CHAPTER 4

OPTICAL SPLICES, CONNECTORS AND PASSIVE NODES

Introduction

This Chapter covers some optical passive elements used in the optical networks, such as optical fibre splices (clause 1), optical connectors (clause 2), passive node elements (clause 3), optical distribution frames (clause 4), optical closures and fibre organizers (clause 5), passive nodes elements for marinized and submarine optical cables (clause 6).

The attention is focused on aspects related to installation, service conditions, transmission, environmental and mechanical characteristics.

1 Optical fibre splices

(For further information, see Recommendations ITU-T L.12 and ITU-T G.671.)

Splices are critical points in the optical fibre network, as they strongly affect not only the quality of the links, but also their lifetime. In fact, the splice shall ensure high quality and stability of performance with time. High quality in splicing is usually defined as low splice loss and tensile strength near that of the fibre proof-test level. Splices shall be stable over the design life of the system under its expected environmental conditions.

At present, two technologies, fusion and mechanical, can be used for splicing glass optical fibres and the choice between them depends upon the expected functional performance and considerations of installation and maintenance. These splices are designed to provide permanent connections.

A suitable procedure for splicing should be carefully followed in order to obtain reliable splices between optical fibres. This procedure applies both to single fibres or ribbons (mass splicing).

All optical fibre splices mentioned in this Chapter should be suitable for indoor applications as well as for outdoor environments, when suitably protected in appropriate accessories.

1.1 Splice losses

As shown in Table 4-1 splice losses can be divided into two categories.

Table 4-1 – Extrinsic and intrinsic splice loss factors

Extrinsic joint loss factors	– transverse offset
	– longitudinal offset
	– axial tilt
	– fibre end quality
	– Fresnel reflections
Intrinsic joint loss factors	– fibre diameter variation (core and cladding)
	– refractive index profile mismatch (multimode)
	– Numerical Aperture (NA) mismatch (multimode)
	– mode field diameter mismatch (single-mode)
	– non-circularity and non-concentricity of fibre mode field (single-mode)

The first category of losses is related to the techniques used to splice fibres and is caused by extrinsic (to the fibre) parameters such as separation and transverse offset between the fibre cores, axial tilt and fibre end quality, as shown in Figure 4-1.

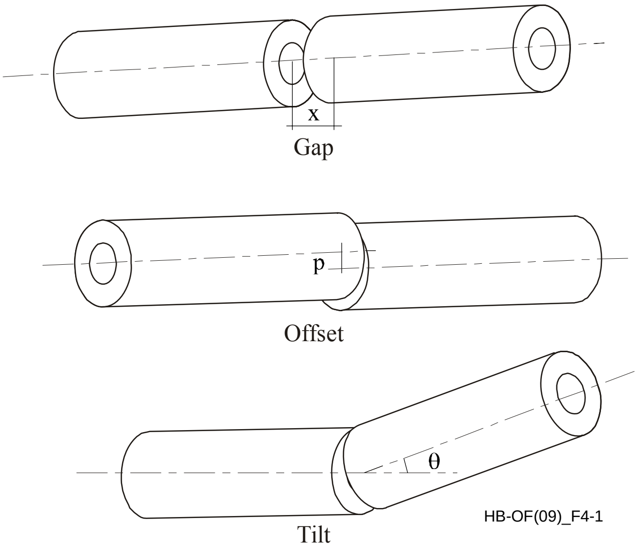

Figure 4-1 – Fibre misalignment

The second category of losses is related to the properties of the fibres spliced and is referred to as intrinsic splice loss. Intrinsic parameters include variations in fibre diameter (both core and cladding), index profile (shape factor and delta mismatch) and non-circularity of the fibre cores. In addition, bending stresses imposed upon the fibre by the splice protection package and/or the fibre organizer must be considered.

1.2 Fusion splices

Different methods exist to obtain a fusion splice of fibres or ribbons. Electric arc-fusion is the most widely used method to make reliable single or mass optical splices in the field. The fusion process is realized by using specially-developed splicing machines.

To make a fusion splice, all the protective coatings are removed from the fibre, the fibres are cleaved and then positioned and aligned between two electrodes in the splicing machine. An electric arc heats the silica glass until the “melting” or softening point is reached and at the same time the fibres are brought together longitudinally in such a way that a geometrically continuous splice is obtained. This process produces a continuous glass filament. The fibre alignment in these machines can be passive (v-groove alignment) or active (light injection and detection system or core/cladding profile monitoring and alignment system). A suitable protection device is then applied to the splice to protect the bare fibre and to allow handling and storage without adversely affecting the physical integrity of the splice. The cleave quality and the intensity and the duration of the arc as well as the differences between the two fibres to be spliced determine the splice loss. In addition, the quality of coating removal, fibre cleaving and splice protection contribute to the long-term mechanical reliability in the field.

1.3 Mechanical splices

Mechanical splices have different structures and physical designs, and usually include the following basic components:

i) surface for aligning mating fibre ends;

ii) a retainer to keep the fibres in alignment;

iii) an index matching material (gel, grease, adhesive, etc.) placed between the fibre ends.

They can be used for single fibres or ribbons. Some designs allow installation on the fibres at the end of a cable in the factory for faster jointing in the field.

An optical matching material between the ends of the fibres can be used to reduce Fresnel reflections. This material shall be chosen to match the optical properties of the fibre. Common index matching materials include silicon gels, UV-curable adhesive, epoxy resins and optical greases. The index of refraction of these materials has a temperature dependence different from the glass fibre.

1.4 Splicing procedure steps

1.4.1 Fibre preparation

For jelly-filled cables, the fibres shall be mechanically cleaned of the water-blocking jelly of the cable using lint-free paper tissue or cotton cloth. Care shall be taken so that the ribbon matrix material and fibre coatings are not damaged either mechanically or chemically. Long-term soaking in solvents can damage the fibre coating.

Where applicable, secondary coatings (tight buffer or loose tube constructions) shall be removed to the distance recommended by the splice protector manufacturer using an appropriate tool in order to expose the primary coating.

Coating removal could be the most critical operation in the splicing procedure, especially if it has to be performed on fibres that have been in the field for many years. The ability to remove coating may be more difficult due to ageing. Therefore, this step must be performed carefully, because the final strength of the completed splice depends on minimizing the exposure that can cause flaws on the bare fibre.

The stripping method could be chemical, thermal or mechanical, depending on the applications and on the desired performance.

When fibre end cleaning is needed, the bare ends shall be cleaned with paper tissue soaked with reagent grade alcohol to eliminate residual coating, paying attention not to break them. Avoid wiping the fibre more than necessary to clean off debris.

The bare fibre ends shall be cleaved perpendicularly with respect to the longitudinal axis; the cut surface shall be mirror-like without chips or hackle.

For fusion splices, end angles shall be typically less than 1° from perpendicular for single fibres and less than 3° to 4° for ribbons (depending on the fibre type) to achieve a satisfactory splice. The cleaving tool shall be capable of achieving these values with a controlled length of bare fibre, compatible with the splicing system and protection device.

For mechanical splices, two types can be identified: perpendicular cleaved, with typically the same cleave angle as fusion splices; and angle cleaved, with a cleave angle of at least 4°.

