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Management Centre: rue de Stassart, 36   B-1050 Brussels

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Foreword

This European Standard (EN 4533-001:2006) has been prepared by the European Association of Aerospace Manufacturers - Standardization (AECMA-STAN).

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

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2007, and conflicting national standards shall be withdrawn at the latest by January 2007.

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Introduction

a) The handbook

This handbook draws on the work of the Fibre Optic Harness Study, part sponsored by the United Kingdom's Department of Trade and Industry, plus other relevant sources. It aims to provide general guidance for experts and non-experts alike in the area of designing, installing, and supporting multi-mode fibre-optic systems on aircraft. Where appropriate more detailed sources of information are referenced throughout the text.

It is arranged in 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 and inspection*

b) Background

It is widely accepted in the aerospace industry that photonic technology offers a number of 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). To date, the latter has been the critical driver for airborne fibre-optic communications systems because of the growing use of non-metallic aerostructures. However, future avionic requirements are driving bandwidth specifications from 10's 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 in sensing many of the physical phenomena on-board aircraft.

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 lead 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.

c) The fibre-optic harness study

The Fibre-Optic Harness Study concentrated on developing techniques, guidelines, and standards associated with the through-life support of current generation fibre-optic harnesses applied in civil and military airframes (fixed and rotary wing). Some aspects of optical system design were also investigated. This programme has been largely successful. Guidelines and standards based primarily on harness study work are beginning to emerge through a number of standards bodies. Because of the aspects covered in the handbook, European prime contractors are in a much better position to utilise and support available fibre optic technology.

1 Scope

1.1 General

This Part of EN 4533 examines the termination aspects of fibre optic design for avionic installations. By termination is meant the mechanism used to interface from one component (usually a fibre) to another. This is normally performed by a connector, which aligns the fibre with another component (usually another connector) to a sufficient accuracy to allow continued transmission of an optical signal throughout the operational envelope.

This Part will explain the need for high integrity terminations, provide an insight into component selection issues and suggests best practice when terminating fibres into connectors for high integrity applications. A detailed review of the termination process can be found in Clause 4 of this part and is organised broadly 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 almost impossible. Because of the problems of defining a generic termination instruction, this handbook has concentrated on 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 the repair part of this handbook.

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 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. This is often expressed as the need for reliable connectors, but in reality it is the need for a reliable cable to connector termination process. The essence of this requirement is the need to assure reliable light transmission through each optical connector throughout the operational envelope. This needs to be achieved through a robust process that enables a high level of optical performance over the lifetime of the terminations.

Many factors can contribute to an optical connector’s in-service performance, such as basic connector design, choice of optical fibre, cable, operating and maintenance environment etc. However, one of the main factors governing in-service connector performance is the quality of the cable to connector termination.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 4533-002, *Aerospace series – Fibre optic systems – Handbook – Part 002: Test and measurement.*

3 Component selection

3.1 Elements

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 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.

3.2 Fibre optic cables

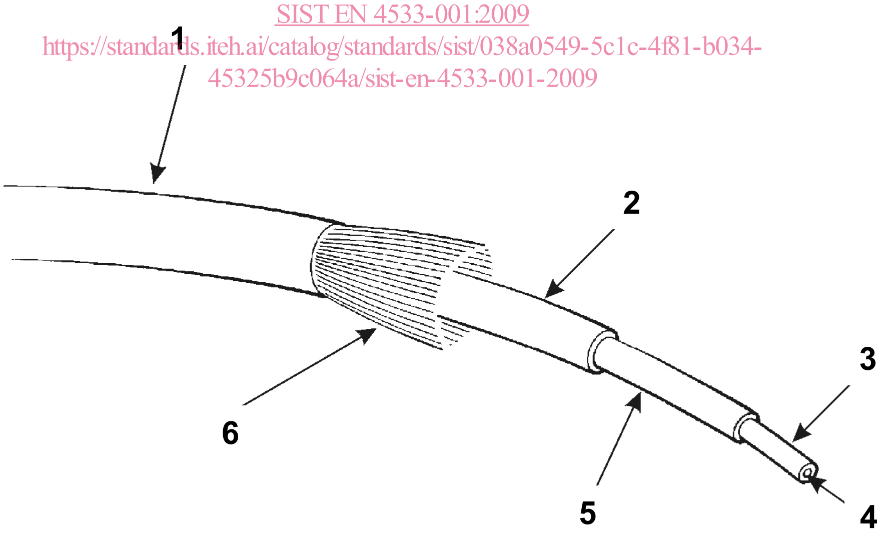
3.2.1 General

One of the main aspects to be addressed is the implication of choosing one cable construction over another.

There are various types of fibre optic cable on the market ranging from loose tube to tight jacket construction, containing a single fibre or an array of many fibres; however, at the time of publication of this handbook the range of options available to aerospace users is somewhat limited. Most of the possible cable types are only suitable for telecommunication applications due to environmental capability limitations, with avionic solutions being generally limited to single fibre, tight jacket constructions.

