**SLOVENSKI STANDARD**

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**Aeronavtika - Sistemi iz optiļ nih vlaken - Priroļ nik - 002. del: Preskuġanje in merjenje**

Aerospace series - Fibre optic systems - Handbook - Part 002: Test and measurement

Luft- und Raumfahrt - Faseroptische Systemtechnik - Handbuch - Teil 002: Prüfung und Messung

Série aérospatiale - Systèmes des fibres optiques - Manuel d'utilisation - Partie 002 : Essais et mesures

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# EN 4533-002

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English Version

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# Foreword

This European Standard (EN 4533-002:2006) 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of an identical text or by endorsement, at the latest by January 2007, and conflicting national standards shall be withdrawn at the latest by January 2007.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

The 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

Insertion loss is the most frequent measurement performed on a fibre optic link. The avionic system designer will want to know or predict the insertion loss of a link to determine its performance. Aircraft manufacturers will want to measure the insertion loss of harness components during assembly and before it is delivered to the customer to highlight faults and to provide a record of the performance of the harness at the beginning of its lifetime (footprinting). The insertion loss will be measured at intervals during the lifetime of the aircraft to discover or identify faults and any gradual degradation in performance of the harness.

There is, however, one problem. It is difficult to collect reliable and consistent measurements of the insertion loss on any multi-mode fibre optic harness where the distance between components is relatively small (less than 100 metres). The reason is that the insertion loss of a component or a harness depends on the power distribution of the light injected into it. This leads to very large differences in the measured value of the insertion loss [1] depending on the power distribution of the source used to make the measurement.

This Part of EN 4533 will explain the measurement problem and the techniques used to overcome them in greater detail.

## 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 4533-004, *Aerospace series – Fibre optic systems – Handbook – Part 004: Repair, maintenance and inspection.*

ARP5061, *Guidelines for Testing and Support of Aerospace, Fiber Optic, Inter-Connect Systems.* [1]

## 3 Problem areas and limitations

### 3.1 The problem of testing avionic, multi-mode fibre installations

The insertion loss of a fibre optic harness can be divided into two contributions. The first is the intrinsic loss of the harness caused by the properties of the materials such as the absorption of the silica of the fibre core. In the case of multi-mode fibres, this would include the variation in the loss of the component caused by changes in the power distribution. When discussing insertion loss, the term ‘power distribution’ will be used to describe the spatial and angular variation of the power across the fibre’s core rather than the temporal variation of the power along the length of the fibre. The second contribution is the additional loss that is introduced into the harness from extrinsic losses such as misalignment errors in connectors and contamination.

The insertion loss of components used in any fibre optic link depends on the power distribution of the light that passes through them. However, in some types of fibre harness, the shape of the power distribution does not change as the light propagates through it and the component insertion loss is independent of its position within the harness. For example, the power distribution in single-mode fibre harnesses is fixed by the fibre parameters and the source’s wavelength. Long-haul (a few kilometres between components), multi-mode fibre harnesses also effectively have a fixed power distribution because the distance between components is sufficient for the power distribution to reach an equilibrium state that depends only on the fibre parameters. The insertion loss of a long-haul multi-mode harness component is defined by this equilibrium power distribution.

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1) Published by: Society of Automotive Engineers (SAE), 400 Commonwealth Drive, Warrendale, PA 15096-0001.

In contrast, short-haul multi-mode fibre harnesses (less than 200 metres), like those found in avionic systems, do not have sufficient distance between components to allow the equilibrium power distribution to be attained. The power distribution entering a component within such a harness will now depend on the original power distribution from the source and changes to this distribution caused by the preceding components of the harness. There are two consequences of this power distribution dependent insertion loss:

a) The insertion loss will depend on the source used to make the measurement.

b) The insertion loss of a particular component will depend on its position within the harness.

A way of reducing the variation in the measured insertion loss is to use modal filters on the source and power meter that alter the source's power distribution to a known or standard distribution. If all measurements are made with the same power distribution, the insertion loss value will be much more repeatable. Clause 5 will describe some of these standard distributions and the various techniques that can be used to measure the insertion loss of harnesses and their components.