1.4.2 Splicing

1.4.2.1 Electric arc-fusion splicing

Before using the splicing machine, it is fundamental to check its performance. The condition of the electrodes is a critical factor determining whether fusion splicing will proceed normally, especially when working at environmental extremes.

Machine performance is sensitive to atmospheric variations. Either automatic or manual adjustment of arc parameters shall be made to optimize for the existing conditions.

Since the optimal splice conditions (arc current, arc time, etc.) may depend on both the characteristics of the type of fibre as well as the characteristics of the splicing machine, it is recommended to use an arc test procedure, available in many splicing machines.

When testing of the arc condition is completed, splicing can commence. The fibre shall be positioned in the v-grooves of the splicing machine (Figure 4-2).

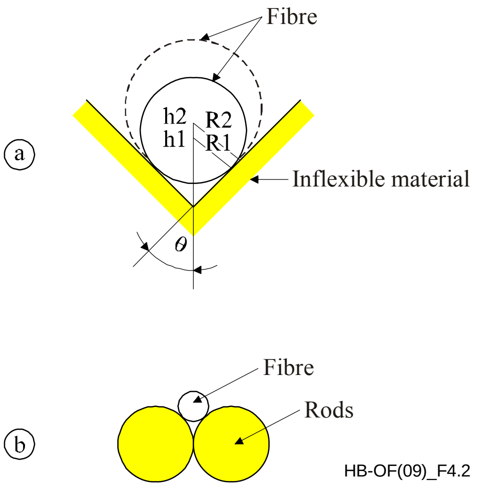

Figure 4-2 – V-groove or two-cylinder alignment

Fusion splicing machines, in general, are divided into two types: active or passive alignment. The use of either type depends on how the fibres are aligned. Active alignment machines use either a vision system or local injection/local detection system and three-dimensional movement of the fibres to actively align the cores or the outside diameters of the two fibres being spliced. The splicing machine minimizes the splice attenuation by either focusing on the core or cladding of the fibres with its vision system to directly align them or optimizing the transmitted light through the fibres and providing an estimate of the splice attenuation after the splice is complete (Figure 4-3).

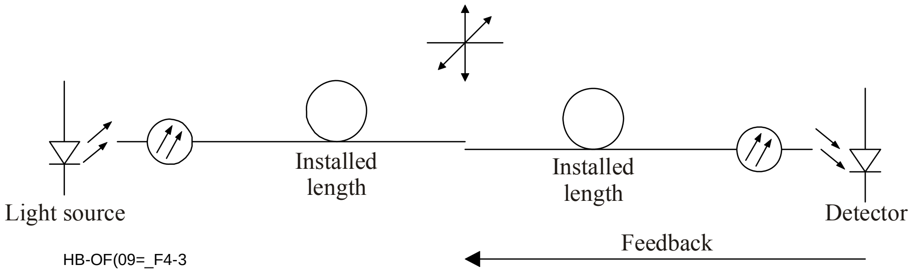

Figure 4-3 – Example of active core alignment

Those systems that compensate for core concentricity errors provide better results in terms of splice attenuation. Splicing machines that use active alignment systems are only suitable for single fibre splicing at this time.

Passive alignment machines use only fibre longitudinal movement so accurate core alignment depends on good fibre geometry. The passive alignment system is currently used to splice ribbons and is also used in single fibre splicing machines where an estimate of splice attenuation may also be provided. For ribbon cables, however, all of the current mass fusion machines estimate splice attenuation by observing fibre alignment before and/or after splicing.

After the splice is completed, it is necessary to check its minimum strength. It is very important to establish a defined level of mechanical strength for the splice that is related to its expected lifetime. As performed for optical fibres just after manufacturing, the splice is subjected to a tensile proof-test for a short period of time. Some splicing machines perform this test with the spliced fibres in the splicing chucks and some perform it after placing the spliced fibres in the holders for heat-shrink protector application. Splices that have their strength below the proof-test level shall be eliminated.

After the proof-test, the protector shall be positioned over the spliced point. The “protector” is a mechanical device or restored coating that provides both mechanical and environmental protection to the single or multiple splices. In all cases, the protection device shall affect neither the attenuation of the splice, nor its functional properties.

Protector designs may include heat-shrink sleeve, “clam-shell”, fibre re-coating, re-coating devices and encapsulating protectors. The protectors for single fibre fusion splices shall be capable of accepting either 250 μm (nominal) diameter coated fibres, 900 μm (nominal) diameter buffered fibres, or 250 μm/900 μm combinations. Typically, these protectors require tools or equipment to install or make.

The protector designs shall be suitable for either aerial, underground or buried applications while stored inside an appropriate enclosure. The manufacturer shall provide information on the compatibility with the splice organizer trays and on the tools or equipment for its application. In particular, the manufacturer shall provide information on the minimum/maximum fibre strip lengths that the protector will accommodate and on the storage dimensions for the completed protector (length, width and height) and on the application details.

1.4.2.2 Mechanical splicing

The mechanical method allows fixing the fibres in a splice-protective housing, generally without the need for electrical power. Some mechanical splices can be tuned by hand for minimum splice loss. An example of multiple mechanical splice is in Figure 4-4.

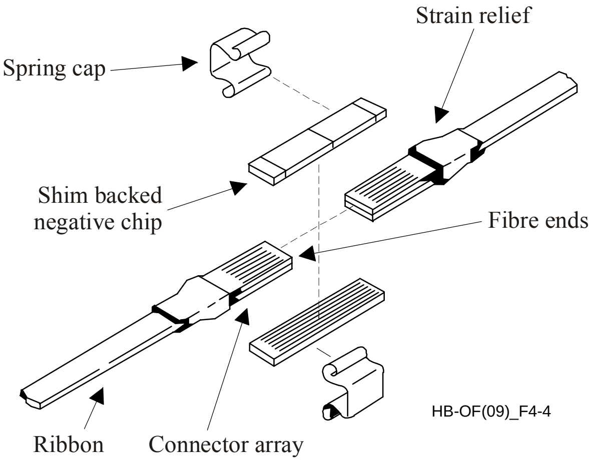

Figure 4-4 – Multiple fibre mechanical splice

After stripping and cleaving operations, described in § 1.4.1, the fibre bare ends are inserted in the mechanical housing (in a guiding structure, for instance a v-groove) and checked for their physical contact. For angle-cleaved splices, it is recommended to maintain the relative orientation of the angled end faces of the fibres during installation in order to obtain optimal optical performance.

For mechanical splices, the proof-test is generally not a part of the installation sequence as it is for fusion splices.

Sometimes, the fibre ends are prepared for splicing by grinding and polishing procedures, especially in factory pre-terminated mass splices.

The mechanical splices shall be versatile, allowing the splicing of different types of fibres, for example, 250 µm with 900 µm diameter buffered fibres.

The integral housing of the splice (different for single or multiple splices) provides mechanical and environmental protection. They shall be suitable for aerial, underground or buried applications. The manufacturer shall provide information on the compatibility with the splice organizer trays and on the tools or equipment for their application.

The index matching material used between the ends of the mating fibres shall be chosen to match the optical properties of the glass. The supplier of the index matching material shall provide complete information about its behaviour at different temperatures (especially the extremes) and its estimated lifetime in terms of maintaining the initial optical performance.

In mechanical splicing, the splice protection is built into the splice design and separate protectors are not required.

