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Part 001: Termination methods and tools

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Date: xx/xx/20xx	Document: ISO/DIS xxxx

1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex **(e.g. 3.1)**	Paragraph/Figure/ Table/Note	**Type of comment**	**Commend (justification for change) by the MB**	**Proposed change by the MB**	**Secretariat observations on each comment submitted**
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

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NORME EUROPÉENNE

EUROPÄISCHE NORM

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prEN 4533-001

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English Version

Aerospace series - Fibre optic systems - Handbook - Part 001: Termination methods and tools

Série aérospatiale - Systèmes des fibres optiques - Manuel d'utilisation - Partie 001 : Méthodes des terminaisons et des outils

Luft- und Raumfahrt - Faseroptische Systeme - Handbuch - Teil 001: Anschlussverfahren und Werkzeuge

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee ASD-STAN.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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Full document details: 24/30487669 DC

Contents

Page

European foreword 4
Introduction 5
1 Scope 6
1.1 General 6
1.2 Need for high-integrity terminations 6
2 Normative references 7
3 Terms and definitions 7
4 Component selection 7
4.1 Elements 7
4.2 Fibre optic cables 7
4.2.1 General 7
4.2.2 Cable construction 8
4.2.3 Fibre choice 9
4.2.4 Cladding materials 11
4.3 Primary buffer materials 11
4.3.1 Function 11
4.3.2 Acrylate 12
4.3.3 Polyimide 12
4.3.4 Silicone 12
4.3.5 Strength members 12
4.4 Outer jacket 13
4.5 Fibre optic interconnects (connectors) 13
4.5.1 Introduction 13
4.5.2 The optical interface 14
4.5.3 Single-way interconnects/connectors 20
4.5.4 Multi-way interconnects/connectors 20
4.5.5 Choice of tooling 21
5 Health and safety aspects 22
5.1 General 22
5.2 Chemicals 22
5.3 Sharps 23
6 Termination process 23
6.1 Objective 23
6.2 Cable preparation 24
6.2.1 General 24
6.2.2 Cutting to length 24
6.2.3 Removal of outer jacket 25
6.2.4 Cable handling tools (gripping the cable) 30
6.2.5 Strength member trimming/removal 31
6.3 Removal of secondary coating(s) 32
6.4 Removal of primary coatings 32
6.4.1 General 32
6.4.2 Mechanical techniques for primary coating removal 33
6.4.3 Alternative techniques 39
6.4.4 Troublesome coatings — Polyimide and Silicone 40
6.4.5 Evidence of strength reduction when stripping primary buffer coatings 42

AVA Documents
Document Sharing Hub
Full document details: 24/30487669 DC

6.4.6 To clean or not to clean 43
6.5 Adhesives 44
6.5.1 General 44
6.5.2 Adhesive types 44
6.5.3 The importance of glass transition temperature (T_g) 46
6.5.4 Epoxy cure schedule 48
6.5.5 Usability 50
6.5.6 Qualification 54
6.6 Connector preparation 54
6.6.1 Dry fitting 54
6.7 Attachment of fibre to the terminus 56
6.7.1 Application of adhesive 56
6.7.2 Inserting fibre 'best-practice' 59
6.8 Adhesive cure 63
6.8.1 General 63
6.8.2 Orientation 63
6.8.3 Curing equipment 63
6.9 Excess fibre removal 67
6.9.1 General 67
6.9.2 Post-cure rough cleaving 67
6.9.3 Pre-cleave 69
6.9.4 Safety 69
6.9.5 Cleaving tools 69
6.9.6 Sprung blade hand tools 70
6.9.7 Cleaving fibres in multi-fibre ferrules 71
6.10 Polishing 71
6.10.1 Rationale 71
6.10.2 Performance metrics 71
6.10.3 End-face geometries 71
6.10.4 End-face geometry parameters 72
6.10.5 Polishing stages 81
6.10.6 Methods for controlling end-face geometry 95

7 Beginning of life inspection 101
7.1 General 101
7.2 Optical or visual inspection 101
7.3 Interferometric inspection 103
7.3.1 General 103
7.3.2 Inspection and pass/fail criteria 105

Bibliography 108

Documents
Document Sharing Hub

Full document details: 24/30487669 DC

European foreword

This document (prEN 4533-001:2024) has been prepared by ASD-STAN.

After enquiries and votes carried out in accordance with the rules of this Association, this document has received the approval of the National Associations and the Official Services of the member countries of ASD-STAN, prior to its presentation to CEN.

This document is currently submitted to the CEN Enquiry.

This document will supersede EN 4533-001:2020.

The main changes with respect to the previous edition are as follows:

— update of the document to remove trademarks.

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Introduction

a) The handbook

The purpose of EN 4533 is to provide information on the use of fibre optic components on aerospace platforms. The documents also include best practice methods for the through-life support of the installations. Where appropriate more detailed sources of information are referenced throughout the text.

The handbook is arranged into 4 parts, which reflect key aspects of an optical harness life cycle, namely:

— Part 001: Termination methods and tools;

— Part 002: Test and measurement;

— Part 003: Looming and installation practices;

— Part 004: Repair, maintenance, cleaning and inspection.

b) Background

It is widely accepted in the aerospace industry that photonic technology offers significant advantages over conventional electrical hardware. These include massive signal bandwidth capacity, electrical safety, and immunity of passive fibre-optic components to the problems associated with electromagnetic interference (EMI). Significant weight savings can also be realized in comparison to electrical harnesses which may require heavy screening. To date, the EMI issue has been the critical driver for airborne fibre-optic communications systems because of the growing use of non-metallic aero structures. However, future avionics requirements are driving bandwidth specifications from 10s of Mbits/s into the multi-Gbits/s regime in some cases, i.e. beyond the limits of electrical interconnect technology. The properties of photonic technology can potentially be exploited to advantage in many avionic applications, such as video/sensor multiplexing, flight control signalling, electronic warfare, and entertainment systems, as well as sensor for monitoring aerostructure.

The basic optical interconnect fabric or ‘optical harness’ is the key enabler for the successful introduction of optical technology onto commercial and military aircraft. Compared to the mature telecommunications applications, an aircraft fibre-optic system needs to operate in a hostile environment (e.g. temperature extremes, humidity, vibrations, and contamination) and accommodate additional physical restrictions imposed by the airframe (e.g. harness attachments, tight bend radii requirements, and bulkhead connections). Until recently, optical harnessing technology and associated practices were insufficiently developed to be applied without large safety margins. In addition, the international standards did not adequately cover many aspects of the life cycle. The lack of accepted standards thus leads to airframe specific hardware and support. These factors collectively carried a significant cost penalty (procurement and through-life costs) that often made an optical harness less competitive than an electrical equivalent. This situation is changing with the adoption of more standardized (telecoms type) fibre types in aerospace cables and the availability of more ruggedized COTS components. These improved developments have been possible due to significant research collaboration between component and equipment manufacturers as well as the end users air framers.

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1 Scope

1.1 General

This document examines the termination of optical fibre cables used in aerospace applications. Termination is the act of installing an optical terminus onto the end of a buffered fibre or fibre optic cable. It encompasses several sequential procedures or practices. Although termini have specific termination procedures, many share common elements and these are discussed in this document. Termination is required to form an optical link between any two network or system components or to join fibre optic links together.

The fibre optic terminus features a precision ferrule with a tight tolerance central bore hole to accommodate the optical fibre (suitably bonded in place and highly polished). Accurate alignment with another (mating) terminus is provided within the interconnect (or connector) alignment mechanism. As well as single fibre ferrules, it is noted that multi-fibre ferrules exist (e.g. the MT ferrule), and these are also discussed in this document.

Another technology used to connect 2 fibres is the expanded beam. 2 ball lenses are used to expand, collimate and then refocus the light from and to fibres. Contacts are not mated together. It helps reducing the wear between 2 contacts and allows more mating cycles. This technology is less sensitive to misalignments and dust. Losses are remaining more stable than butt joint contact even if the nominal loss is higher.

NOTE Current terminology in the aerospace fibre optics community refers to an optical terminus or termini. The term optical contact can be seen in some documents and has a similar meaning. However, the term contact is now generally reserved for electrical interconnection pins. The optical terminus (or termini) is housed within an interconnect (connector is an equivalent term). Interconnects can be single-way or multi-way. The interconnect or connector will generally house the alignment mechanism for the optical termini (usually a precision split-C sleeve made of ceramic or metal). It is important that the reader is aware of these different terms.

An optical link can be classified as a length of fibre optic cable terminated at both ends with fibre optic termini. The optical link provides the transmission line between any two components via the optical termini which are typically housed within an interconnecting device (typically a connector) with tight tolerancing within the alignment mechanisms to ensure a low loss light transmission.

This document explains the need for high integrity terminations, provides insight into component selection issues and suggests best practice when terminating fibres into termini for high integrity applications. A detailed review of the termination process can be found in Clause 4 of this document and is organized in line with the sequence of a typical termination procedure.

