidently connect the CPE knowing that any signalling issues will not be within the carrier’s cloud.

Another important practice is to capture all test records gathered at this phase for baseline/SLA reference and for use during future troubleshooting calls.

### 13.3 Summary of optical testing tools

The following is a list of optical testing tools used for FTTH networks:

| Test Equipment                                      | Function                                                                 | Use                                                   |
|-----------------------------------------------------|--------------------------------------------------------------------------|                                                      |
| Inspection scope                                    | Visual inspection of connectors                                          | Fibre link construction and troubleshooting           |
| VFL (visual fault locator)                         | Continuity check up to 5km, break/bend visual identifier for fibre along patch panel/hub areas | Fibre link construction and troubleshooting at locations where fibres are accessible |
| Optical talk set                                    | Enables communication between engineers using cable link                 | When two engineers are required for end to end test   |
| Light source/power meter or bidirectional loss test set | Measures the fibre link insertion loss, tests continuity                 | Fibre link construction, acceptance testing and troubleshooting |
| Power meter only                                    | Measure the power output of equipments                                  | Equipment and fibre link turn up and troubleshooting   |
| Power meter with clip-on device                     | Estimates the optical power in the link                                  | Equipment and fibre troubleshooting at any location where fibres are accessible, even when connectors cannot be accessed |
| Clip-on fibre identifier                            | Identify traffic and traffic direction on fibre, may also estimate output power along the link | Equipment and fibre troubleshooting at any location where fibres are accessible, even when connectors cannot be accessed |
| 130/1490/1550 selective power meter with through mode | Measures the power levels of equipment and fibre link when OLT/ONT connected | Fibre link and equipment (ONT/OLT) turn-up and troubleshooting |
| ORL meter                                            | Measure the overall optical return loss                                 | Fibre link construction and troubleshooting           |
| OTDR                                                | Measures all the characteristics of the fibre link                      | Fibre link construction, acceptance, troubleshooting |
## Appendix A: IEC Standards

Overview of optical fibre and cable-related International Electrotechnical Commission (IEC) international standards for the access network:

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 60793-1-1 Ed. 2</td>
<td>Optical fibres - Part 1-1 – Measurement methods and test procedures: General and guidance</td>
</tr>
<tr>
<td>IEC 60793-2 Ed 5</td>
<td>Optical fibres – Part 2: Product specifications – General</td>
</tr>
<tr>
<td>IEC 60794-1-1 Ed2*</td>
<td>Optical fibre cables – Part 1-1: Generic specification – General</td>
</tr>
<tr>
<td>IEC 60794-1-2 Ed2*</td>
<td>Optical fibre cables – Part 1-2: Generic specification – Basic optical cable test procedures</td>
</tr>
<tr>
<td>IEC 60794-2-10 Ed 3.0</td>
<td>Optical Fibres – Part 2-10: Product specifications – sectional specification for category A1 multimode fibres</td>
</tr>
<tr>
<td>IEC 60794-2-50 ED 2.0</td>
<td>Optical Fibres – Part 2-50: Product specifications – sectional specification for class B single-mode fibres</td>
</tr>
<tr>
<td>IEC 60794-2 Ed3*</td>
<td>Optical fibre cables – Part 2: Indoor cables – Sectional specification</td>
</tr>
<tr>
<td>IEC 60794-2-10 Ed1*</td>
<td>Optical fibre cables – Part 2-10: Indoor cables – Family specification for simplex and duplex cables</td>
</tr>
<tr>
<td>IEC 60794-2-11 Ed1</td>
<td>Optical fibre cables – Part 2-11: Indoor cables – Detailed specification for simplex and duplex cables for use in premises cabling</td>
</tr>
<tr>
<td>IEC 60794-2-20 Ed1</td>
<td>Optical fibre cables – Part 2-20: Indoor cables – Family specification for multi-fibre optical distribution cables</td>
</tr>
<tr>
<td>IEC 60794-2-30 Ed1</td>
<td>Optical fibre cables – Part 2-30: Indoor cables – Family specification for optical fibre ribbon cables</td>
</tr>
<tr>
<td>IEC 60794-2-31 Ed1</td>
<td>Optical fibre cables – Part 2-31: Indoor cables – Detailed specification for optical fibre ribbon cables for use in premises cabling</td>
</tr>
<tr>
<td>IEC 60794-2-40 Ed1*</td>
<td>Optical fibre cables – Part 2-40: Indoor cables – Family specification for simplex and duplex cables with buffered A4 fibre</td>
</tr>
<tr>
<td>IEC 60794-2-50 Ed1*</td>
<td>Optical fibre cables – Part 2-50: Indoor optical fibre cables – Family specification for simplex and duplex optical fibre cables for use in terminated cable assemblies or for termination with optical fibre passive components</td>
</tr>
<tr>
<td>IEC 60794-3 Ed3</td>
<td>Optical fibre cables – Part 3: Sectional specification – Outdoor cables</td>
</tr>
<tr>
<td>IEC 60794-3-10 Ed 1*</td>
<td>Optical fibre cables – Part 3-10: Outdoor cables – Family specification for duct and directly buried optical telecommunication cables</td>
</tr>
<tr>
<td>IEC 60794-3-12 Ed1</td>
<td>Optical fibre cables – Part 3-12: Outdoor cables – Detailed specification for duct and directly buried optical telecommunication cables for use in premises cabling</td>
</tr>
<tr>
<td>Standard</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>IEC 60794-3-20 Ed1*</td>
<td>Optical fibre cables – Part 3-20: Outdoor cables – Family specification for optical self-supporting aerial telecommunication cables</td>
</tr>
<tr>
<td>IEC 60794-3-21Ed1</td>
<td>Optical fibre cables – Part 3-21: Outdoor cables – Detailed specification for optical self-supporting aerial telecommunication cables for use in premises cabling</td>
</tr>
<tr>
<td>IEC 60794-3-30 Ed1*</td>
<td>Optical fibre cables – Part 3-30: Outdoor cables – Family specification for optical telecommunication cables for lake and river crossings</td>
</tr>
<tr>
<td>IEC 60794-4 Ed1</td>
<td>Optical fibre cables – Part 4: Sectional specification – Aerial optical cables along electrical power lines</td>
</tr>
<tr>
<td>IEC 60794-5</td>
<td>Optical fibre cables – Part 5: Sectional specification for microduct cabling for installation by blowing</td>
</tr>
<tr>
<td>IEC 60794-5-10 (not published yet)</td>
<td>Optical fibre cables – Part 5-10: Family specification for outdoor microduct optical fibre cables, microducts and protected microducts for installation by blowin</td>
</tr>
<tr>
<td>IEC 60794-5-20 (not published yet)</td>
<td>Optical fibre cables – Part 5-20: Family specification for outdoor microduct optical fibre cable duct optical fibre units, microducts and protected microducts for installation by blowing</td>
</tr>
</tbody>
</table>
Appendix B: European Standards

Overview of optical fibre connectivity products related European Standards for the access network:

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 50733-1</td>
<td>Connector sets and interconnect components to be used in optical fibre communication systems – Product specifications – Part 1: General and guidance</td>
</tr>
<tr>
<td>EN 50377-2-x</td>
<td>Product specification – Part 2 – FC connectors</td>
</tr>
<tr>
<td>EN 50377-4-x</td>
<td>Product specification – Part 4 – SC connectors</td>
</tr>
<tr>
<td>EN 50377-7-x</td>
<td>Product specification – Part 7 – LC connectors</td>
</tr>
<tr>
<td>EN 50377-8-x</td>
<td>Product specification – Part 8 – LSH connectors</td>
</tr>
<tr>
<td>EN 50377-10-x</td>
<td>Product specification – Part 10 – MU connectors</td>
</tr>
<tr>
<td>EN 50377-14-x</td>
<td>Product specification – Part 14 – Patchcords</td>
</tr>
<tr>
<td>EN 50411-1</td>
<td>Fibre organisers and closures to be used in optical fibre communication systems – Product specifications – Part 1: Fibre organisers</td>
</tr>
<tr>
<td>EN 50411-2</td>
<td>Fibre organisers and closures to be used in optical fibre communication systems – Product specifications – Part 2: General and guidance for optical fibre cable joint closures, protected microduct closures, and microduct connectors</td>
</tr>
<tr>
<td>EN 50411-2-2</td>
<td>Product specification – Part 2-2: Sealed pan fibre splice closures Type 1, for category S &amp; A</td>
</tr>
<tr>
<td>EN 50411-2-3</td>
<td>Product specification – Part 2-3: Sealed inline fibre splice closures Type 1, for category S &amp; A</td>
</tr>
<tr>
<td>EN 50411-2-4</td>
<td>Product specification – Part 2-4: Sealed dome fibre splice closures Type 1, for category S &amp; A</td>
</tr>
<tr>
<td>EN 50411-2-5</td>
<td>Product specification – Part 2-5: Sealed closures for air blown fibre microduct, type 1, for category S &amp; A</td>
</tr>
<tr>
<td>EN 50411-2-8</td>
<td>Product specification – Part 2-8: Microduct connectors, for air blown optical fibres, type 1</td>
</tr>
<tr>
<td>EN 50411-3-2</td>
<td>Product specifications – Part 3-2: Singlemode mechanical fibre splice protectors</td>
</tr>
<tr>
<td>EN 50411-3-3</td>
<td>Product specifications – Part 3-3: Singlemode optical fibre fusion splice protectors</td>
</tr>
</tbody>
</table>
## Glossary