1.4.2.3 Field splice loss measurements

One critical requirement for an optical fibre communication system is the total end-to-end loss of each link. Considering the number of splices in a link, a realistic maximum splice loss should be set.

In practice, the field measurement of each splice loss during construction of a fibre route can be indicated by the fusion splicing machine (when loss estimation is a facility) to decide whether the splice should be remade; the use of one-way OTDR (Optical Time Domain Reflectometer) measurement is not recommended. After construction is complete, the actual splice loss in the field should be determined by bidirectional OTDR if necessary.

For single-mode fibre the true splice loss is determined by the bidirectional average of the OTDR readings at a splice. A one-way OTDR measurement should not be used as actual splice loss because Mode Field Diameter (MFD) tolerances and other intrinsic parameter differences in fibres can cause gross errors. In case of single-mode fibres, OTDR single direction readings can be high, being either positive or negative. In addition, any measurable spike from a fusion splice requires that the splice be remade. Acceptance levels for splice loss before remake depend on the loss budget of the link.

Recommendation ITU-T G.671 gives a maximum value of 0.3 dB for the insertion loss of fusion splices with active alignment and a maximum value of 0.5 dB for the mechanical splices and for fusion splices with passive alignment. All these values should be considered as worst-case end-of-life values over all specified temperature, humidity and perturbations.

2 Optical connectors

(For further information, see Recommendations ITU-T L.36 and ITU-T G.671.)

Fibre optic connectors provide a method for jointing the ends of two optical fibres. Such a joint is not a permanent one, but it can be opened and closed several times. The optical connectors are required in the points of the network in which it is necessary to have flexibility in terms of network configuration and test access. A generic connector is shown in Figure 4-5.

Fibre optic connectors have application in all types of network, at the input and output ports of the transmission systems and are also used to connect test equipment and instrumentation.

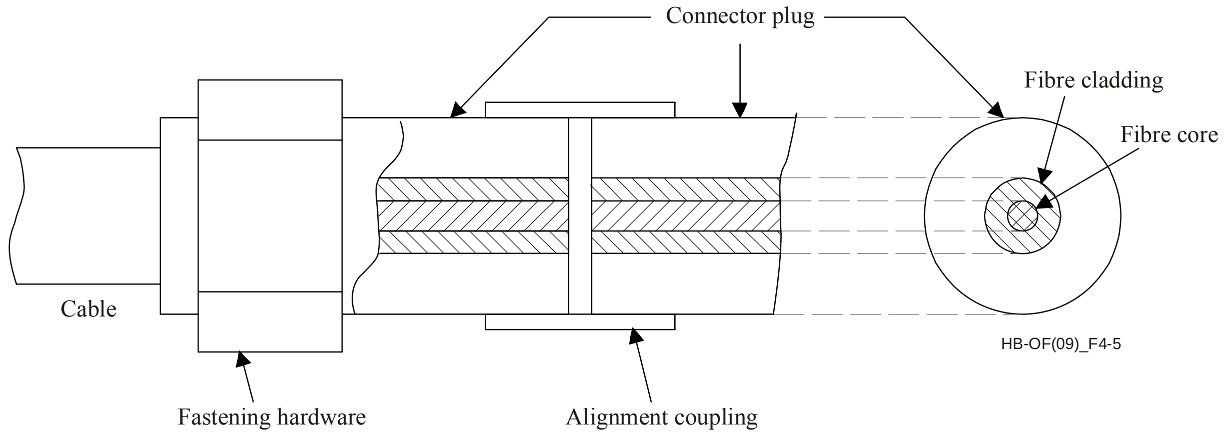

Figure 4-5 – Generic connector

The connection can have a plug-adapter-plug or a plug-socket configuration.

The main effects of the introduction of a connector in an optical line are attenuation of the transmitted signal and reflection of part of the signal.

2.1 Types and configurations

Fibre optic connectors can be classified on the basis of:

i) the type of fibre;

ii) the type of cable;

iii) the fibre alignment system;

iv) the fibre end face finish;

v) the type of coupling mechanism;

vi) the number of jointed fibres;

vii) the outer diameter of the ferrule *(*2.5 mm or 1.25 mm*)*;

viii) the connector mating lay out (“plug and socket” or “plug-adapter-plug”).

Additionally, the fibre density achievable with different type of connectors (the connector “Form factor”) plays an important role in situations where a high number of connectors has to be packed in limited space (e.g. in an optical distribution frame, as shown in § 4.3.2).

2.1.1 Fibre types

The type of connector and in particular its grade of mechanical accuracy depend on the type of fibre to be jointed. The fibres to be considered are those specified in Recommendations ITU-T G.651.1 through ITU-T G.657. Note that great accuracy is necessary to align two single mode fibres in which the light is guided in a core of about 9 µm or less.

2.1.2 Cable types

The connector can be assembled with:

i) primary coated fibre (250 µm);

ii) secondary coated fibre (900 µm);

iii) single fibre cable (typically from 1 mm to 3 mm).

2.1.3 Fibre alignment system

i) *Direct alignment*: In this type of solution the bare fibre is directly aligned by V-groove or capillary tubes;

ii) *Secondary alignment*: In this case the fibre is fixed in a structure. These structures are usually cylindrical ferrules for single or duplex fibre connections, or rectangular section bodies for duplex or multiple fibre joints. These structures are aligned by means of sleeves, pins or other systems;

iii) *Lens alignment*: The optical alignment of the fibres is obtained by means of a lens.

The alignment ii) is the most commonly applied. Loss criteria of most standards are established for this type of connector.

2.1.4 Fibre end face finish

For both direct alignment and ferrule-based connectors, the end face of the fibre or the ferrule is prepared (normally by polishing) to give fibre-to-fibre contact, either where the end faces are perpendicular to the fibre axis, or at a small angle to the perpendicular.

2.1.5 Coupling mechanism

The most common systems for mating together two plugs (or the plug and the socket) are:

i) push-pull mechanism;

ii) screw mechanism;

iii) bayonet mechanism.

2.1.6 Number of jointed fibres

Essentially, all of the connectors used today join single fibres. However, to join fibre ribbons or join ribbons to individual fibres (fanouts), there is application for a multiple-fibre connector. Multiple-fibre connectors permit higher spatial density of fibre connections.

Connections can be made between ribbons, fanouts or ribbons to fanouts. Examples of fanout connectors are shown in Figure 4-6.