The vast number of cable constructions and connectors available make defining a single termination instruction that is applicable to all combinations very difficult. Therefore, this handbook concentrates on the common features of most termination practices and defining best practice for current to near future applications of fibre optics on aircraft. This has limited the studies within this part to currently available ‘avionic’ silica fibre cables and adhesive filled butt-coupled type connectors. Many of the principles described, however, would still be applicable for other termination techniques. Other types of termination are considered further in EN 4533-004.

It is noted that the adhesive based pot-and-polish process is applicable to the majority of single-way fibre optic interconnects connectors and termini for multi-way interconnects and connectors. They share this commonality.

1.2 Need for high-integrity terminations

In order to implement a fibre optic based system on an aircraft, it is vital to ensure that all the constituent elements of the system will continue to operate, to specification, over the life of the system. An important aspect of this requirement is the need for reliable interconnection components.

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Interconnects are a key component in any fibre optic system or network. Digital communications links, sensor systems, entertainment systems, etc. all require interconnects both at equipment interfaces and for linking cables and harness sections together over the airframe.

Interconnects need to be robust to mating and demating operations, environmental changes and also the effects of contamination. They need to be amenable to inspection and cleaning for through life support.

The choice of technology used in optical links and connections is mainly dependant of the environment. In service performance is a pillar in the component selection. Cable to connector interface needs to be assessed to prove the effectiveness of the solution.

High-integrity terminations are required to ensure reliable, low loss light transmission through the interconnection. High-integrity terminations are produced by observing best practice and using the correct materials, tools and procedures with appropriate controls.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp/

— IEC Electropedia: available at https://www.electropedia.org/

4 Component selection

4.1 Elements

All interconnection technologies are taken into account in the context of EN 4533-001.

It is important to recognize that a fibre optic termination, while appearing straightforward, is in fact a complex interaction of the constituent elements such as: fibre, ferrule, fibre coatings, connector design, cable strength member anchorage method, adhesive type, and cure regime (where used), material properties and so on. Each of these elements will have an impact on the termination, in terms of reliability, integrity and process complexity.

The following sections discuss the key elements to the termination.

4.2 Fibre optic cables

4.2.1 General

There are many types of fibre optic cable on the market today. Cables are essentially assemblies that contain and protect the optical light guide (used to carry the system light signal). The central light guide is usually made from silica glass although other materials can be used. Glass is inherently strong although it must be protected from external damage and other factors that could cause weakening (generally moisture and fluid contamination in the presence of any defects and stress). The cable provides the protective layers to the glass and generally also incorporates a strength member (this element is important in the termination for providing strain relief) and a protective outer jacket.

For aerospace applications, most encountered cables will carry a single, central optical fibre (suitably protected as discussed in the following sections). There can be variation in single fibre cable designs.

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Some may be of tight jacket construction, some of loose jacket construction. Cables are also being developed with many fibres contained within a protective tube construction. It is noted that many of the cable designs used in terrestrial telecommunications and data communications will not be suitable for aerospace use. This is generally due to environmental capability limitations often due to environmental characteristics.

4.2.2 Cable construction

As mentioned in the introduction, the cable construction provides the protection to the central lightguide(s).

Although the design of fibre optic cable for use on aircraft is fairly similar from one manufacturer to another there are important differences between cables. The two main areas of difference are fibre coatings and the cable strength member materials. Each has its own positive and negative attributes in the context of termination procedures. Avionic fibre optic simplex cables are typically constructed as in Figure 1.

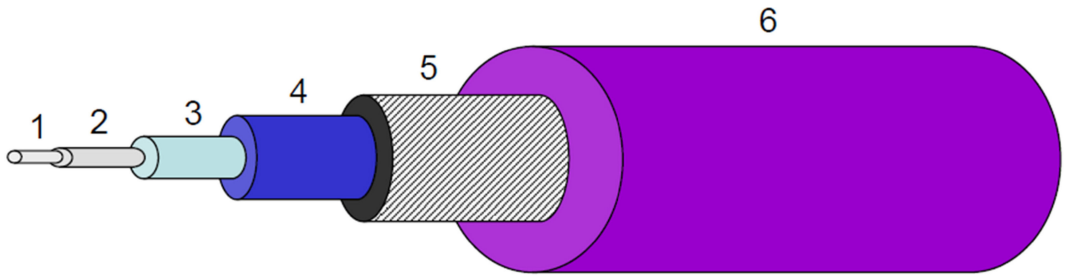
Another distinction between cable designs is whether all the coatings are “tight” or “semi loose” onto the underlying layers. This will also impact the operation of the terminated cable, (referring to full pull proofness achievable with loose structure cables)

A tight cable is a cable which shows no movements between all layers.

A semi-loose cable is a cable which shows limited movements between layers. It could be a movement between the fibre and the buffer (case of 900 µm cables) or between the buffer and the above layers (case of simplex 1,8 mm cables)

A tight construction is generally easier to terminate but can be more sensitive to environmental changes if materials are not well chosen. Some cable designs have a semi-loose construction where the central fibre has some mobility within one of the cable layers (usually an inner sheath). This design is generally more difficult to terminate but can have superior environmental performance (because the fibre is isolated from the other layers).

The behaviour of the connector is different whether the cable is tight or semi loose. Generally, on tight construction fibre contact is interrupted when pulling. The semi loose construction permits a pull safe termination.



Key

1 Core
2 Cladding
3 Primary buffer
4 Secondary buffer
5 Strength member
6 Outer jacket

Figure 1 — Typical avionic fibre optic cable construction

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NOTE The glass fibre lightguide comprises the core and cladding regions.

Figure 2 highlights the key elements of an aerospace fibre optic cable. These elements are now discussed in more detail.

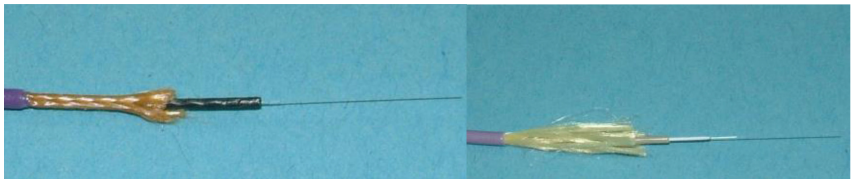


Figure 2 — Examples of EU standardized cables

4.2.3 Fibre choice

The central lightguide is defined by the core/cladding region. This is the fibre that needs to be suitably protected by the cable. It is noted that both the core and the cladding are generally formed from glass. The glass in the core is of higher refractive index than the cladding and this allows light guiding along the fibre via total internal reflection. Whilst most aerospace fibres are made from glass it is recognized that other fibre constructions exist including plastic optical fibre (POF), plastic clad silica (PCS). Very novel fibres such as photonic crystal fibres (PCF) or polarization maintaining fibre (PM) may also find some specialized aerospace applications in the future.

One of the primary distinctions between cables is whether the cable carries a single-mode or a multimode optical fibre lightguide. The choice of lightguide will be dictated by the system or network. Most current data communication systems on aircraft use multimode based cables. The relatively short lengths encountered on aircraft mean that multimode fibres can currently provide sufficient bandwidth (up to ~10 Gbps) and their relatively large cores are easier to interconnect (compared to single-mode). Sensor systems will generally require single-mode-based cables. Future bandwidth requirements or the need for data multiplexing down common fibres may drive the need for more single-mode fibre cables in aerospace although it must be recognized that single-mode fibres (~9 µm core size) are harder to align and keep free from contamination.

Multimode fibres can be either Step Index (SI) or Graded Index types. Graded index fibres have a graded profile to the refractive index of the fibre. In essence this increases the bandwidth of the fibre by equalising the various possible light paths within the core region (thus reducing any dispersion or data pulse spreading that can occur). Higher data rates are possible with graded index fibres. Step index fibres may be seen particularly on legacy systems. As its name suggests, the refractive index profile shows a step change in value defining the change from core to cladding material.

Historically, avionic fibre sizes have tended to be larger than the standard high-volume fibres such as those used in the data communication and telecommunication market and have therefore had an associated cost and availability penalty (associated components required for termination have also been non-standard and therefore more expensive). Examples of larger fibre sizes are 200 µm/280 µm, 100 µm/140 µm (where the convention denotes the core/cladding dimension). The data communications and telecommunications industries typically use fibres of size 62,5 µm/125 µm, 50 µm/125 µm (multimode) and 9 µm/125 µm (single-mode). The last fibres are now being specified for new systems on aircraft with these fibre sizes, which is becoming the standard configuration.

Importantly for termination, these fibres have a common outer cladding diameter of 125 µm. This means that the ferrules used in fibre optic termini can be lower cost (these components are mass produced for the telecommunications market). A number of companies are now packaging these data communication and telecommunication standard fibres in an aerospace cable meaning that higher bandwidth cables are now available to the aircraft industry.

