14 FIBRE OPTIC ISOLATORS

14.1 Introduction

Fibre optic isolators are passive fibre optic devices intended to suppress backward reflection along a fibre optic link and at the same time having minimal insertion loss in the forward direction. Fibre optic isolators are used to avoid backreflections in communication links where these backreflections might deteriorate the performance of certain components, for instance DFB (distributed feedback) lasers. Isolators are also used in applications were multiple reflections can cause undesired effects, for instance in fibre optic amplifiers where multiple reflections may cause lasing instead of amplification.

The difference in transmission between the forward and backward direction is achieved by using polarisers and Faraday rotators. The polarisers are positioned at both ends of the Faraday rotator. The angle between the two polarisers are 45°. The Faraday rotator changes the polarisation of the light in the forward direction such that it is transmitted by the other polariser. The direction of polarisation of the light in the backward direction is also changed in the Faraday rotator, but such that the polarisation is normal to the direction being transmitted by the polariser at the other side of the rotator. The light is thus not transmitted.

The Faraday effect is dependent on the wavelength of the light, the magneto-optic constant, the magnetic field and the length of the crystal. A fibre optic isolator is thus made for a specific wavelength range. If the length of the rotator changes or the magneto-optic constant changes, the isolator would change operation wavelength range. Both the length of the crystal and the magneto-optic constant will be temperature dependent. There is thus a fundamental temperature dependence of the fibre optic isolator which limits the operating temperature range. The insertion loss and the backward loss may still be approximately the same, but the wavelength range have changed.

A fibre optic isolator is usually made from miniature versions of bulk optical components. The alignment of the different components will be critical and thus vulnerable to mechanical and environmental loads. The operation of the device is dependent on the magnetic field. The device should therefore be completely shielded from external magnetic fields.

The mechanical characteristics of the fibre optic component is strongly dependent on the packaging. Nominally the same component, but with different packaging should therefore be tested and qualified separately.

The general test strategy is described in Chapter 4 and will also be followed here. Each test method has been given a number, and these numbers are tabulated and described in Part 3 Ch.14.

14.2 Evaluation testing

14.2.1 Purpose

The purpose of the evaluation testing is to determine the operational limits of the fibre optic isolator with respect to critical mechanical and environmental parameters, to overstress specific characteristics in order to identify failure modes, to demonstrate the suitability of the isolator for proceeding on to qualification testing and to get information which can be of value for a detailed planning of the test programme to be used in the procurement of the component.

14.2.2 Properties to evaluate

The main properties of interest are :

- mechanical properties
- effects of high levels of vibration and shock
- effects of temperature extremes
- effects of external magnetic fields
- effects of rapid depressurisation and vacuum operation
- effects of ionizing radiation
- effects of solar radiation and UV radiation
- resistance to solvents and contaminating fluids

For some special applications the optical power handling capability may be of concern.

It is expected that the fibre used in the input/output ports of the component is characterised with respect to space applications. It is thus not necessary to include tests for fibre properties such as bandwidth, coating dimensions, numerical aperture, etc. in the evaluation of the passive device. The characteristics of the fibre with respect to environmental loads such as ionizing radiation and temperature extremes should also be known.

Coatings, buffers and materials used in the packaging shall be space qualified, see Chapter 4. However, an evaluation related to their properties may be necessary to eliminate any undesired interactions between the various materials and effects of changes in the material properties on the behaviour of the device.

The flammability of the isolator is not expected to be of special concern. The materials used in the component should all undergo a test with respect to flammability in the material evaluation, see Chapter 4. These properties will not depend on the manufacturing or the assembly of component, and the test is thus not included. A test with respect to dust is not included because this is not expected to be of special concern in space applications. A test with respect to corrosive atmosphere is not included either. The materials in the component will be tested with respect to resistance to corrosion in the material evaluation, see Chapter 4, and the property is not expected to be critical to the performance of the device, as it is not meant to be mated like for instance a connector.

14.2.2.1 Mechanical properties.

The optical components as well as the packaging must withstand mechanical loads such as crush, impact, drop, bump and acceleration. In addition, the fibre attachment should be tested with respect to pulling, axial compression, flex and torsion. The largest mechanical loads are expected to occur during installation. The mechanical loads will therefore be imposed on the component before it is exposed to environmental effects. The mechanical properties such as strength of fibre attachment and resistance to crush, drop, impact and bump are determined by the package. A manufacturer of fibre optic components will usually apply the same mechanical design to several types of components (couplers, branching devices, isolators and attenuators). It will therefore not be necessary to evaluate these properties for each component type if it has previously been evaluated for another component with identical package.