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADSS</td>
<td>all-dielectric self-supporting</td>
</tr>
<tr>
<td>APC</td>
<td>Angle-polished connector</td>
</tr>
<tr>
<td>ATM</td>
<td>Asynchronous Transfer Mode</td>
</tr>
<tr>
<td>CATV</td>
<td>cable television</td>
</tr>
<tr>
<td>CWDM</td>
<td>Coarse Wavelength Division Multiplexing</td>
</tr>
<tr>
<td>DWDM</td>
<td>Dense Wavelength Division Multiplexing</td>
</tr>
<tr>
<td>FCP</td>
<td>fibre concentration point</td>
</tr>
<tr>
<td>FBT</td>
<td>fused biconic tapered</td>
</tr>
<tr>
<td>FBT</td>
<td>fibre distribution hub (another term for FCP)</td>
</tr>
<tr>
<td>FTTC</td>
<td>fibre to the curb</td>
</tr>
<tr>
<td>FTTB</td>
<td>fibre to the building</td>
</tr>
<tr>
<td>FTTH</td>
<td>fibre to the home</td>
</tr>
<tr>
<td>FTTN</td>
<td>fibre to the node</td>
</tr>
<tr>
<td>FTTx</td>
<td>generic term for all of the fibre-to-the-x above</td>
</tr>
<tr>
<td>FWA</td>
<td>fixed wireless access</td>
</tr>
<tr>
<td>G.650</td>
<td>ITU Rec. G.650 Definition and testing methods for single mode fibres</td>
</tr>
<tr>
<td>G.651.1</td>
<td>ITU Rec. G.651.1 Characteristics of a 50/125 µm multimode graded index optical fibre cable for the access network (G.651 is obsolete)</td>
</tr>
<tr>
<td>G.655</td>
<td>ITU Rec. G.655 Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable</td>
</tr>
<tr>
<td>G.657</td>
<td>ITU Rec. G.657 Characteristics of a bending loss insensitive single-mode optical fibre and cable for the access network</td>
</tr>
<tr>
<td>Gbps</td>
<td>Gigabits per second</td>
</tr>
<tr>
<td>HDPE</td>
<td>high-density polyethylene</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute for Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IL</td>
<td>insertion loss</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organisation for Standardisation</td>
</tr>
<tr>
<td>IEC</td>
<td>International Electrotechnical Commission</td>
</tr>
<tr>
<td>ITU-T</td>
<td>International Telecommunication Unit – Telecommunications Standards</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LI</td>
<td>local interface</td>
</tr>
<tr>
<td>LSZH</td>
<td>low smoke, zero halogen</td>
</tr>
<tr>
<td>Mbps</td>
<td>Megabits per second</td>
</tr>
<tr>
<td>MMF</td>
<td>multimode fibre</td>
</tr>
<tr>
<td>MDU</td>
<td>main distribution unit</td>
</tr>
<tr>
<td>MDU</td>
<td>multi-dwelling unit</td>
</tr>
</tbody>
</table>

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**Fibre to the Home Council Europe**

101  www.ftthcouncil.eu
ODF  optical distribution frame
OLT  optical line termination (another term for ONU)
OLTS  optical loss test set
ONU  optical network unit
OPGW  optical power ground wire
OTDR  optical time domain reflectometer
PE  polyethylene
PMD  polarisation mode dispersion
PON  passive optical network
POP  point of presence
PTP  point-to-point
PVC  polyvinylchloride
RL  return loss
ROW  right of way
SMF  singlemode fibre
STP  shielded twisted pair
UPC  ultra polished connector
UPS  uninterruptible power supply
UTP  unshielded twisted pair
WDM  Wavelength Division Multiplexing
WLAN  wireless LAN (Local Area Network)