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Other factors worth mentioning in the choice of fibre are:

— bandwidth:

  o Multimode fibres (within the cable) are designated by the OM identification (meaning 'optical multimode'). OM1 describes 62,5 µm/125 µm fibre, OM2, OM3 and OM4 describe 50 µm/125 µm fibres of increasing bandwidth;

— radiation resistance (radiation hard):

  o these may be specified on some military programs;

— bend resistance:

  o cables with bend tolerant or bend resistant fibres are now also becoming more widely manufactured. These cables exhibit lower losses when bent compared to the ones which are based on bend sensitive fibres. However, as noted elsewhere in EN 4533, fibres should not be bent beyond their recommended minimum bend radius. They are no stronger than conventional fibres.

Table 1 is summarizing the basics feature of a fibre. Fibres have been categorized according to ITU rules.

Table 1 — Basics feature of a fibre according to ITU rules

Mono/multi-mode	**Ø core** (µm)	**Minimum modal Bandwidth** (MHz.km) 850 nm/1 310 nm	**Category**
Mono	9	n/a	G652
Mono	9	n/a	G657
Multi	62,5	200/500	OM1
Multi	50	500	OM2
Multi	50	1 500/2 000	OM3
Multi	50	3 500/4 700	OM4

From the perspective of termination there is little difference between small and larger core optical fibres. The main fibre issues that impact upon the termination process relate to cladding size and primary coating materials.

The use of multifibre array connectors (e.g. those based on the MT ferrule discussed later) in some aerospace applications means that cables with multiple fibres are required. A typical construction is shown below. Early multifibre cables designs were of a flat 'ribbon' type. However more recent designs have been of a round profile cable with loose fibres (suitably protected) within. The cables typically also include a strength member. This technology is not yet standardized. Figure 3 shows an example of a multi-way cable.

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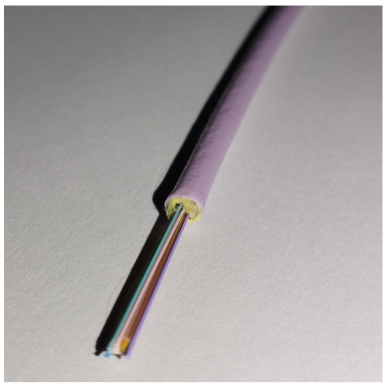


Figure 3 — Example of multi-way cable

4.2.4 Cladding materials

4.2.4.1 Coatings and buffers — A note on terminology

The central lightguide is protected in the cable by various layers of material. The reader should be aware that different texts will refer to these layers in different ways. Common to most texts however is the designation of the order of layers. Thus, primary layers exist immediately next to the lightguide (usually applied onto the cladding layer of the fibre). Secondary layers will be applied above the primary layer and so on.

Where there is sometimes confusion is the inconsistent use of terms such as coatings, buffers and sheaths. For instance, it is common for the terms primary buffer and primary coating to be seen in different texts. Terms such as secondary coating and secondary buffer would also refer to a coating lying above the first (primary) layer of protection. Secondary layers can sometimes be hybrid, composed of different materials (sometimes difficult to separate). Finally, a boundary sheath layer may exist in the cable. The term boundary sheath implies a tube type construction that allows the coated fibre to move within the cable (semi loose).

4.3 Primary buffer materials

4.3.1 Function

Immediately above the optical fibre is a primary buffer layer. The major function of the primary buffer is to protect the fibre from abrasive and environmental damage. It also limits micro-bending losses in the fibre. Generally, this coating is applied at the time of fibre manufacture. It provides the first layer of protection to the glass. It shall provide protection but also be easily removable when performing a termination.

Most fibres use an acrylate type material for the primary buffer, other materials can be encountered however, such as silicone, polyimide, proprietary polymers and even metal, such as gold or aluminium (although these are somewhat specialized and will not be considered here). These alternative buffer materials can extend the operating temperature of the fibre. Carbon is sometimes applied to special fibres to hermetically seal the fibre surface and prevent moisture reaching the glass surface (typically used on space applications). For a detailed review of materials see below sections

It should be emphasized that the temperature capability of a glass fibre is not limited over the operational envelope of an aircraft. Glass will survive (and indeed is used in other applications) at very high and very low temperatures. It is the temperature range of the protective layers (which are essential in preventing damage to the fibre) that limit the temperature performance of the cable. In comparison, other types of fibre (e.g. POF and PCS) may be fundamentally limited by the operating temperature of the fibre material itself.

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In aerospace applications, the most widely used primary coating materials are, acrylate, polyimide and silicone. A brief description of each material is placed below.

4.3.2 Acrylate

This is perhaps the most common of all the optical fibre primary buffer materials and is relatively easy to remove with hand tools. The buffer is usually a UV cured acrylate that is translucent and is typically the same thickness as the fibre. Standard acrylates have a limited temperature performance of up to approximately 90 °C to 100 °C (above this temperature they can break down and become discoloured and brittle) however in recent years higher temperature acrylate (HTA) has become a standard buffer material and is now being packaged in aerospace cables. HTAs extend the operation to the region of 150 °C and up to 180 °C. Low temperature limits are in the region of −60 °C. Acrylate is subject to degases when used in unpressurised environments. Some manufacturers have operated these buffers down to − 65 °C with no degradation.

4.3.3 Polyimide

This buffer has a higher temperature range than UV cured acrylates and can be used in temperatures up to 300 °C and up to 400 °C short term. Although useful for high temperature applications, polyimide buffers are difficult to remove using common mechanical tools. Fibres employing this material are designed to be installed into connector ferrules without the need to remove the primary buffer. This is only possible because the core/cladding/primary buffer concentricity and outer diameter tolerances are tightly controlled. This would appear to be an ideal design solution because the fibre surface does not need to be touched. However, the enlarged polyimide diameter is not compatible with standard connector ferrule bore dimensions, thus non-standard ferrules need to be used with an associated cost and availability penalty. Removal of polyimide buffers is discussed later in this document (see subclause 6.4.4). Polyimide is not degassing when used in unpressurised environments.

4.3.4 Silicone

The main benefits of silicone as a primary coating are the reduction of fibre micro-bend effects due to the “cushioning” effect of the soft primary coating layer, its high temperature capability (up to 200 °C), its resilience to water penetration and its low flammability. However, as with acrylate, this material needs to be stripped prior to inserting optical fibres into fibre optic connectors. This is by no means easy (see later section on removing troublesome primary coatings) and can leave a residue which could compromise fibre/ferrule bonding. Again, removal of silicone is also discussed in subclause 6.4.4 some ‘soft silicone’ coatings may allow lower temperature operation of fibres e.g. down to −100 °C.

4.3.5 Strength members

Almost all fibre optic cables employ some form of strength member layer. Its function is to isolate cable external loads from the fibre within and provide excellent longitudinal strength; it is usually in the form of stranded fibres running along the fibre axis or woven in a braid. The most common material used for this purpose is a very tough, strong material known as aramid yarn. However, it is by no means the only material used for this purpose – fibreglass being one of the main alternatives. New designs of aerospace fibre optic cable are now implementing a fibreglass/aramid yarn mix to provide a strength member with lower smoke emissions than that of a pure aramid yarn strength member.

Fibreglass is better matched to the optical fibre’s thermal coefficient of expansion compared to aramid yarn and has been used where high temperature (>135 °C) dimensional stability is required of a cable. This aspect shall be considered if a cable is to be subjected to prolonged exposure of rapid thermal cycling stresses over a wide temperature range. However, aramid yarn appears to meet most current avionic temperature requirements (−65 °C to 150 °C).

These two materials need to be treated in quite different ways in order to achieve effective optical fibre load isolation during the termination process. Aramid yarn and other similar materials can be crimped directly onto a connector or termini; fibreglass cannot because it is too brittle. Cables employing

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fibreglass strength members should be bonded with adhesive or crimped to the contact body via the cable outer jacket.

Strength members need to have a limited impact on the optical performance of the fibre when pulled with strength below the tensile strength.

4.4 Outer jacket

Optical cables are sharing the same environments as electrical cables. The required performances are remaining similar.

Outer jacket permit to give the cable its chemical resistance. Cables are subject to be in contact with on board fluids such as fuels, hydraulic fluids, cleaning fluids, oils, de-icer…

The cable needs to not be altered by this stress. Outer jacket material choice is mainly based on the fluids' resistance.

Cables need to resist to mechanical stress as well such as abrasion, pulling, flexion, torsion, crush, impact.

The outer jacket permits to give the cable a resistance to radials stress. Outer jacket is a kind of absorber which limits the effect of those stresses.

The outer jacket material needs to not affect the optical performance at extreme temperature.

The outer jacket material needs to not limit the bending of the cable.

For some application sealing of the connector is made by the outer jacket fixed in the back shell of the connector. Dimension of the cable is therefore very critical.

For some applications, cable needs to meet with flammability or toxicity requirement. This performance is not linked to the outer jacket only, but it is a combination of all materials layers.

Fluoropolymer is one of the mostly used materials for this topic.

4.5 Fibre optic interconnects (connectors)

4.5.1 Introduction

The purpose of a fibre optic interconnect or connector is to align two or more optical fibres and to keep the fibres positioned within tight physical constraints such that a good optical interface is maintained with good light transmission. This can be achieved in a number of ways.