## 3.2 Limitations of current insertion loss prediction and measurement techniques

### 3.2.1 General

This section outlines some of the limitations of the current design and measurement techniques that are used to determine the insertion loss of multi-mode fibre optic harnesses. (See Figure 1)

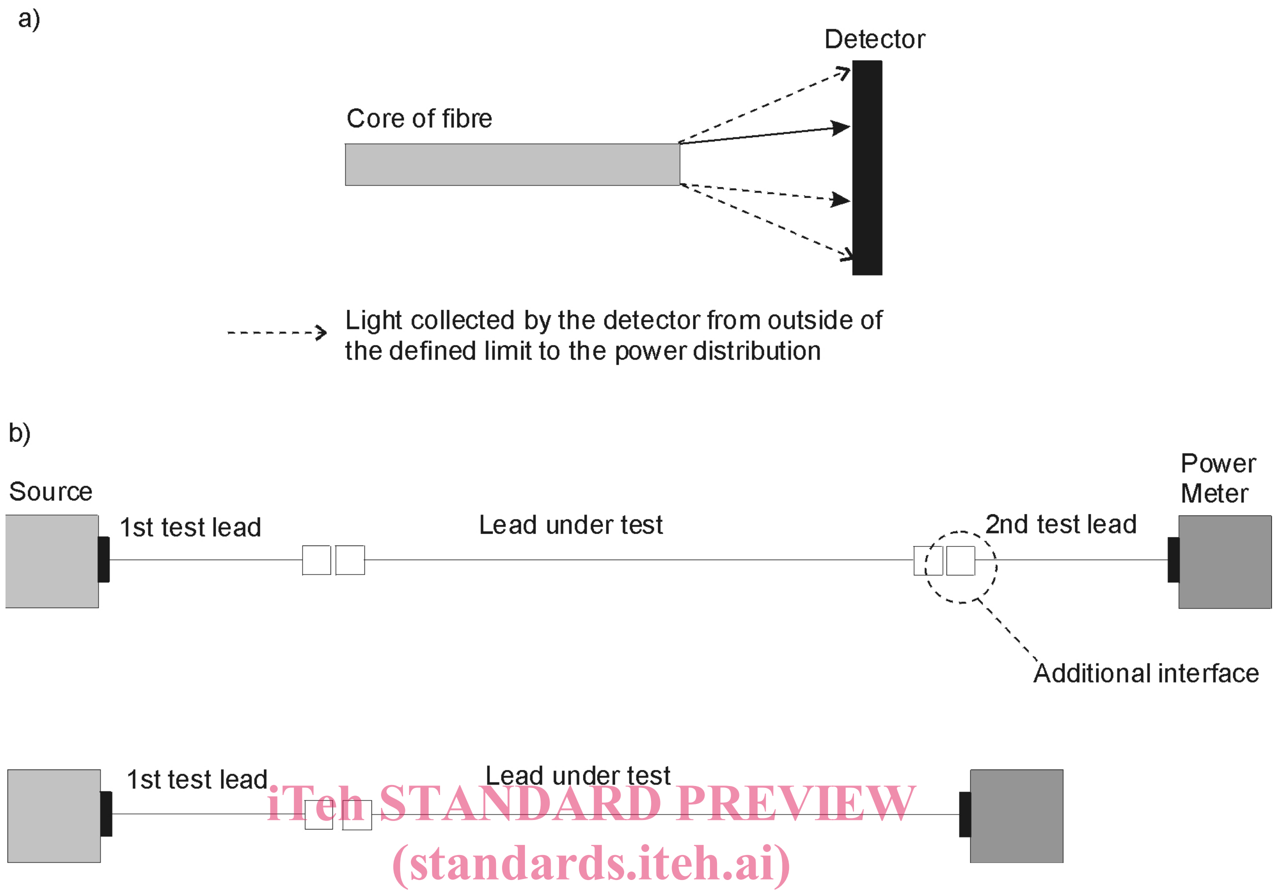
### 3.2.2 Harness design

It is difficult for fibre optic harness designers to predict with accuracy the harness performance. It is unlikely that insertion loss values of commercially available components will have been measured with a specific power distribution based on the parameters of any avionic fibre. The designer will therefore usually apply a pessimistic estimate for the insertion loss and obtain a much poorer prediction of the harness performance than may necessarily be the case. This may not be important in simple point-to-point communication links between transmitter and receiver where there can be a very large power budget. However, it will be significant in more complex networks, where there are many connector breaks, or in networks that contain components such as passive star-couplers where the power budget is likely to be much tighter.