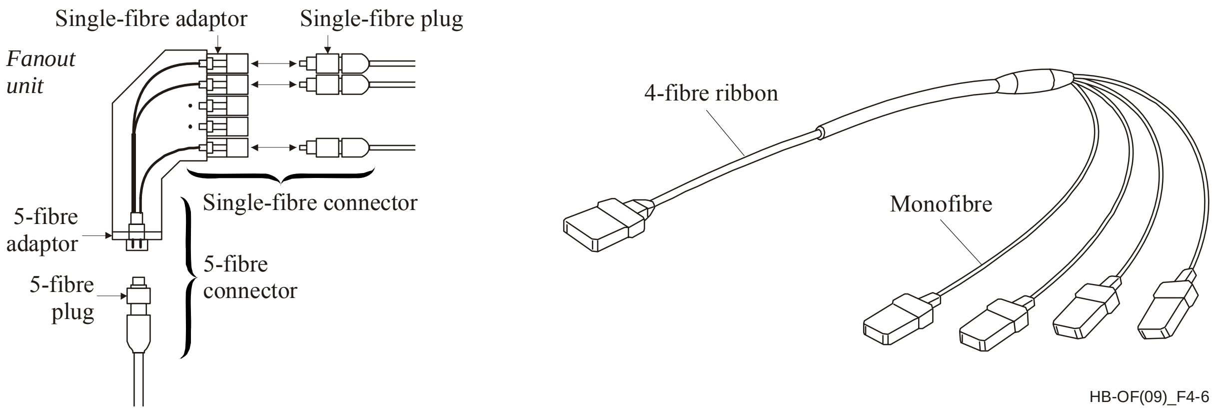

Figure 4-6 – Fanout connectors

2.2 Connector performance parameters

The primary factors affecting optical performance of fibre optic connectors are insertion loss and return loss. Both of these should be measured and expressed in terms of randomly selected product-to-product mating.

The intrinsic properties of the fibres, circularity, concentricity, numerical aperture, mode field diameter, etc., affect connectors in the same way as they do splices. They may lead to variations in insertion loss that are not attributable to connector performance and should be selected to minimize these effects. In connectors the dominant cause of insertion loss is fibre-to-fibre transverse offset, but the angular offset of the fibre also has a significant effect.

Optical-fibre connectors shall be constructed so that they will survive the normal mechanical handling and stresses that occur in the outside plant applications without degradation of optical performance. Standard post-handling cleaning procedures, as recommended by the manufacturer, should be in place to guarantee optical performance along the life span of the connector.

The outside plant environment varies greatly from season to season and from one geographic area to another. For an optical transmission system to operate satisfactorily under changing environmental conditions, the components of the system should be insensitive to these changes. A number of tests have been developed to stress the connectors in a controlled manner to allow a prediction to their performance in the outside plant environment.

More information on the tests to be carried out on the optical connectors, on the test methods and on the values which could be expected is in Recommendation ITU-T L.36. In particular, the transmission parameters that characterize the optical connectors are listed, with the relevant test methods, in Recommendation ITU-T G.671.

3 Passive node elements for fibre optical networks

(For further information, see Recommendation ITU-T L.51.)

The quality of an optical network is determined by the performance of each of its individual components. Nodes in this network are one of the key components of the physical network.

A “node” is defined as a point of intervention in the network, e.g. it occurs at each opening or end of a cable jacket. “Passive” applies to nodes that do not contain active electronics or other devices that are exothermic. Examples of passive nodes are optical distribution frames, joint closures for underground and aerial applications, street cabinets etc. Each node shall be capable of performing its expected function in the network, while exposed to the environment in which it is intended to reside.

3.1 General requirements for passive node elements

In order to achieve and to maintain a suitable network performance level the passive optical nodes should be able to properly store and protect all compatible passive devices without altering their performance characteristics. Examples of passive devices are:

- i) splices and splice protectors;
- ii) optical connectors;
- iii) other optical components.

In order to obtain an end-to-end reliable network, all different network nodes shall be evaluated using the same methods and metrics.

A network node should be able to fulfil its optical functionalities, including the ability to be reconfigured, in all conditions of the environment, in which the node will reside.

3.2 Fibre reconfiguration

In a node, the optical fibres are to be properly managed and guided from where a cable or pigtail enters the node, to where it leaves again. A *fibre organizer*, put inside the node, comprises the whole of the means and features that are intended to guide and store fibres, pigtails, splices, connectors and passive devices inside a node, at any location where they are not protected by the cable sheath. (See also Recommendation ITU-T L.50).

Moreover, the fibre organizer system of a node shall provide features and methods to store fibre excess lengths (over-length) in a reliable and consistent way. The organizer system shall provide the means to manage the related over-length in an orderly manner (i.e., controlled bend radius, accessibility). Fibre over-length is related to:

i) *Splices*. The fibre over-length is typically to be stored on the same organizer element as the splices. It will permit the removal of the splice to the splicing equipment or tools and back to the splice holder. The length should be such that it allows at least 3 resplices. If reconfiguration is necessary, the over-length should be sufficient to allow rerouting and storage of a splice in any other splice position in the organizer system;

ii) *Uncut fibre at initial installation*. The unused fibres remaining after opening the cable shall not be cut, but shall be stored together or separately. These fibres may be branched at some future time. Therefore, the over-length of the uncut fibres shall be sufficient to meet the splicing requirements of the above paragraph i);

iii) *Patchcords and pigtails*. Optical connectors are used at nodes where frequent reconfiguration is expected. Connectors may need to be rerouted to different positions with the same pigtail length. The length of pigtails and patchcords should be such that they can reach all required positions within the organizer system;

iv) *Unspliced fibre ends*. At some nodes, non-live fibre ends need to be stored. Depending on the future destination, they may be stored *en masse*, by element, or individually. This can be done in a storage basket, a dedicated storage area for unspliced fibre, or on splice trays.

3.3 Application environments

Once installed, optical nodes typically may reside in one of the basic environments quoted in Table 4-2.

Table 4-2 — Application environments

Indoor	temperature controlled	IC
	non-temperature controlled	IN
Outdoor	above ground	OA
	at ground level	OG
	under ground (sub-terrain)	OS

The five basic environmental classes indicated in Table 4-2 cover the majority of the applications around the globe and can be described as follows:

i) IC: Indoor temperature controlled

   - inside buildings protected by a roof and walls all around, heating or air-conditioning available;
   - contact with chemical and biological contaminants is negligible, e.g. inside central offices, some remote network buildings/houses, residential buildings.

ii) IN: Indoor non-temperature controlled

   - inside buildings protected by a roof and walls all around, no heating or air-conditioning available;
   - contact with chemical and biological contaminants is negligible, e.g. cable vaults, basements, remote network buildings/houses, inside garages, warehouses, homes.

iii) OA: Outdoor above ground

   - all outdoor non-sheltered locations, above ground level;
   - no other sources of heat or extreme temperatures than the surrounding air or solar radiation;
   - exposed to contaminants and dust that may occur in the atmosphere in rural, city or industrial areas, e.g. wall mounted, pole mounted, strand mounted nodes.

iv) OG: Outdoor ground level

   - outdoor, standing on the ground, perhaps with a base that resides partially below the ground; this class may also apply to outdoor, wall mounted products that are close to ground level;
   - exposed to contaminants and dust that may occur in the atmosphere in rural, city or industrial areas. The base of the product may be permanently in contact with soil, biological and chemical contaminants that occur at or just below ground or street-level, e.g. along roads, pavements and railroads.

v) OS: Outdoor underground (sub-terrain)

   - outdoor below ground level;
   - exposed to soil or water-borne contaminants, including organic and inorganic agents related to the presence of roads and traffic, e.g., in manholes, handholes or direct buried.

Table 4-3 summarizes the typical parameters for the five basic environmental classes.

When a node is exposed to conditions that are more extreme than those defined in these five basic environmental classes, this is to be classified as an "*extreme*" *environment (E)* which is defined as:

- any environment for which at least one of the environmental parameters exceeds the boundaries of the five basic environmental classes as specified above: e.g. more extreme temperature excursions.

In this case specific test settings are to be agreed between supplier and customer.