There are a large variety of connectors available with associated termination processes. It is therefore necessary to understand the differences between these connector types and their associated features. When specifying a fibre optic connector, it will be necessary to define: the optical interfacing method, the fibre attachment method, the number of fibres to be accommodated and the structure of the cable (see subclause 4.2.2).

A different terminus design is generally required for each of these different designs to prevent any possible kinking of the fibre when two termini are mated together. Many connectors use a spring-loaded ferrule within the terminus. When mated, the fibre/ferrule assembly moves backwards towards the rear of the interconnect (connector). This type of terminus requires a semi-loose tube cable construction to accommodate the fibre movement. The contact will accommodate movement of the fibre in the cable and will reduce bend losses.

A tight cable would have no capacity to accommodate the fibre movement, leading to stress and possible bend loss. Some manufacturers produce special termini for tight cable constructions. These termini deflect in a different way to avoid fibre kinking.

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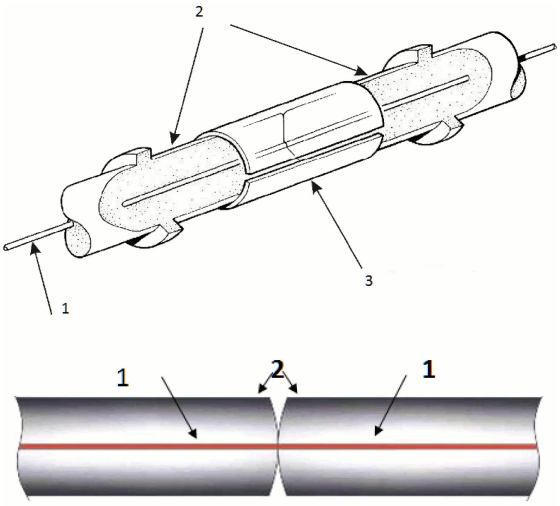
4.5.2 The optical interface

4.5.2.1 General

Fibre optic system designers have the option of using optical connectors with one of two types of interfaces, these being “butt-coupled” or “expanded beam”. These different types of interfaces are now discussed.

4.5.2.2 Butt-coupled interface

A typical butt-coupled arrangement is shown in Figure 4. The fibres physically ‘butt’ together at the connection.



Key

1 Optical fibre
2 Ferrules
3 Split alignment sleeve

Figure 4 — Butt-coupled fibre optic connector interface

Lower image shows detail of physical contact or butting of the fibres and ferrules.

This is the simplest of the two in terms of the number of elements in the optical path. However, the performance of this interface is highly dependent upon the quality of the fibre end-face. This implies stringent requirements in terms of cleanliness and polishing (or cleaving) as well as alignment.

Most butt coupled interfaces are formed when two mating ferrules are held in intimate contact. A spring in the terminus body or within the interconnect (connector) provides the necessary force. As will be discussed in later sections, for glass fibre terminations the end of the ferrule is generally produced with a radius of curvature (a domed profile). Flat profile ferrules were used in early systems, and these may occasionally be seen in legacy systems. For the domed ferrule case, two ferrules compress together elastically such that the two fibres are held in intimate contact. The resulting interface can be very low loss and can have low back reflection if polished correctly.

Because of the physical contact between the fibres, it is commonly known as a PC connection. If the fibre/ferrule end-face is polished to higher quality with lower back reflection, the term UPC (Ultra PC) may be seen.

All the back reflexions given below are linked to the optical fibre.

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A variant of the butt coupled interface is the angle polished connector (APC) (see Figure 5). Here, the ferrules are also in intimate contact, but the end profile of the ferrule is produced with an angle (typically 8 degrees) to ensure that any reflected light is not directed back down the fibre (such reflection could perturb a laser source for instance and cause instability in some systems). APC connections can reduce the back reflection to ~ −65 dB.

APC connections are generally used in single-mode systems that are sensitive to back reflection. An example would be RF over Fibre links. Such systems are now starting to be used on aircraft. For identification, APC connections usually have a green identification band on the optical terminus. APC termini should not be mated with normal PC termini. The resulting connection will have a high connection loss.

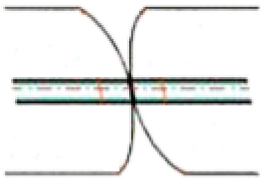


Figure 5 — Angle Polished Connector (APC) interface

Butt-coupled connections are generally tolerant to fluid contamination because the fluids will be either squeezed out of the contact region or if any fluid remains it can act as an index matching fluid thus enhancing light coupling across the interface.

It is noted that in multi-fibre ferrule interconnects (using the rectangular MT ferrule), the connections are essentially an array of butt coupled fibres. Multimode fibres generally have a PC-type end-face profile. Single-mode fibres in an MT array may be produced with an angled end-face. The precision required to polish the profile of a multi-fibre MT ferrule means that machine polishing is the only viable means of production. Reflectance and loss performance of optical connectors are given in Table 2.

Table 2 — Reflectance and loss performance of optical connectors

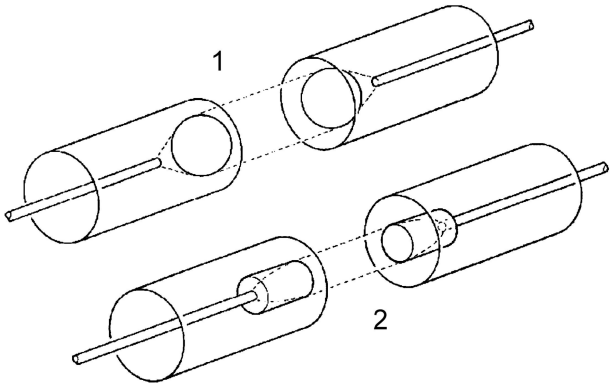
Connection	**Typical reflectance** (dB)	**Typical losses** (dB)
PC	40	0,2
UPC	55	0,09
APC	65	0,15

4.5.2.3 Expanded beam interface

An alternative to the butt-coupled interface is to place lenses between the two fibre ends (see Figure 6). Connectors employing such lenses are referred to as ‘expanded beam’ connectors. The purpose of the lens is to take the small diameter, diverging output of the fibre and convert it into a larger diameter, collimated (parallel) beam of light. This has advantages in terms of enhanced tolerance to particulate contamination. The inclusion of lenses, however, will increase connector insertion loss compared to butt-coupled interfaces as well as adding cost and complexity to the termination process. However, further expanded beam connector will provide lower typical insertion losses than current technology.

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Key

1 Ball lens

2 GRIN lens

Figure 6 — Expanded beam fibre optic connector interface (GRIN = GRaded INdex)

Expanded beam connectors may be further sub-divided into those with integrated optics (see Figure 7) and newer designs with removable termini (see Figure 8). Connectors with integrated inserts contain the optics and fibre/ferrule assemblies within a sealed connector body. Optical channels cannot easily be replaced. Some may feature optical windows above the lenses to make cleaning easier. Newer designs of expanded beam interconnects utilize removable termini. These can be replaced in a multi-ways connector (interconnect).

Some designs have expanded beam tips that interface to a conventional fibre optic terminus thus transforming it into an expanded beam type.

Expanded beam interconnects are not common in aerospace applications at the present time but this situation is moving. Generally, they are used in ground based and maritime applications, often where links are daisy-chained together.

By virtue of the larger beam size, expanded beam connectors are more resistant to particulate contamination. However, care shall be taken not to trap fluids in expanded beam connectors. Fluids can refract and scatter the beam leading to higher losses. Cleaning may be required routinely before reconnection to ensure no fluid contaminants are present.

Because of reciprocal arrangement of the optics on either side of the interconnect, expanded beam connectors are tolerant to lateral movement between the two halves of the connection. However, they are intolerant to tilt of the fibre/ferrules.



Figure 7 — Example of expanded beam connector with integrated optics

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Lenses are clearly visible.