14.2.2.2 Temperature extremes

A fibre optic isolator will be comprised of several materials with probably different coefficient of thermal expansion. This may lead to misalignment of the different components and increased insertion loss during temperature cycling. Thermal expansion may also induce microbend loss on the fibres within the component or cause the fibres to be put under tension. Fibre optic isolators will, as discussed in 14.1., have an inherent temperature dependence. The purpose of the temperature tests will both be to establish the maximum operating temperature range and the change in operating wavelength as a function of temperature.

If the device is intended to be used in applications where it may be exposed to humidity, this shall be included in the evaluation test programme. Humidity and temperature extremes may induce other failure mechanisms than dry heat.

14.2.2.3 Rapid change of temperature

Rapid change of temperature may cause excessive tension as the thermal response of the component may be slower than the rate of change of temperature. Large thermal gradients across the component may therefore arise, challenging the mechanical alignment and the strength of the mounting of each part of the component. The components involved are, however, quite small which should reduce the effect of rapid change of temperature.

14.2.2.4 External magnetic fields

The change of state of polarisation in the Faraday rotator is dependent on the strength of the applied magnetic field. If the field changes, for instance under the influence of an external magnetic field, the rotation and thereby the properties of the isolator will change as well. The isolator should thus contain an protection such that external magnetic fields have no influence on the properties of the device.

14.2.2.5 Rapid depressurisation

Rapid depressurisation may cause mechanical stresses because trapped air in pockets inside the component may give large pressure gradients.

The test with respect to the effect of rapid depressurisation will not be necessary if devices with similar structure have been previously evaluated. This applies to devices with different functions (branching devices, WDMs, isolators), but with nominally the same package.

14.2.2.6 Vacuum operation

The materials used in the isolator shall all be space qualified, see Chapter 4. This means that the effects of vacuum operation (outgassing, change of material properties) should be very small. Interactions between the different media may, however, arise with deleterious effects such as misalignment of the different parts of the component and mechanical stresses.

The test with respect to vacuum operation might not be necessary if devices with similar structure have been previously evaluated. This applies to devices with different functions (branching devices, WDM, isolators), but with nominally the same package.

14.2.2.7 Ionizing radiation

In space applications fibre optic components are exposed to high levels of ionizing radiation which may induce losses in the optical components as well as change the properties of the other materials in the package. Even if all the materials are space qualified, see Chapter 4, interactions may occur. Any possible interaction should be revealed during the evaluation of the component.

Fibre optic isolators are dependent on the change of polarisation through the Faraday rotator. The radiation effects on this magneto-optic material is not known in detail.

The test with respect to the effects of ionizing radiation might not be necessary if devices with identical optical design, but slightly different package (with respect to mechanical design, but not to material selection) have been previously evaluated.

14.2.2.8 Solar and UV radiation

Solar and UV radiation could affect the properties of the material in the package. If the isolator is not properly designed, solar and UV radiation may also be coupled into the optical path and interfere with the signal propagation. Solar radiation and UV radiation may also affect the Faraday rotator.

The test with respect to solar and UV radiation might not be necessary if devices with the identical optical design, but slightly different package (with respect to mechanical design, but not to material selection) have been previously evaluated.

14.2.2.9 Resistance to solvents and contaminating fluids

During installation or service the component might be exposed to solvents and contaminating fluids. These fluids may deteriorate the materials in the component and thereby the performance.

14.2.2.10 Optical power handling capability

The power handling capability of a fibre optic isolator can be limited by four different phenomena:

- heating due to absorbed power
- radiation induced colour centres which will cause loss
- various non-linear optical effects
- formation of cracks, pits, etc.

As with optical fibres, the fibre optic isolator is usually operated at wavelengths with low loss and power levels in the order of 1 mW or less. The above phenomena will only be of concern in special applications were the component is used to transmit high power levels.

<u>14.2.3 Sample distribution and test programme sequence</u>

14.2.3.1 Sample distribution

The fibre optic isolator shall be selected at random from a representative production lot. The size of the lot shall be 2 times to 3 times the total number of the selected samples.