Table 4-3 – Summary of typical parameters for the basic environmental classes

	Indoor		**Outdoor**		
	IC	**IN**	**OA**	**OG**	**OS**
Exposure	**Temp controlled**	**Temp non-controlled**	**Above ground**	**Ground level**	**Underground**
Temp Min (°C)	+5	–10	–40	–40	–30
Temp Max (°C)	+40	+60	+65	+65	+60
Solar Radiation	No		Yes	Yes	No
Relative Humidity (max) (%)	93% (decreasing once above 30° C)		100% (occasional/permanent exposure to water possible)		
Precipitation	No		Rain, Snow, etc.	Rain, Snow, etc.	N.A.
Submersion	No (Note 2)		No	No (Note 2)	Yes
Vibration (m/s^2)	10-55 Hz 1 m/s^2 (~0.1 g) (whole system) 5 m/s^2 (~0.5 g) (components)		5-500 Hz 10 m/s^2 (~1 g) (due to e.g., traffic, wind, etc.)		
Chemical	Negligible (Note 1)		Atmospheric	Atmospheric + Soil (base only)	Soil/waterborne
Biological	Negligible		Atmospheric	Atmospheric + Soil (base only)	Soil/waterborne

NOTE 1 – In areas where corrosive atmospheres can be expected (marine and coastal areas, industrial areas, urban pollution), increased corrosion protection may be requested as an additional requirement.

NOTE 2 – If accidental flooding may occur, e.g., in vaults or basements, this is to be added as a conditional requirement.

4 Optical distribution frames

(For further information, see Recommendation ITU-T L.50.)

An optical passive node, which resides in a central office environment, is generally contained in a rack or frame. This is commonly referred to as an optical distribution frame (ODF) or optical termination frame (OTF).

The term *ODF* refers to a frame including the fibre organizer and the means to store and guide pigtails and cables inside the frame. ODF does not include the means for routing cables or pigtails outside the frame (also known as pigtail ducts or "raceway" systems).

The term *Frame* refers to the mechanical structure to which cables are attached and that holds all other elements of the ODF. It may be a rack and shelve type of structure, similar to what is used to contain the electronics, as well as any other type of structure. Its main functions are: mechanical support and a basic level of protection of its content.

Since ODFs are optical passive nodes, the general principles outlined in § 3.1 are applicable.

The specific requirements for ODFs are given below, sorted by their typical functions. Not all of these functions are necessarily present simultaneously in each individual ODF.

4.1 General characteristics

The ODFs provide for the general functions of test access and organizing the cable fibre, connectors and jumpers at termination nodes and distribution nodes in the fibre network (Figure 4-7). The functionality and flexibility of a fibre distribution unit is especially important when the fibres in the network are to be brought into service over a period of time, with types of service, geographic distribution of service, connector type and activation procedures which may change.

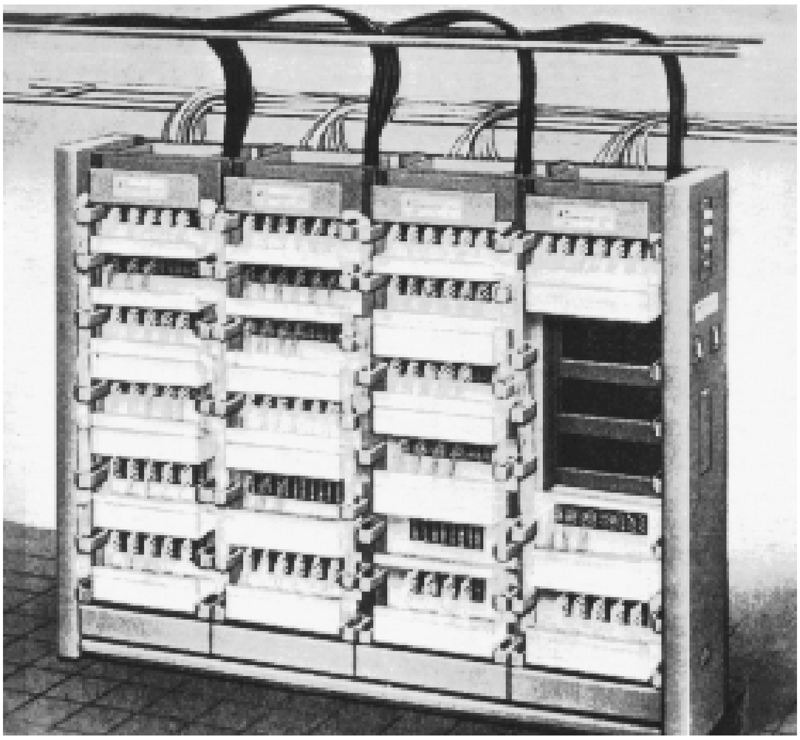

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Figure 4.7 – Optical fibre distribution frame (with jumpers)

There are two main configurations for terminating cable fibres at a distribution frame. Connectors can be installed on the cable fibres that are then connected to a bulkhead connector on the frame, or a connectorized pigtail is spliced to the cable fibre. The pigtail is then connected to the bulkhead connector.

Jumpers then connect the distribution frame to the transmission equipment. Jumpers are comprised of two connectors joined by a length of fibre with strength members and protective means. A jumper is used to connect a bulkhead connector to nearby transmission equipment. A jumper is also used to connect two bulkhead connectors and establish a network path that can be readily rearranged. Jumpers usually are long enough to reach the longest distance expected. Many of them have excess lengths that must be organized.

In cases where rearrangements are not expected to occur, the cable fibres may be taken directly to the equipment frames and connected directly to the transmission equipment eliminating the distribution frame or patch panel (Figure 4-8).

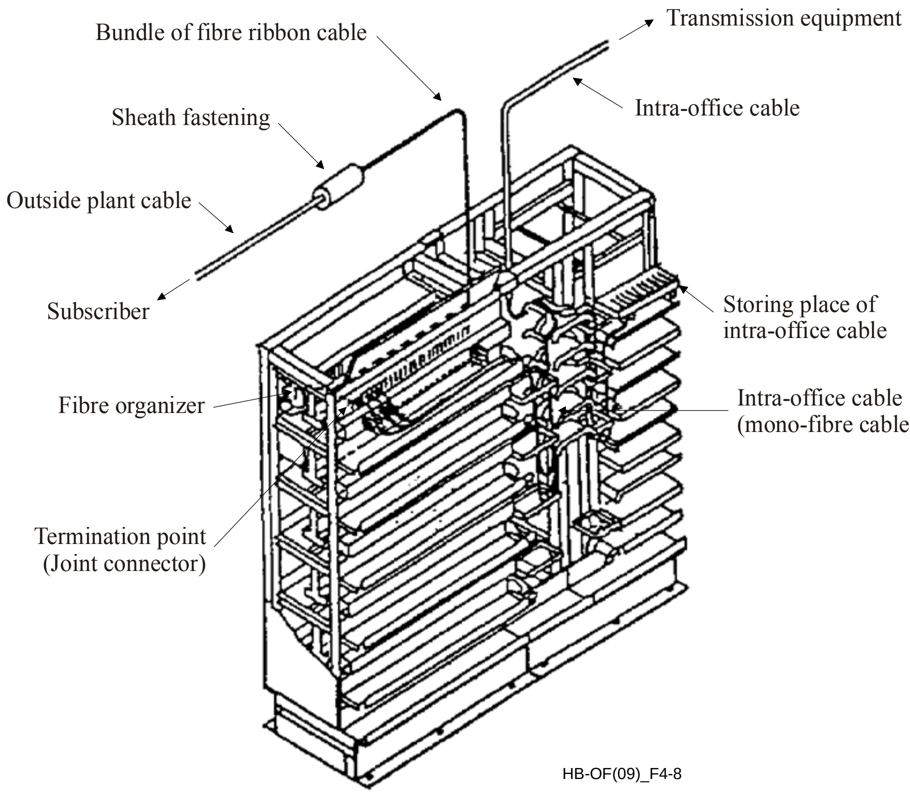

Figure 4-8 – Optical fibre distribution frame (without jumpers)