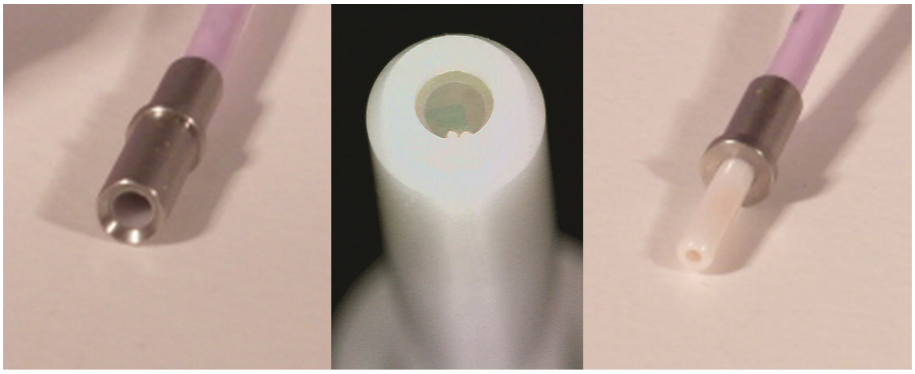
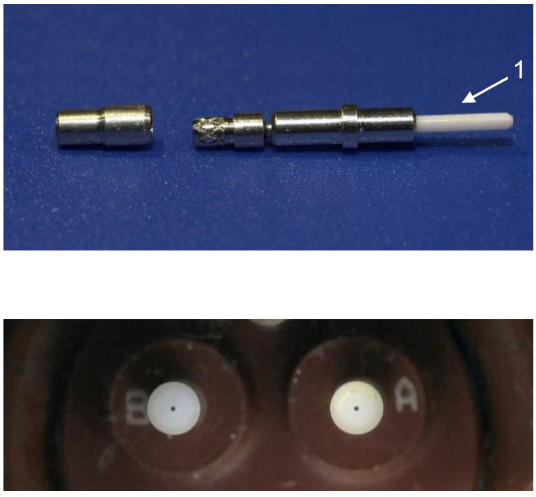


Figure 8 — Example of expanded beam connector with removable termini. The lens element is visible on the end of the termini (us)

4.5.2.4 Circular ferrules

Most modern fibre optic interconnects will use a circular ceramic ferrule (usually zirconia) to hold the fibre in position. The ferrule has a bore hole in the centre that is only marginally larger than the fibre cladding diameter. For single mode applications (where the fibre core is very small ~9 µm) the bore hole may only be 1 µm to 2 µm larger. Multimode ferrules may have a slightly larger bore hole, but many connector manufacturers now specify single mode tolerance ferrules as standard even in multimode interconnects (connectors). This ensures better fibre core alignment and lower loss.



Key

1 Ceramic ferrule at end of terminus

Figure 9 — Detail of fibre optic terminus showing ceramic ferrule used to accurately align the fibre in an interconnect

The end view in Figure 9 shows the fibre in the centre of the white ceramic ferrule (here a 2 channel connector is shown).

In early fibre optic connector designs the ferrule material was usually made from some form of metal, with a wide ferrule bore over much of the length of the ferrule. Only a small length of ferrule tip would usually contain the high precision fibre alignment bore or 'jewel'. Metal ferrules could be polished easily; thereby running the risk of over-polishing even ceramic ferules can be easily over polished. It

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shall, however, be born in mind if metal ferrules are to be used mating would create particles which will pollute the end-faces. Lower cost circular polymer ferrules also exist but would not be recommended for aerospace applications.

The alignment (lateral and axial) of two fibres is produced when they are brought together in an alignment assembly (physical contact only). Typically, this is a split-C profile sleeve again often made of ceramic although metal alignment sleeves may also be used (e.g. phosphor bronze). Ceramic sleeves tend to give better repeatability and lifetime. A contact made with mixed materials is possible, but it will lead to the creation of chips or swarfs.

The alignment sleeve is used in single-way connectors, each mated pair having its own alignment sleeve. Typical circular ferrules seen in the aerospace industry have diameters of 1,25 mm, 2,5 mm and 1,6 mm. The ferrules are aligned axially by spring pressure, either provided in the optical terminus or with a separate spring in the interconnect (connector).

Figure 10 shows a multimode fibre (end view) potted in a ceramic ferrule.

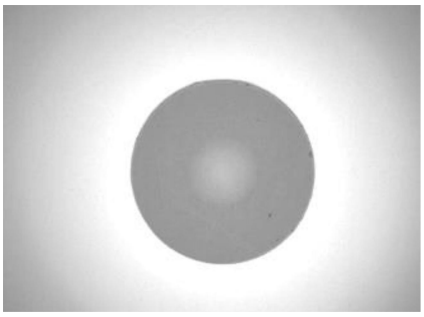


Figure 10 — Multimode fibre (end view) potted in a ceramic ferrule

Subclause 4.2.2 noted the existence of tight and semi-loose design cables. A different terminus design is generally required for each of these different designs to prevent any possible kinking of the fibre when two termini are mated together. Many connectors use a spring-loaded ferrule within the terminus. When mated, the fibre/ferrule assembly moves backwards towards the rear of the interconnect (connector). This type of terminus requires a semi-loose tube cable construction to accommodate the fibre movement. A tight cable would have no capacity to accommodate the fibre movement, leading to stress and possible bend loss. Some manufacturers produce special termini for tight cable constructions. These termini deflect in a different way to avoid fibre kinking.

4.5.2.5 Multi-fibre ferrules (MT)

Although not widely used at the present time, some avionic systems are starting to specify the use of multi-fibre MT ferrules. These are rectangular ferrules generally made from a thermoplastic material typically Polyphenylene Sulfide (PPS) often reinforced with silica particles as shown in Figure 11 and Figure 12. The fibres are linearly positioned on a pitch of 250 µm. Typically, they feature up to 12 fibres in a row, but the rows can be stacked to give up to 72 fibres in one connector ferrule. MT connectors are used in systems to give a high channel count in a small space envelope. Generally, MT ferrules are qualified in the standard temperature range −40 °C to 85 °C. Some aerospace testing is being performed in the temperature range −55 °C to 125 °C.

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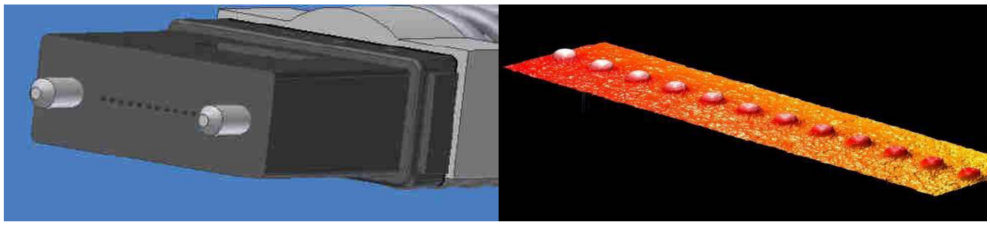


Figure 11 — A multi-fibre MT ferrule

This image shows a 12-fibre single array version. The 12 precision bore holes are on a 250 µm pitch. The large pins (stainless steel) near the outer edge are for alignment and mate with corresponding cavities in the mating half. The right image shows the slight fibre protrusion of each fibre in the array.

The end of the ferrule shall be very carefully polished to achieve the correct profile. The polishing process produces some protrusion to the individual fibres as shown in Figure 11.

MT ferrules can use single or multimode fibres and the ferrules are available in single and multimode grades, single-mode having tighter tolerance holes. MT ferrules are designed to interface to multi-fibre cables. Interconnect manufacturers are now producing rugged connectors that house the MT interface within. In some cases, several MT ferrules may be contained in one interconnect or connector shell.

The alignment sleeve is used in single-way connectors and also in multiway connectors, each mated pair having its own alignment sleeve. Typical circular ferrules seen in the aerospace industry have diameters of 1,25 mm, 2,5 mm and 1,6 mm. The ferrules are aligned axially by spring pressure, either provided in the optical terminus or with a separate spring in the interconnect (connector).

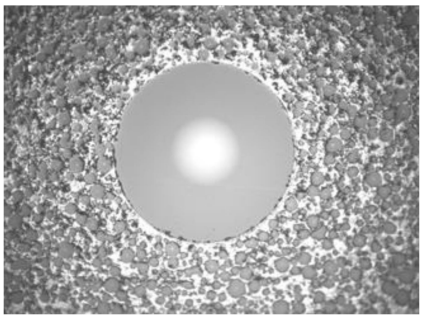


Figure 12 — A multimode fibre (end view) potted in a multi-fibre MT ferrule

Both fibre/ferrules have been polished. Note the ‘aggregate’ particles in the thermoplastic MT material.

4.5.2.6 Fibre attachment method

There are two main types of fibre to connector attachment processes. The first is termed “pot and polish”, where a fibre is bonded into a ferrule using adhesive and subsequently polished. This process generally uses a heat cured adhesive, a source of heat for curing the adhesive and various grades of polishing film and polishing tools to achieve an optimized fibre end finish.

Although the pot and polish process is achievable in an aircraft environment, it has notable differences to a conventional electrical wire termination process. This has led to significant effort being invested into the search for a mechanical based, dry, termination process that doesn’t require a heat source for attaching fibres to connectors. Some adhesive terminations can be performed with specialist adhesives e.g. anaerobic adhesives, without the need for a heat source. However, the performance of these adhesives is inferior over temperature to that of heat cured epoxies.

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There are of course other connector termination processes; however, they tend to be variants or hybrids of the above two techniques. The one notable exception is a variation on fusion splicing (a fibre repair process designed to permanently join two fibres). In this technique a cleaved fibre is inserted into a connector and fused by an electric arc to a pre-installed, pre-polished fibre. This is not a widely used technique and has significant safety implications for on-aircraft use.

However, this technology is used for maintenance purpose when a cable is broken for example. The fusion spliced fibres are protected in a specific casing to recover the initial performance of the cable. Life duration is then preserved.