### 3.2.3 Insertion loss measurements

Many measurements that are made on short-haul fibre optic harnesses use no form of filtering on the output of the source to modify its power distribution. This may not be very important if the measurements are for comparison with measurements made with exactly the same source. However, they cannot give reliable measurements of insertion loss that can be reproduced by another manufacturer's set of test equipment. These measurements cannot be used to guarantee the performance of the harness to a customer because it is unlikely that the customer will be able to check the loss measurements without using the supplier's test equipment.

The filtering used to modify the power distribution could also be inappropriate for an avionic application. For example, a power distribution more appropriate for telecommunication links may be used which will underestimate the loss of components in an avionic harness. Additionally, the power distribution used to make the measurement should be changed for each fibre type that is used because the fibre parameters will be different.



a) A large area detector collects light from the fibre that is outside of the defined limits for the source.

b) The removal of an interface by not using a test lead between the lead under test and the power meter.

**Figure 1 — Causes of unrepresentative power measurements**

### 3.2.4 Optical time domain reflectometry

Optical time domain reflectometry (OTDR) is a single ended diagnostic/measurement technique that relies on the backscatter of light from ‘imperfections’ and discontinuities in a fibre-optical system. It is used extensively in the telecommunication industry for optical system commissioning and testing. OTDR technology potentially enables a reference insertion loss footprint to be generated requiring only a single measurement to characterise an entire harness under test. Furthermore, comparison between current and previous traces can be performed automatically by standard OTDR software largely de-skilling measurement and diagnostic operations. However, current OTDRs struggle to meet the specific requirements of airborne optical harnesses, in particular spatial resolution (dead zone) performance.

## 3.3 The way forward

The following three options would enable a more reliable means of predicting and testing the performance of multi-mode fibre optic harnesses:

1) A method of predicting the power distribution throughout the harness. Those power distributions can be used to find an exact value for the insertion loss of each component. The insertion loss will then be specific to that particular component at that particular position within the harness.

2) A fixed power distribution that is used to measure the insertion loss of all the harness components. If the same distribution is always used, the value of the insertion loss should be consistent and independent of the test equipment used.

3) A means of measuring the power distribution throughout the harness by interrogating the harness at a single access point (probably a connector). This would be realised by optical time domain reflectometry.

The first option is more applicable to the system designer and two methods are mentioned here and explained in more detail in Clause 3. The first method is a validated computer design package that can predict the power distributions and calculate the expected insertion losses of the individual components for any source (see 5.2). The second method is the use of matrices that represent the harness components rather than the more common insertion loss value. They represent how the power distribution is altered by the component and can be multiplied together to find the overall system loss (see 5.3).

The second option is applicable to the practical measurement of the insertion loss. There has to be a well defined power distribution that has to be used when making insertion loss measurements. The distribution should be ‘appropriate’ for short-haul avionic harnesses and is likely to vary for different fibre types and parameters (see 5.2). The measurements should also be made with well defined procedures that minimise the systematic errors (see 5.3).

The third option is again applicable to the practical measurement of the insertion loss. However, the use of an OTDR (as opposed to a power meter) potentially enables the entire optical system to be measured from a single connector break or purpose built test port. Exactly the same criteria apply with regard to the need for a well defined power distribution from the OTDR’s source that is representative of short-haul avionic harnesses. Although attractive, this solution is limited by the performance of current OTDR instruments (see 5.6).

## 4 Techniques for system design

### 4.1 General

The introduction outlined the problems of making consistent measurements of component and system loss in short-haul, multi-mode fibre optic harnesses typical of aircraft installations. A system designer needs to be able to predict the optical power distribution at any point in the harness before he can accurately predict the loss of the individual components and the overall system. Alternatively, the designer can use the worst case loss for all of the harness components and simply add them together. However, this will produce a pessimistic estimate of the transmission of the harness and could put unnecessary constraints on the harness design. For example, it may restrict the number of connectors that can be included in the harness and therefore reduce the maintainability of the harness. The following will describe the problem of using insertion loss values from component data sheets and two methods available to the designer that can help to more accurately predict the loss of components and harnesses.