In order to provide for replacement of connectors, pigtails and fibre splices, due to errors or rearrangement, excess fibre is stored in a *fibre organizer* near the fibre splice. Frequent changes may require access to individual fibres. Frequently the organizer and the fibre splice holder are integrated into one unit. Furthermore, the ability to accommodate various connector types within the same organizer unit may also be considered. For more information about fibre organizers see § 5.2.

4.2 Applications

Typical applications of the ODFs are the following:

i) *Fibre termination at transmission equipment*. The rapid pace of technological change in electro-optic transmission equipment implies that the fibre network will be used to connect several generations of transmission equipment. A fibre distribution unit is used to provide a standard termination node for the fibre network to which transmission equipment can be readily connected. Sometimes the fibre distribution unit is mounted in the same rack of cabinet as the transmission equipment. The connectors in a termination application are sometimes replaced by fibre splices, reducing the number of connectors in the link.

ii) *Fibre rearrangement at network nodes*. Changes in types of topography, wavelength, fibre, service, geographic distribution of service, response to service interruptions, etc., imply that a high degree of flexibility is needed.

An ODF should be re-accessible without interruptions to the live circuits, other than the ones that are subject to reconfiguration.

An ODF should allow the termination of one or more cable ends of various cable construction and diameter (attachment of the cable sheath, termination of strength members, and electrical connection of metallic cable elements).

The ODF should be able to properly store fibre splices, different types of passive devices (including coupler and filter devices, used for network testing purposes) and the related bare fibre or ribbon overlengths.

It should be possible to connect and reroute any incoming circuit to any outgoing circuit, with a fixed length of patchcords or pigtail end. Each individual connector must be accessible, without the need to disconnect other (adjacent) connectors.

An ODF contains an organizer (see § 5.2) with the necessary means to guide and store pigtail overlengths in an orderly manner;

iii) *Testing*. The connectors in a fibre distribution unit permit attachment of test equipment such as power meters or optical time domain reflectometer to locate breaks and measure loss.

iv) *Signal modification*. The connectors are also convenient locations to attach passive signal modification devices such as attenuators. Couplers or wavelength division multiplexers may also be attached, although it is more common for them to be separated.

4.3 Design consideration

4.3.1 Cable fibre and jumper management

It is recommended that the bend radius of a fibre should not be smaller than 30 millimetres to ensure the residual strain of the fibre will not exceed 0.2%. However, for some fibre designs, a larger bend radius may be necessary to prevent an increase in optical loss at long wavelengths.

Splices of fibres in service should not be disrupted by installation of new fibres or maintenance of other installed fibres. There are many types of fibre splices. It can be expected that there will be new ones in the future. Fibre distribution units should be chosen to accommodate all the types of splice that are anticipated to be used, and to adapt easily to new ones.

A suitable slack should be foreseen so that the cable fibre stored in the fibre organizer should not experience bends below the above-referred value. In addition, the fibres in service should not experience such bends, e.g. when other fibres are being brought into service or when fibre splices are replaced. This includes bends in the fibre outside the organizer due to motion of the fibre organizer in storing or gaining access to it.

4.3.2 Connectors management

There is a large range in the number of connections in a fibre distribution unit. In central offices and network nodes, there may be up to 500 or more connections. At customer premises there may be only one or a few connections. Furthermore, more fibres are usually installed than are needed; some are connected at once, with the remainder being brought into service as demand increases. Usually the excess fibres are not connectorized and, therefore, the number of connectors usually increases with time.

There is also a large range in the available space at a network node or termination node. Usually the space originally planned for the fibre termination unit becomes too small, as unexpected demand and growth occurs. A fibre distribution unit should provide for a high density of connectors while maintaining easy access and allowing effective management.

Technological evolution, ordinary wear and breakage imply a shorter life for the bulkhead connector than for the fibre network. A fibre distribution unit should provide for easy replacement of a bulkhead connector without affecting the fibres in service.

4.4 Climatic considerations

As pointed out above there is a wide range of climatic factors for fibre distribution units. Many are installed inside human-occupied spaces and have mild temperature and humidity variation. Some may be installed in the outside plant and need to endure broad temperature and humidity variations. Fibre distribution units installed in the open and exposed to the sun's radiation typically receive more thermal stress than those installed in central offices near transmission equipment.

4.5 Mechanical considerations

Fibre distribution units are installed in a wide variety of situations, including rack, cabinet and wall mounting. As fibre is often added to an existing network, small size is important.

Fibre distribution units installed in the open and in manholes will receive more mechanical stress than those installed in central offices and other buildings near transmission equipment.

Experience indicates that more fibre optic cables are added to the network over time. A fibre distribution unit that can grow in incremental additions will gracefully accommodate new cables.

5 Fibre closures and fibre organizers

(For further information, see Recommendation ITU-T L.13.)

5.1 Optical closures

A node occurs at each opening or end of a cable sheath. When an optical node resides in an outdoor environment, it is generally contained in a sealed enclosure. This is commonly also referred to as an optical closure, optical cable joint or optical sheath joint. Here the term "optical closure" will be used.

An optical closure comprises a mechanical structure (closure housing) that is attached to the ends of the sheaths joined and a means (organizer) for containing and protecting the fibres and passive optical devices.

The term closure housing only refers to the sealed container or box, not including the organizer system. Its main functions are: sealing to the cables, mechanical attachment of the cable and protection of its content.

The fibre organizer is described in § 5.2.

The optical closure will:

i) restore the integrity of the sheath, including mechanical continuity of strength members when required;

ii) protect the fibres, fibre joints and optical devices from the environment in all types of outdoor plant (aerial, direct buried, in ducts and underwater);

iii) provide for the organization of the fibre joints, passive devices and the storage of fibre overlength;

iv) provide electrical bonding and grounding of the metal parts of the sheath and strength members where required.

An example of fibre closure is in Figure 4-9.