Fibre attachment is predominantly achieved by use of adhesive in the aerospace community, while crimping is more widespread in the telecommunications community. No aerospace suitable mechanical based termination process is presently available for silica fibres. Terminations using adhesive are thus the only ones considered in detail in this document. This is not to say that all-mechanical crimp and cleave terminations will not become available in the future.

The third process is mixing crimping and epoxy.

4.5.2.7 Number of fibre channels

The fibre optic system designer has a single choice when deciding how to join multiple optical fibres to equipment and to other optical fibres: whether to use multiple single-way connectors or a multi-way connector. Single and multi-way connectors are illustrated in Figure 13.

4.5.3 Single-way interconnects/connectors

The simplest fibre optic interconnect (connector) is the single-way connector. This connector terminates a single cable to another with integral strain relief and (generally) some form of environmental sealing. The fibre end-face is usually easily accessible for cleaning and inspection in such connectors, either by disassembly or by virtue of using exposed ferrules and a separate guide tube or adapter. Since this type of connector is designed to handle individual fibre optic cables this type of connector is not very space efficient when used for multiple fibre optic cables. Single-way connectors may be plug/receptacle type, with male/female or hermaphroditic termini (same design on both mating connectors). Spring loading will probably be supplied on at least one side of the single-way connection to keep the fibres in intimate contact.

4.5.4 Multi-way interconnects/connectors

As the name suggests this type of connector is designed to join two or more optical fibres simultaneously. Since the connector coupling hardware is common for a number of optical ferrules (or termini), this arrangement is fairly space efficient. Cleaning and inspection can be difficult with this type of connector unless the connector features a removable ferrule alignment assembly (sometimes referred to as a removable front insert). While single-way connectors achieve fibre load isolation by terminating the cable strength member to the rear of the connector, multi-way connectors may rely on a separate back shell typically for sealing and strain relief. This component is usually screwed onto the rear of a multi-way connector and acts as the anchor point for each individual cable's strength member. Figure 14 shows a typical multi-way fibre optic connector (an example with back shell fitted).

The MT array connector can be classed as a multi-way connector, in a small space envelope although the individual channels cannot be removed. An example of a rugged connector that employs an MT ferrule is shown in Figure 15.

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Key

1 Multi-way connectors

2 Single-way connectors

Figure 13 — Examples of multi-way connectors

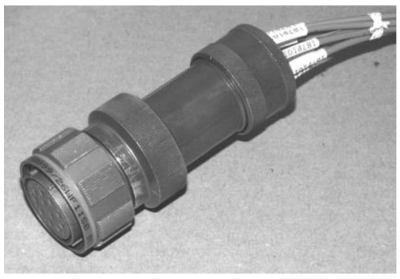
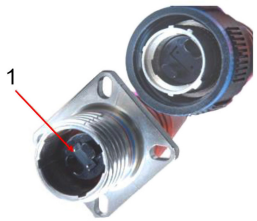


Figure 14 — Typical multi-way fibre optic connector (with back shell fitted)



Key

1 MT ferrule

Figure 15 — Multi-way connector featuring a multi-fibre array (MT) ferrule

4.5.5 Choice of tooling

The development of fibre optic termination processes has led to a broad range of tools becoming available for the attachment of optical fibres to optical connectors.

The aspects of fibre termination will be discussed in Clause 6 but tools are required for the main processes as follows:

— cable preparation (cutting to length);

— removal of outer jacket;

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— cable handling;

— removal of coatings;

— application of adhesives;

— curing of adhesives;

— cleaving of fibre;

— polishing (by hand or machine process).

Because silica has vastly different properties to copper, the following points shall be taken into account:

— most tools for cable preparation are similar to those for electrical connectors/cables;

— appropriate choice of tools generally reduces the skill level requirements;

— optical termination differs from wire termination because final termination quality is not a simple function of tool quality, but can also be dependent upon operator skill and judgement (although some automation is possible);

— the optical termination process generally requires access to a power source (for epoxy curing processes);

— care has to be taken when selecting tooling, particularly for any operation that will expose the silica fibre. Small changes to a tool or the way the tool is used can make resolvable differences to the strength of the fibre.

5 Health and safety aspects

5.1 General

The use of fibre optic systems in an aerospace environment led to health and safety considerations similar to that required of industry in general. The processes and associated risks involved have resulted in the following main points to be considered.

5.2 Chemicals

Adhesives and cleaning products invariably contain chemicals and other substances, which require specific referral to the relevant specific health and safety data. Chemicals will require observance of the required COSHH handling and exposure indications. In addition, specific termination processes may require risk assessments to be carried out. The following list gives the scope of the factors that need to be addressed prior to the use of any chemical, which may be needed at various stages of any harness assembly, whether optical or electrical:

— identification (bullets points added);

— composition;

— hazard identification;

— first aid measures;

— firefighting measures;

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— accidental release measures;

— handling and storage;

— exposure controls /personal protection;

— physical and chemical properties;

— stability and reactivity;

— toxicological information;

— ecological information;

— disposal considerations;

— transport information;

— regulatory information.

This list is not intended to deter the use of fibre optic systems because the procedure is no different to that used for any other substance in industry generally.

5.3 Sharps

Sharp edges can be encountered not only due to the fibre itself but also due to fibre preparation tooling used during the termination procedures. Sharp ends of unprotected fibre may occur due to damage or breakage of the completed harness or during any stage of manufacture, in particular the cleaving stage of termination will routinely produce fibre optic sharps. Another common sharp hazard is the needle attached to a syringe used to inject epoxy adhesive into a connector ferrule.

During the termination of fibres, the sharps produced need to be disposed of safely and precautions taken to protect the operator, i.e. to prevent penetration of the skin and eyes or inhalation of glass fragments.

It is now standard practice in many organisations to use medical ‘sharp bins’ to dispose of fibre optic sharps. These yellow containers have a disposal slot that can be sealed when the bin is full. Disposal is usually carried out by incineration at an approved waste disposal site. The list of factors for chemicals above can be used to classify the risks involved in handling “sharps” in a similar manner.

Due to the varied nature of chemicals and substances contained within adhesives, cleaning agents, and the handling of sharp items used during the manufacture of fibre optic harnesses, it is recommended that for regulations and application of such materials the local or company health and safety representative needs to be consulted.

6 Termination process

6.1 Objective

The main objective of a fibre optic termination procedure is to retain an optical fibre within an alignment element (usually the ferrule of an optical terminus which then fits inside a connector) and keep it there, throughout the manufacturing, installation and through life operation of the terminated assembly. The fibre, alignment element and their respective dimensional tolerances need to be pre-selected to ensure good fibre core alignment. The accuracy of fibre core alignment is generally achieved by installing the fibre into a ferrule with a high precision, tight tolerance, bore. It is also necessary to

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achieve a suitable fibre end-face quality to ensure good optical transmission and where required low optical back reflection.

To achieve this, it is necessary to perform a number of distinct, sequential processes. The exact sequence of these processes may vary from one manufacturer's termination procedure to another. However, most procedures will involve a significant proportion of the stages that are described in the following subclauses.

6.2 Cable preparation

6.2.1 General

In order to gain access to the fibre it is necessary to prepare a fibre optic cable prior to attachment to the connector ferrule. This involves the removal of various protective layers to specific dimensions and includes outer jacket and buffer layer stripping, as well as trimming of the strength member to length and eventually the bounding layer if it is present.

6.2.2 Cutting to length

The objective for this activity is to consistently cut through a specified fibre optic cable (fibre, strength member and any additional protective layers), avoiding cable damage that makes subsequent cable preparation processes more difficult. This process will also ensure both tool life and ease of use are optimized.

Cutting a piece of fibre optic cable to length may seem like a rather trivial issue. However, it should be noted that most avionic specification, fibre optic cables contain silica optical fibres and aramid yarn strength members. These materials are hard and tough respectively, a combination, which will significantly shorten the life of conventional, hardened steel wire cutters. One can expect blade damage to a hardened steel tool after the first cut through a typical avionics fibre optic cable as shown in Figure 16.

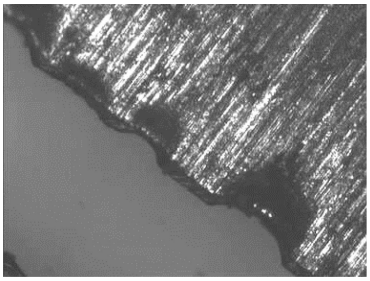


Figure 16 — Hardened steel tool damage after cutting through silica optical fibre

The best type of tool for cutting fibre optic cable has been found to be piano wire cutters with tungsten carbide blades. The blades shall be of the butting rather than shearing type, since shearing blades will place an unacceptably high load on the tool's hinge joint. A tungsten carbide bladed tool has been shown to last for many thousands of cuts, with little or no evidence of wear. Such a tool is shown in Figure 17.

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Figure 17 — Tungsten carbide stripping tool tipped cutter through fibre optic cables

This tool is also useful for stripping strength members.