3.2.2 Cable construction

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 cable strength member materials. Each has its own positive and negative attributes in the context of termination procedures. Avionic fibre optic cables are typically constructed as follows, see Figures 1 and 2.



Key

1 Outer jacket
2 Buffer
3 Cladding
4 Core
5 Primary coating
6 Strength member

Figure 1 — Typical avionic fibre optic cable construction

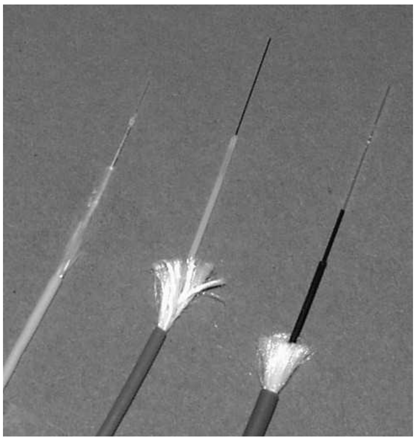


Figure 2 — Examples of typical avionic fibre optic cables

3.2.3 Fibre choice

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 and primary coating materials. Current generation of avionic fibre sizes tend to be larger than the standard high volume fibres such as those used in the datacomm/telecomm market and so have an associated cost and availability penalty.

3.2.4 Cladding materials

Most avionic fibres employ an "all silica" fibre, i.e. both the core and the cladding are made from glass and may be treated as a single glass filament. Some designs use non-glass materials for the cladding e.g. plastic (acrylate) or epoxy. These fibres are referred to as Plastic Clad-Silica (PCS) and Hard Clad-Silica (HCS) respectively. Although these fibres have been used in a number of aircraft applications they are somewhat limited in thermal endurance capabilities and thus tend to be confined to the more benign environmental applications. The termination processes described in this handbook refer to all-silica fibres.

3.3 Primary coating materials

3.3.1 Function

The major function of the fibre buffer coating [1] is to protect the fibre from abrasive and environmental damage. Many materials have been used for the primary coating of optical fibres but the most widely known and used of these are, acrylate, polyimide and silicone. The pros and cons of each are briefly described below.

It should be noted that most fibres use an acrylate type material for the primary coating. Other materials can be encountered however, such as silicone, proprietary polymers and even metal, such as Gold or Aluminium (although these are somewhat specialised and will not be considered here).

3.3.2 Acrylate

This is perhaps the most common of optical fibre primary coating materials and is relatively easy to remove with hand tools. The coating is usually a UV cured acrylate that is translucent and typically is the same thickness as the fibre. Acrylate's have a limited temperature performance of up to approximately 100 °C therefore, for high temperature applications other additional coatings are also applied.

3.3.3 Polyimide

This coating has a higher temperature range than UV cured acrylates and can be used in temperatures up to approximately 350 °C. Although useful for high temperature applications polyimide coatings are difficult to remove and are not amenable to tool stripping. Widely used on aircraft programmes in the United States. Fibres employing this material are designed to be installed into connector ferrules without the need to remove the primary coating. This is only possible because the core/cladding/primary coating 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 bore dimensions, thus non-standard ferrule bore sizes need to be used with an associated cost and availability penalty.

3.3.4 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, it’s high temperature (up to 200 °C) capability, its resilience to water absorption 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).

3.4 Aramid yarn versus fibreglass strength member

Almost all fibre optic cables employ some form of strength member layer. Its function is to isolate cable external loads from the fibre within. The most common material used for this purpose is Kevlar®; a very tough, strong aramid yarn. However, it is by no means the only material used for this purpose – fibreglass being one of the main alternatives.

Fibreglass is better matched to the optical fibre’s thermal coefficient of expansion than Kevlar® and has been used where high temperature (> 135 °C) dimensional stability is required of a cable. This aspect should be considered if a cable is to be subjected to prolonged exposure of rapid thermal cycling stresses over a wide temperature range. However, Kevlar® appears to meet most current avionic temperature requirements (– 55 °C to 135 °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. Kevlar® and other similar aramid yarns can be crimped directly onto a connector or termini; fibreglass cannot because it is too brittle. Cables employing fibreglass strength members should be bonded with adhesive or crimped via the cable outer jacket.