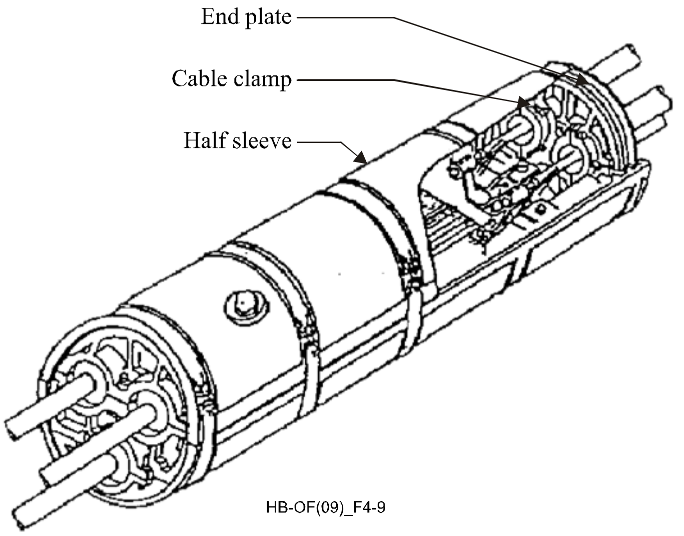

Figure 4-9 – Example of closure

5.1.1 Design characteristics of optical closures

Each optical closure must comply with the general requirements listed in § 3.1.

Closure housing designs employ either cold or hot systems depending on the sealing methods used. Mastic, tapes, grommets, o-rings, cured rubber shapes, pastes, potting compounds, rubber gels and (cold) adhesives are cold processes. Thermo-shrinkable materials, hot-melts and polyethylene injection welding are the primary hot processes. The heat source may be electrical resistance heating, infrared heating, hot air, or a gas flame. Regardless of which of these processes is used, the following shall be considered:

i) the materials used for making the cable joint shall be compatible with each other, with the materials of the sheath and with other materials normally used in the outside plant;

ii) a design may allow for jointing together two or more cable ends. The cables entering the closure may be of differing sizes and/or types;

iii) a design should allow for jointing together at least one pair of cables which are not at the end of a cable i.e., without cutting all the fibres between both cable ends (this application is also known as “external node”, “mid-span closure” or “balloon splice”);

iv) it is desirable that closures can be re-opened when necessary and remade without interruptions to working circuits;

v) a single design, which may be used for all of the above applications and in all outdoor environments;

vi) if joint sealing encapsulant is used, information is required for adjustments in setting time due to variations in ambient temperature and humidity; the use of encapsulant is not recommended for re-enterable closures;

vii) if a heat source is required to seal the closure and/or closure to the sheath, a suitable heat source (gas flame or electrical power) needs to be available at the jointing points. Consideration shall be given to control of the heat source to protect personnel and prevent damage to the closure or cable;

viii) all materials that are exposed to the environment must be sufficiently resistant to fungi. Materials that will be exposed to solar radiation must be UV-resistant.

5.2 Fibre organizers

5.2.1 Design of the organizer system

Fibre organizers are an integral part of an optical closure. The organizers are comprised of one or more sheets or trays that have means for routing and holding fibre joints and fibre over-length in an orderly manner, and should minimize fibre strain.

5.2.2 Characteristics of fibre organizers

The functions of an optical fibre organizer are:

i) to provide means for routing, storing and protecting fibre joints or other passive devices in a predetermined order, from one cable sheath end to another;

ii) to separate optical circuits in one of the separation levels defined in Recommendation ITU-T L.51. The number of fibre joints in one organizer may vary according to the size and shape of the fibre joint and the number of fibres in a cable sub-unit;

iii) to ensure that the fibre bend radius shall not be less than 30 mm in general applications. For special applications a minimum bend radius of 20 mm may be agreed between customer and supplier. Even lower curvature radii may be acceptable when using ITU-T G.657 fibres. In order to maintain mechanical reliability and minimize losses in the network, the cumulative length of fibre, exposed to this smaller bend radius should be limited;

iv) to provide easy identification and access to any stored fibre joint for re-jointing;

v) to separate optical circuits up to the appropriate separation level as indicated in Recommendation ITU-T L.51. This will limit the risk of interruption of traffic to those fibres that belong to the same group of circuits;

vi) to provide a means for storing the fibre over-length required for jointing and for possible re-jointing in the future.

The materials used for making the organizer shall be compatible with the other materials in the cable joint and the degreasing agents as recommended in the installation instructions.

5.2.3 Configurations of optical fibre organizers

The trays or sheets of an organizer may be configured in one of the following ways:

i) lateral sliding from a frame – similar to removing a book from a shelf;

ii) rotation about a hinge – similar to turning a page in a book (Figure 4-10);

iii) lifting from a stack – similar to lifting a book from a stack;

iv) unrolling – similar to locating a page on a scroll.

All movements of the organizer parts should proceed in a predetermined way in order to eliminate optical losses or interruption of traffic due to organizer manipulations.

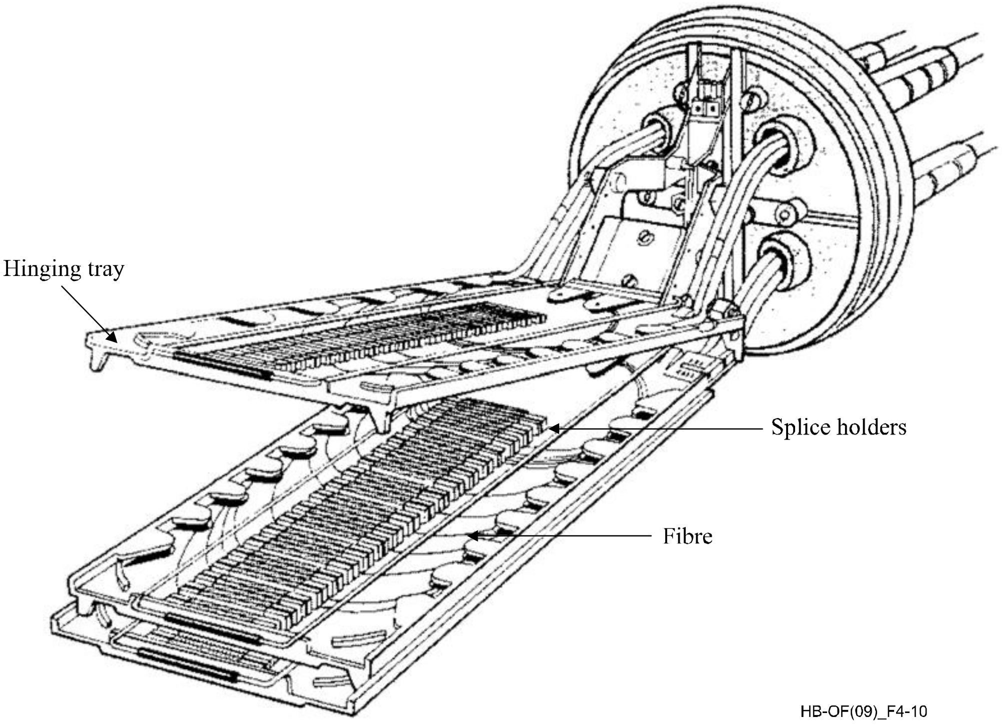

Figure 4-10 – Example of organizer

6 Passive node elements for marinized and submarine optical cables

(For further information, see Recommendations ITU-T G.972 and L.54, Supplement 41 to the ITU-T G-series of Recommendations, and the ITU Handbook, *Marinized Terrestrial Cables*.)

The components of these systems are quite similar, in many respects, to those used in terrestrial cable systems; however, there some specific requirements, which are outlined in this clause.