It is possible that the action of cutting the cable produces a splayed out or “chiselled” end to certain types of fibre optic cable, this is particularly evident at the end of cables containing polyimide primary coated fibre Figure 18. Generally, polyimide-coated fibres retain the coating when bonded into the high precision bore hole, so any distortion of the coating diameter can prevent insertion into the ferrule.

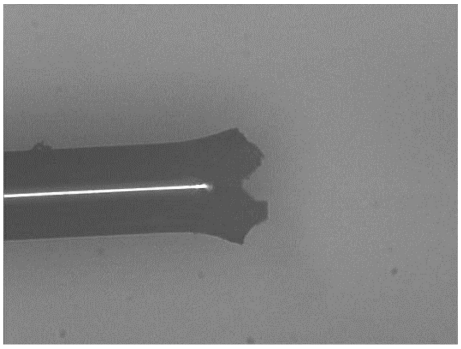


Figure 18 — Splayed out polyimide fibre end

6.2.3 Removal of outer jacket

6.2.3.1 Objectives

The objectives for this activity are to consistently remove a controlled, pre-defined length of cable jacketing material, without damaging cable sub-layers, while also ensuring that the remaining cut face of the jacket is perpendicular to the fibre and free from rough edges (e.g. “ears”). This can also be achieved with both long tool life and ease of use.

The range of possible tools for performing this activity is vast and as with many manual processes, the choice of outer jacket stripping tool will depend upon personal preference as well as functional performance. However, several important aspects concerning striping tool choice shall be taken into account.

6.2.3.2 Rotary tools

Looser tube (jacket) cables may allow the use of simple rotary tooling (Figure 19), which is rotated around the jacket, scoring the material. The ‘slug’ (the portion of jacket to be removed) is then simply pulled off, revealing the stripped length. This sort of tool cannot be used on many tight jacket cables because the jacket is tightly extruded over the underlying members. So, even when scored, the jacket does not slide off easily. Where these tools can be used it shall be ensured that the coating is scored rather than cut through. Otherwise, the underlying strength members or buffer layers can be damaged. Regular calibration of the blade depth is recommended for his reason.

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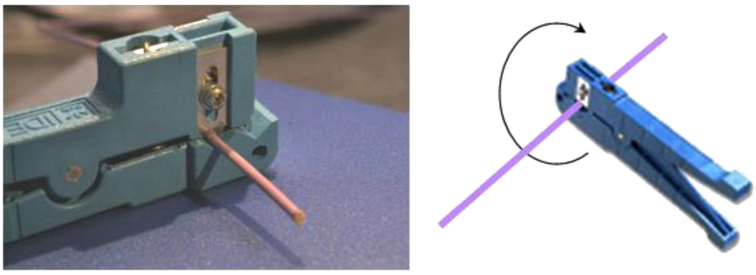


Figure 19 — Example of rotary tool (used by engaging and rotating around the cable jacket)

6.2.3.3 Stripmaster-type tools

This type of tool (shown in Figure 20) is sometimes used to remove fibre optic cable jackets. The mechanism has an element of automation. The cable is positioned between the gripping surfaces (discussed shortly) and aligned to the correct stripping aperture. As the handles are squeezed together, the blades engage around the cable. Squeezing the handles further will separate the bladed part from the gripping part, thus removing the jacket section. Care needs to be taken to make sure the tool is fully engaged and that the parts separate properly, otherwise the cable can be bent beyond its minimum band radius and may break. Two of the common blade types are now discussed.

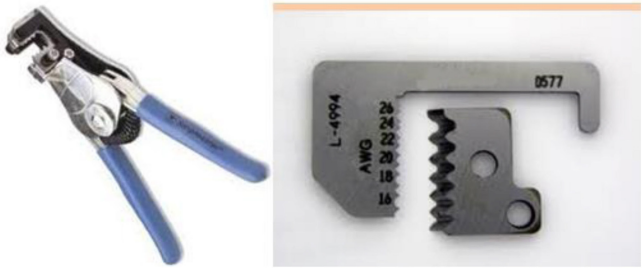


Figure 20 — Example of strip master type tool and blade set

The Stripmaster-type tools generally have two types of blades namely butting knife-type blades and butting die-type blades

Butting knife type blades (Figure 21) are sharp and have a very small, sharp contact area at blade closure, which will tend to wear. In this situation, as the tool wears, the stripping hole will become smaller and more oval, with the possibility of eventually touching and damaging the sub-layers. However, tests have shown that these tools produce some of the best strip results when new. An optimum result (produced by knife-type blades in this case) is illustrated in Figure 22. Note the clean edge to the remaining cable jacket and integrity of the underlying strength member.

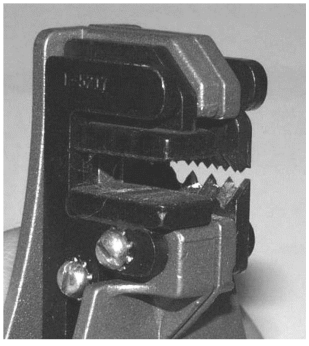


Figure 21 — Butting knife type blades (stripmaster type tool)

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Figure 22 — Example of stripped jacket shows a good strip result from knife blades

Butting die-type blades (Figure 23) have a relatively large contact area on blade closure. This contact surface hardly wears at all. Consequently, the only area to wear will be the precision ground cutting blades, which become larger in diameter with use. Thus, as the tool wears, the stripping performance drops off to the point where the tool will no longer strip the cable's outer jacket. This is a relatively safe tool failure mode. The size of cavity or clearing behind the Die-type blade will dictate whether the remaining cable will be 'trapped' as the blades engage. It is this trapping that will lead to the generation of 'ears' on the remaining cable jacket. An illustration of these ears is shown in Figure 24.

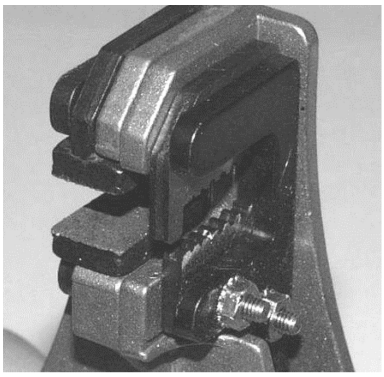


Figure 23 — Die-type blades on stripmaster type tool

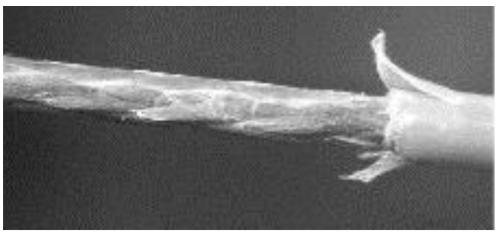


Figure 24 — Example of stripped jacket showing jacket 'ears' caused by trapping of remaining jacket in die blades

Correct choice of die-type blades can give results similar to knife-type blades but care should be taken to make sure ragged 'ears' are avoided.

NOTE This method is outdated and not preferred on loose structure cable.

Clearly, a clean jacket edge is desired from the stripping process. Ragged 'ears' to the jacket can interfere with subsequent insertion into an interconnect (or connector).

6.2.3.4 Shearing blade tools

Shearing (or scissor-like) knife type blades (e.g. Figure 25) often have sharpened V-shaped apertures to cut through the outer jacket. These operate in the same way as domestic electrical wire strippers with

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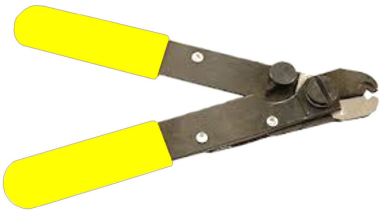


Figure 25 — Shearing knife type blades on jacket stripper

Shearing blade tools can cause the cable to bend significantly depending on the jacket and cable thickness as the tool cuts through the jacket. It is also important not to angle the tool in operation, to keep the tool oriented perpendicular to the cable axis (stripping along the cable axis direction). This is to ensure the stripping aperture does not close down to a smaller elliptical aperture (rather than a circular profile). Clearly, a smaller aperture could damage the underlying layers and also cut or damage the strength member.

6.2.3.5 Precision multi-aperture cable strippers

Precision multi-aperture strippers can be used for stripping fibre optic cables. As the name suggests they have several apertures for stripping various sizes of cable. Some may have apertures for stripping the outer jacket and additional apertures for stripping underlying coatings and buffers. Dedicated fibre optic tools are available but electrical wire stripping tools can also sometimes be used. Examples are shown in Figure 26. These tools may have properties common to both the butting die type blades and the shearing knife type blades.

In terms of blade wear, effects depend on the contact point that 'stops' the stripping aperture. If the control point of contact (at tool closure) is located at the tip of the tool, this shall not wear. The precision stripping hole will tend to get larger as the tool wears. However, the precision hole is formed at the junction of two shearing knife blade edges. It has been found that these very fine unsupported edges can tend to break, giving rise to the creation of "ears" on the stripped cable end. This is due to small gaps at the point of contact between the blades. Similar wear characteristics have been observed for primary coating removal tools also. For wire strippers, the tools often have the aperture size specified in terms of SWG or AWG (Standard Wire Gauge or American Wire Gauge). These numbers cannot be relied upon to give a consistent aperture size, i.e. 22 AWG on one tool will not necessarily have the same size stripping hole as a 22 AWG on a different tool. Therefore, care should be taken in specifying and using tooling of this type. For any stripping tool, calibration and control of the stripping aperture is recommended to ensure that tools are of the correct size and fit for purpose.