### 4.2 Interpretation of component data sheets

During the system design phase the designer or engineer responsible for the physical interconnect has to derive how an optimum physical implementation can be achieved whilst keeping within the system power budget. Many decisions have to be considered when deciding on the optimum physical implementation, such as:

a) How many connections there should be and where they should they be placed to ease maintenance and repair while maximising reliability?

b) If the system is not point-to-point then what type of component is going to be used to provide the required connectivity?

c) Are specific components such as cable and connectors already mandated for the system?

When choosing components to meet the system requirements, the designer would ideally like to have all of the relevant performance data on the components that could meet his requirements. The designer can then make an informed decision as to which components best meet his needs. Determining the path loss should simply be a case of extracting the insertion loss figures from the data sheets of components that lie between the source and receiver and adding them to obtain the total path loss. However, these values cannot presently be treated in this way because, as already discussed in Clause 3, the insertion loss of short haul systems is critically dependent on the power distribution of the light launched into it.

The test method may be relevant when used on another application, e.g. long haul telecommunications, but it is unlikely that it will be appropriate for short haul avionic installations. Many of the test procedures that components are qualified against use a launch condition that is not required to fill the fibre to the same extent as those recommended as a result of work in the Harness Study 2). This underfilled launch results in an optimistic estimate of the insertion loss.

Ideally, component manufacturers would not specify a loss of a component specifically but define how the input launch is changed by the component before launching into the next component by means of a component matrix. This matrix method will be described in 5.4. Using this approach, a representative loss of the component can be achieved that is accurate for all launch conditions. The problem with this method is that, at present, there is no internationally accepted practical test for component manufacturers to determine the matrix elements.

A more practical approach is for the component manufacturer to specify an optical performance figure based on a test that is representative for short haul applications. These test conditions have been defined using raytracing software developed within the Fibre Optic Harness Study and these may require different test sources for the specific fibre types being used.

If the structure and typical tolerances of a commercial component are known, it should be possible to use the raytracing model that will be described in the next section to convert the insertion loss attained with the manufacturer's launch condition into the loss for a standard, avionic launch condition.

## 4.3 Computer modelling

A computer can be used to predict the way in which the optical power distribution in an optical system changes as it passes through components. There are many optical design packages in the marketplace which can be roughly divided into two types. The first are lens design packages that use raytracing to predict the power distributions in lens systems such as those found in photographic equipment. The second are waveguide design packages that calculate the strength of the light's electric field to find the power distributions in integrated optic components. Raytracing is a valid technique where it can be assumed that the apertures of the components are large compared to the wavelength of the light passing through them. Multi-mode fibres have core diameters that normally fulfil this criterion and it is therefore valid to use raytracing to predict the power distributions in multi-mode harnesses.

During the Fibre Optic Harness Study, a multi-mode fibre optic system design package was written that uses raytracing to predict the power distributions. This model was validated against experimental data. Figure 2 is a view of the model screen showing the various components that can be connected together to construct a complete harness. The model can be used to predict the power distribution at any point in the harness and can calculate the loss of individual components. Amongst other facilities, typical component errors can be introduced, as can representations of contamination. It is also capable of calculating the component matrices that will be described in the following section.

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2) For graded index fibre the best correlation between the two estimates of system loss was found for a useable power definition of 95 % of the core diameter and 95 % of the maximum acceptance angle. In step index fibre the best definition of useable power was found to be 100 % of the core diameter and 90 % of the maximum acceptance angle.