6.1 Marinized cables

6.1.1 Fibre splices

Fusion splicing is more common for marinized terrestrial cables due to the small size, low-loss and low reflection characteristics of the splices as well as reliability over the long life of these cables. Mass fusion splicing of ribbonized fibres may be used to reduce splicing time. Fibre ribbons, typically up to 12 fibres per ribbon, may be spliced all at once or in subsets of the fibres in a ribbon. The electric arc fusion splices are often reinforced by heat-shrinkable sleeves in order to protect the splices from stresses. The electrical arc fusion splices are essentially the same as splices in terrestrial fibre cables.

The spliced area of the fibre may also be recoated to the same size of the virgin fibre, using the same, or similar, materials used to originally coat the fibre. This provides a very small size splice, which may be virtually indistinguishable from the unspliced fibre.

As for the terrestrial cables, there are two main objectives:

i) to minimize the splice losses;

ii) to ensure a strength reliability suitable for the long-term through appropriate proof-test.

6.1.2 Fibre organizers

Organizers accommodate the spliced optical fibres and their splices. A certain amount of slack fibre is required when splicing optical fibres and it is necessary that this slack be accommodated so that its bending radius is greater than the minimum allowable fibre bending radius (typically ≥ 30 mm).

The following factors should be considered for fibre organizers:

i) *Bending radius*. Fibres should be accommodated so that their minimum bending radii are not violated, to prevent increased loss and possible reduction of long-term reliability;

ii) *Accommodation of slack*. Accommodation of an amount of slack necessary to permit the splicing of the optical fibres and for a few splice remakes is desirable. Design and assembly should preclude pinching the fibres, or degrading the fibres/splices over the life of the system;

iii) *Heat resistance*. When a heating process, such as moulding of PE, heat shrinkable sleeves, etc., is used during the assembly of a splice closure, organizers should have suitable heat resistance characteristics in order to withstand the temperatures involved;

iv) *Vibration-resistance characteristics*. The splice organizer should accommodate the splices such that vibrations during installation and service will not cause the splices to move within the organizer and violate the allowable minimum bend radii requirement. It is especially important to secure any splice reinforcement points, since these are comparatively harder and heavier than the fibres;

v) *Design*. The design of the organizer should be chosen to be suitable for the cable design, size and number of fibres.

6.1.3 Closures

A splice closure for terrestrial marinized cables (TMC) applications is designed:

i) to restore the integrity of sheath, including mechanical continuity of strength members of TMC;

ii) to protect the fibres, fibre splices and optical devices, from the external environment (water) and unwanted handling;

iii) to provide proper storage of fibre splices, passive devices (if any) and excess of fibres;

iv) to resist corrosion;

v) to prevent hydrogen effects;

vi) to allow re-intervention on cables and splices;

vii) to provide for electrical continuity, if required.

6.1.3.1 Physical and structural factors

The closure should be of a simple design and construction in order to expedite its assembly. With this in mind, the following factors should be considered:

i) *Size*. It is preferable that the closure be a minimum size to meet all the strength and material properties above, while protecting the splice organizer(s) and fibre splices. It should be compatible with the installation method proposed, including any cable-laying equipment, and take into account any corrosive environment;

ii) *Weight*. It should be as light in weight as possible, while meeting all of the strength and material properties above while protecting the slice organizer(s) and fibre splices. Ability to be handled by a single person is desirable;

iii) *Bending forces*. Significant bending forces can be encountered during the lay/recovery of long and/or large diameter closures over a sheave, if applicable;

iv) *Strength members*. Tensile strength members for marinized terrestrial cables can be anchored in the closure to prevent a cable unit from being pulled out or pushed in when the cable is subjected to tensile force. The tensile strength provided should be greater than the operational strength of the cables joined;

v) *Mechanical strength*. Mechanical strength greater than the operational strength of the unspliced cable with respect to: tensile force, lateral pressure and water pressure;

vi) *Corrosion-resistant characteristics*. In order to function for a long period of time, the components of the closure, and any auxiliary structure that are in direct contact with the water, should have excellent corrosion-resistant characteristics;

vii) *Moulding*. If a moulding process is used during the splicing operation, the closure design should limit the temperature so as not to damage the fibre coating and/or fibre splices.

6.1.3.2 Components

The main components of a closure for marinized cables are the following:

i) *Cable-anchoring section*: In this section strength members of the cable are anchored to the closure and the operational strength of the cable is restored;

ii) *Pressure-resistant chamber*: A pressure-resistant chamber can be used to protect the optical fibres and splices from water pressure, tensile force, and other external forces. It should be provided with sufficient strength to withstand lateral pressures as well as tensile forces;

iii) *Seals*: This may be a layer that provides a water-tight seal around the splices and cable entries, or seals between the cables and a water tight closure, that should adequately withstand the required water pressures;

iv) *Boots*: Tapered rubber boots may be used to smooth the closure/cable transition in its passage through the cable transporter and over the sheave in installations where such equipment is used.

6.1.4 Beach closures

The marinized terrestrial cable is normally joined to the terrestrial cable in a manhole near the landing point. A beach closure is used to make the connection. This may be a specially designed closure or may be a terrestrial splice closure with auxiliary components for anchoring the marinized terrestrial cable.

6.2 Submarine cables

(For further information, see Recommendation ITU-T G.977.)

What has been said in § 6.1 about fibre splices, fibre organizers, closures and beach closures of marinized cables applies also to submarine cables, taking account the different depth of laying of the cables (up to 7 500 m for the submarine cable and around 300 m for the marinized cable).

Moreover there are two passive nodes that are specific to submarine cables: the submarine repeater housing and the branching Unit.

6.2.1 The submarine repeater housing

The submarine repeater housing is the mechanical piece-part of a repeater.

A submarine repeater is equipment that essentially includes one or more regenerators or amplifiers and associated devices.

Submarine repeater housing must be designed to allow operation, laying, recovery, and re-laying in large depths with no degradation in mechanical, electrical and optical performance.

Technical requirements for submarine repeater housings are as follows:

i) *The internal unit*. Inside the repeater housing, the internal unit can contain several power feed modules and OFA (optical fibre amplifiers) pairs to amplify in both directions optical signals from one or several fibre pairs;

ii) *Corrosion protection*. The external housing of an OSR (optical submarine repeater) should be designed to not suffer from corrosion due to sea water;

iii) *Water pressure resistance*. The OSR must be designed to support large pressure strengths in deep sea water;

iv) *High-voltage insulation*. High-voltage insulation is required between the repeater housing and the internal unit to ensure repeater operations;

v) *Thermal management*. Heat generated by the electronic components inside the OSR may be dissipated sufficiently via thermal conduction with the repeater housing;

vi) *Repeater housing sealing*. The repeater must be provided with a protection against water and gas ingress, both directly from the surrounding sea and from axial cable leakage resulting from a cable break close to the repeater;

vii) *Ambient atmosphere control*. Reliability and proper operation of components may require a controlled internal atmosphere regarding relative humidity or any expected gas that may be generated inside the repeater.

6.2.2 The branching unit

The branching unit (BU) is an optical node in which it is possible to interconnect three cable (and not only two, as in terrestrial closures), allowing a complete connectibility among the cables (Figure 4-11).

Figure 4-11 – Example of branching unit

With the use of the branching units it is possible to interconnect three landing points (three terminal stations) with only one submarine cable. The deployment of two BU on the same cable widens the number of landing points that can be reached with the same submarine cable.

Technical requirements for a branching unit housing are very similar to those of a submarine repeater housing.