Figure 26 — Left: Precision multi-aperture fibre stripping tool — Right: Electrical wire stripper

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Again, it is recommended that these tools are held perpendicular to the cable axis (i.e. side-on) during the stripping process. However, if the cable is of a tight-jacket construction, this operation may be difficult. The remaining cable will generally be restrained by the operator's free hand and the cable may bend excessively when trying to pull the jacket off. One of the main considerations when handling and installing fibre optic cables is not to exceed a *minimum bend radius*. This can drastically reduce the lifetime of the cable or in extreme cases, break the fibre completely.

Depending on the cable size, stripping in smaller sections can cause less disruption to the underlying cable than trying to remove a larger section in one go.

6.2.3.6 Blade settings

When considering any fibre optic stripping tool for use in an aircraft environment, tight control over the tool's performance should be imposed whilst limiting the scope for misuse.

Any tool that permits the blade cutting depth to be manually adjusted to compensate for wear shall be avoided unless sufficient control measures are in place, as this can lead to incorrectly set blades and the possibility of damaging cable sub-layers.

Generally, the stripping aperture of the blades will be chosen to be just larger than the underlying coating (or strength member) as shown in Figure 27. It is desirable not to disrupt underlying layers as this may reduce fibre protection.

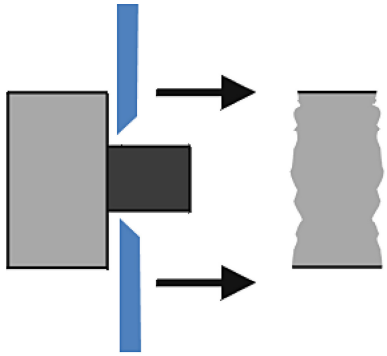


Figure 27 — Stripping tool apertures should be chosen to be just larger than the underlying coating or cable layer

Choosing blade apertures that are too small in relation to the underlying coating or strength member may cause damage to that element of the cable. This is illustrated below in Figure 28. The damage (chafing) to the strength member was caused by using too small an aperture on a jacket stripper.



Figure 28 — Strength member damage caused by inappropriate aperture size

6.2.3.7 Automated jacket strippers

Automated machines are also available (or may be encountered) for removing the outer jacket of a fibre optic cable. These may require the operator to simply insert the cable into an aperture. Within these machines will be alignment features and a stripping mechanism. This type of machine should be

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regularly serviced and calibrated to ensure stripping blades are in good condition and the mechanism is performing correctly If the strength members are too woven, then the mechanism can become entangled in the strength member.

It should be noted that some cable designs may be problematic when used in automatic stripping machines. Effects such as strength member entanglement can occur in the stripping mechanism. In addition, some fibre optic cables may feature a retaining yarn or thread that is wrapped around the strength member. Again, this can become entangled in automated tools. It should be ensured that automated tooling is set up correctly for the cable type to be stripped.

6.2.4 Cable handling tools (gripping the cable)

Cable guiding and support can be achieved in a number of ways: by hand, by integration into the stripping tool or by an entirely separate tool. Some tools have small v-groove sections that help to align the cable to the cutters as well as preventing small diameter cables moving from side to side once clamped.

The actual process of gripping avionics fibre optic cable is important for two reasons. Because these cables are designed for high-temperature use under exposure to aggressive chemicals, it is usual to have an outer jacket that may be of low friction (for example Ethylene Tetrafluoroethylene (ETFE)). Jacket materials may therefore be difficult to grip. In addition, these cables can be easily deformed by sharp ribbed type gripping mechanisms (common on some electrical wire strippers, e.g. the Stripmaster type).

It has been found that the best cable “gripper” for most jacket materials is a cable clamp with either a high coefficient of friction rubber or a hard surface with a “grit” type surface finish. The “gritty” surface is less likely to damage fibres than hard knurled or parallel fine ridge types. Use of ridge type cable grippers can cause serious deformation to avionic fibre optic cables and shall therefore be avoided. Figure 29 illustrates the difference. As noted above, use of the hand to grip and support the remaining cable (as might be done when using wire-stripping tools) can cause severe bending of the cable so the process should be done in a controlled manner. Figure 29 shows a fibre optic cable handling tool

The use of cable gripping mechanisms should be carefully controlled when using semi-loose cable designs where there is some mobility of the fibre within the cable construction. Clearly, excessive pressure on the cable could deform the underlying layers such that the fibre may be trapped, and its movement impeded. For these cable designs, jacket stripping tools that do not clamp the jacket would be preferred.

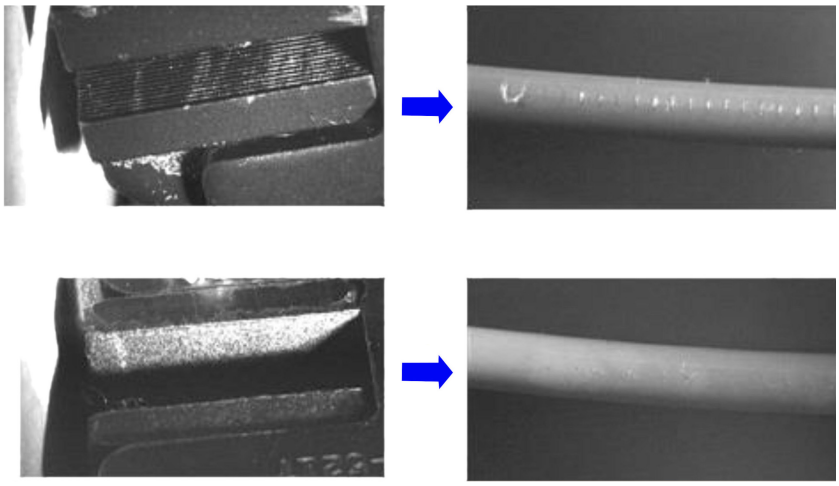


Figure 29 — Cable clamping plate damage on optical fibre cables

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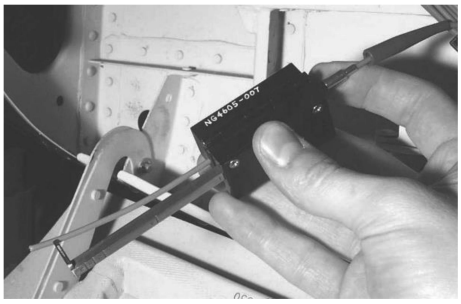


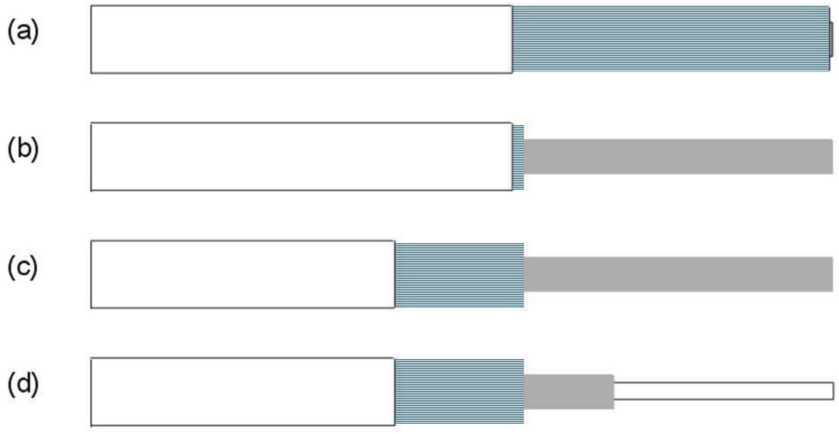
Figure 30 — Fibre optic cable handling tool

6.2.5 Strength member trimming/removal

Most termination procedures for fibre optic cable containing aramid yarn strength members will require the strength members to be cut to a specific length. The exposed strength member length is important as this determines the surface area of strength member that can be trapped during subsequent crimping stages. This in turn governs the cable-to-termination pull-off strength.

NOTE The strength of the fibre to ferrule epoxy bond is not considered under this point, as the strength member attachment regime is designed to isolate the fibre/ferrule assembly from externally applied tensile loads.

This stage is quite difficult to perform accurately and the best way to achieve a reasonably tight tolerance on exposed strip length is to perform a two-stage “cut and strip”. In this process the outer jacket is stripped, and the strength member is removed as fully as possible at this strip length. The outer jacket is then further stripped to expose the required length of strength member Figure 31.



Key

a Strength member
b Strip jacket to set distance
c Trim strength member neatly to jacket edge
d Strip further set distance of jacket

Figure 31 — Sequence showing a cut-and strip technique for attaining a neat end

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