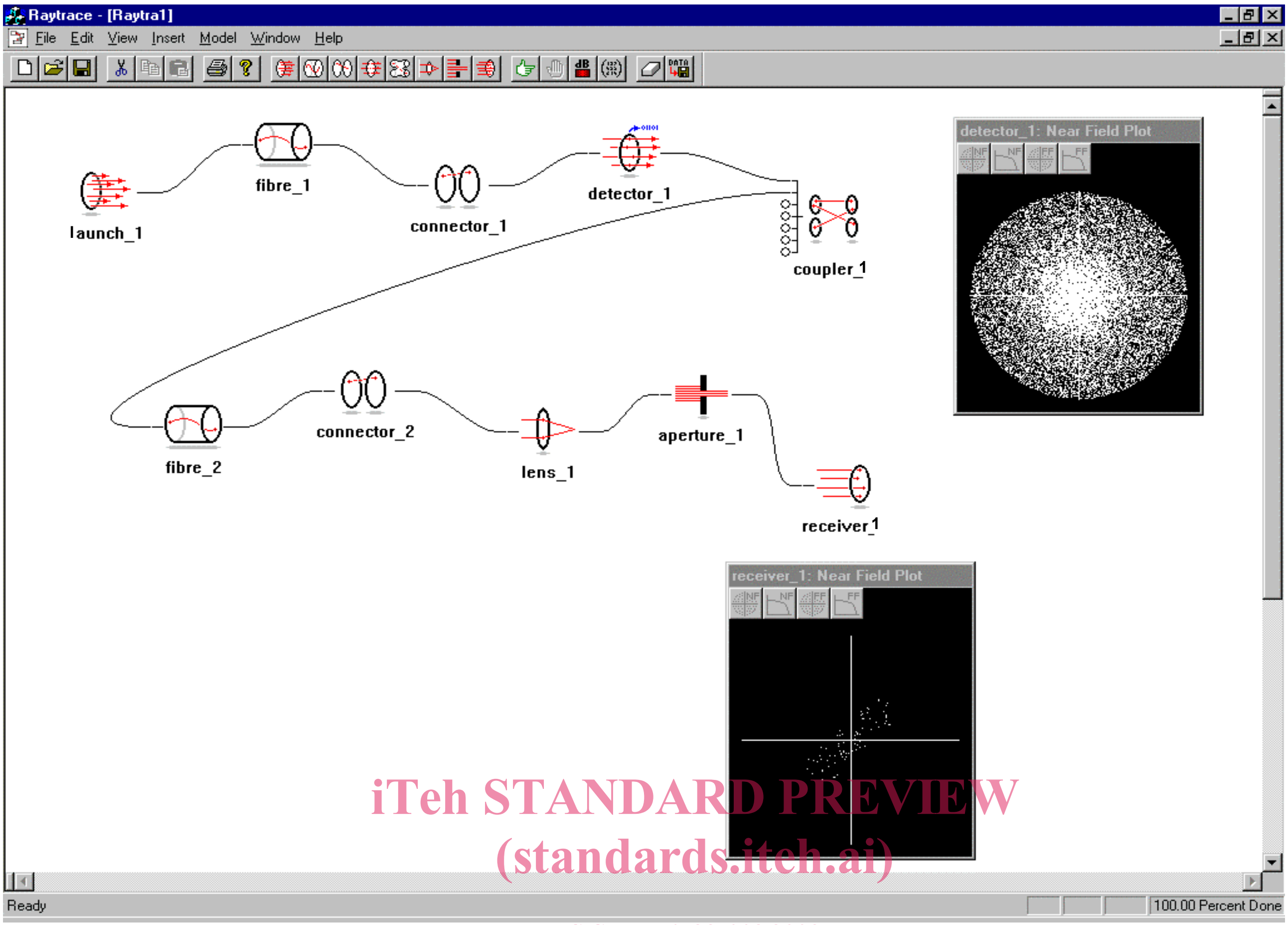
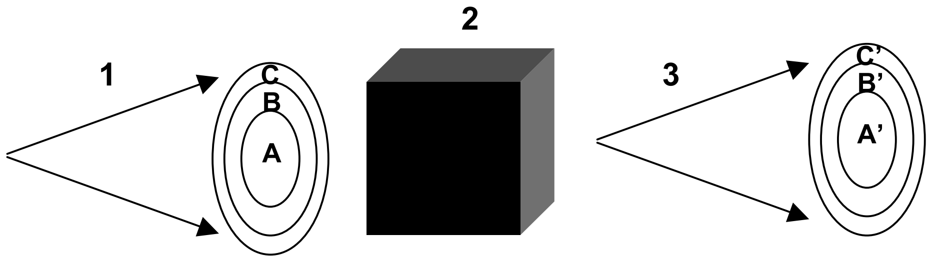


Figure 2 — The user interface for the raytracing model showing the various components that can be included

## 4.4 Matrices

In a fibre system in which the power distribution does not change, it is possible to represent the component losses by a single number, the insertion loss. As discussed in Clause 3, this applies to single-mode fibre systems and multi-mode harnesses where the component separation is large, e.g. telecommunication links. In shorter links, a single insertion loss value will say nothing about the way in which the component's loss is influenced by the power distribution into it or how the component itself alters the power distribution. Representing the components as matrices can overcome these problems. [2][3][4]



**Key**

1 Input light
2 Component
3 Output light

Figure 3 — Matrix representation of a fibre-optic component