3.5 Fibre optic connectors

3.5.1 Purpose

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

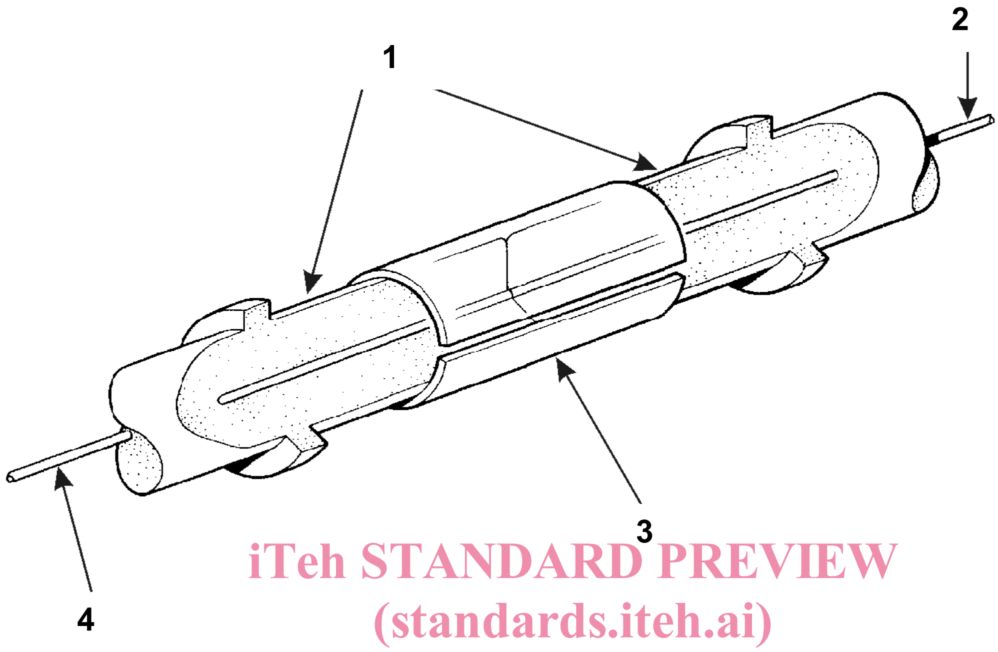
3.5.2 Connector types

3.5.2.1 General

There are a large variety of connectors available, ranging from single way “crimp and cleave” to complex multi-way “pot and polish” devices. 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 and the number of fibres to be accommodated.

3.5.2.2 Optical interface

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". A typical butt-coupled arrangement is shown in Figure 3. The fibres physically 'butt' together at the connection.



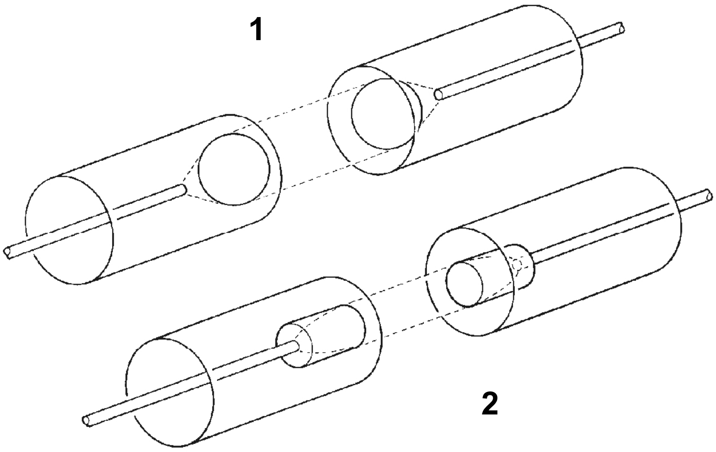
Key

1 Ferrules
2 Optical fibre
3 Spit alignment sleeve
4 Optical fibre

Figure 3 — Butt-coupled fibre optic connector interface

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).

An alternative to the butt-coupled interface is to place lenses between the two fibre ends (see Figure 4). 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.



Key

1 Ball lens

2 GRIN lens

Figure 4 — Expanded beam fibre optic connector interfaces

3.5.2.3 Fibre attachment method

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

The second process, referred to as “crimp and cleave” is an attempt to satisfy the need for an electrical wire equivalent process. This is where a connector ferrule is crimped down onto the fibre or some other element of the fibre’s jacketing layers, with the fibre end being prepared by cleaving rather than polishing.

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.

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.

3.5.2.4 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.

3.5.2.5 Single-way connectors

The simplest fibre optic connector is the single-way connector. This connector terminates a single tight jacket 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 it is designed to handle individual fibre optic cables it is not very space efficient when used for multiple fibre optic cables.

3.5.2.6 Multi-way connectors and back-shells

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 provision is made for a removable ferrule alignment assembly. While single-way connectors achieve fibre load isolation by terminating the cable strength member to the rear of the connector, multi-way connectors generally rely on a separate backshell 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 5 shows a typical multi-way fibre optic connector (with backshell fitted).

Figure 5 — Typical multi-way fibre optic connector (with backshell fitted)

3.5.2.7 Choice of tooling

The development of fibre optic termination processes has lead to a broad range of tools becoming available for the attachment of optical fibres to optical connectors. Because silica has vastly different properties to copper, the following points should be noted:

- 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 is also dependent upon operator skill and judgement;
- 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.

4 Health and safety aspects

4.1 General

The use of fibre optic systems in an aerospace environment lead 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.

4.2 Chemicals

Adhesives and cleaning products invariably contain chemicals and other substances, which require specific referral to the relevant specific health and safety data. 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;

— Composition;

— Hazard identification;

— First aid measures;

— Fire fighting measures;

— 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.

4.3 "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.

During the termination of fibres the trimmed ends 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.

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.