Number of samples: 22-63, dependent on the extent of the test programme, as discussed in the text

The number of devices needed for the evaluation test programme is quite extensive. New devices are used for each test, both because each test is considered destructive and to be able to distinguish between the effects of the different parameters. The number of samples for each test is shown in Chart 14.1 (see end of Chapter). In order to get a picture of the spread in values, the number of samples of each test is 3 or larger. The evaluation test programme will give a better picture of the statistical fluctuations if more components were used for each test. A sample size of 3 will however, give an indication of the variations. If large variations are observed, the number of samples should be increased.

14.2.3.2 Test range and failure criteria

The different tests are performed on a step stress basis. This means that the load is increased in steps from a starting value. Generally, the load is increased until the component has suffered physical destruction or a substantial deterioration in performance, as appropriate. In some of the tests the upper stress limit is determined from the most severe loads expected, as listed in Chapter 4, with some margin added. If more severe loads are expected, the upper test level should be increased accordingly.

The criteria for defining the component as failed is that the minimum insertion loss increases 3 dB. The insertion loss is at any time measured at the optimum wavelength.

All results shall be recorded.

14.2.3.3 Test programme sequence

The specified tests are summarised in Chart 14.1. The mechanical and environmental tests which may be dependent on application and previous evaluation of similar components, are shown in a dotted box.

The initial measurements are all optical measurements and will not have any influence on the properties of the tested components. The indicated order is based on the importance of the different parameters. The insertion loss and the backward loss are measured first to establish the basic performance of the device. The return loss is measured to establish the backreflected level. This is of special concern in fibre optic isolators since the purpose of applying an isolator is to reduce the backreflected level from other parts of the system. The return loss from the isolator itself should therefore be as high as possible. The sensitivity to the polarisation of the incoming light will also be important. The susceptibility to ambient light coupling shall also be measured.

For the mechanical, environmental and endurance tests new devices are used for each test. The test order will therefore not affect the test result and is as such of no importance. It is generally recommended to perform the easiest and least expensive tests first and the more complicated and expensive tests in the end. If the component fails during the cheap and least expensive part of the test programme, it can be stopped before large expenses have been incurred.

We suggest to do the mechanical tests first. This is a test of the component's and the package's ability to withstand mechanical loads and the package's ability to protect the optical part of the component. The strength of fibre attachment is tested first. This will be an important property during installation and handling of the component of the system. The resistance to acceleration, impact, drop, bump and crush is tested thereafter.

The environmental tests are performed after the mechanical tests. We recommend to do the temperature tests first. Testing with respect to temperature will both reveal fundamental temperature dependent properties of the optical design and temperature dependent properties of the assembly. The temperature tests include testing with respect to temperature extremes, rapid change of temperatures and condensation. The test with respect to temperature extremes shall be performed first to establish the limits for the other tests.

The sensitivity to external magnetic fields is tested thereafter. This will be an important property of an optical isolator applied in an environment with magnetic fields.

The tests with respect to the effects of vibration and shock are tested before the vacuum and ionizing radiation test. The materials applied in the component are, in advance, tested with respect to such material related effects. The latter tests are performed to ensure that no unexpected effects occur. The characteristics of the component when it is exposed to loads such as vibration and shock is less predictable and in addition easier and less expensive to perform.

The tests with respect to the effects of rapid depressurisation and vacuum operation are performed on the same samples. The effects of rapid depressurisation should be tested before the effects of vacuum operation. If the device fails in the rapid depressurisation test, there will be no point in proceeding to the test with respect to vacuum operation.

The effect of radiation (ionizing as well as solar and UV radiation) is tested in the end, such that only components that have passed the other tests are subjected to this test. Radiation resistance is a fundamental requirement for components in space applications. The device should be based on materials and fibres exhibiting minimal radiation effects, and the test is performed to ensure that no unexpected effects will occur. The Faraday rotator is less well known with respect to radiation effects.

If it is of special concern, the resistance to solvents and contaminating fluids shall be tested.

The endurance tests are ageing and optical power handling capability, if applicable. The conditions during the ageing test are determined by the test with respect to temperature extremes. The test will thus have to be started after this test. This is a long term test with measurements at regular intervals and can be performed in parallel with the other tests.

14.2.3.4 Use of control group

The use of a control group is not considered necessary in the mechanical and environmental tests. In these tests the parameters of interest are usually monitored while the test is performed. The stability of the source output and the repeatability of the measurements are ensured by a control of the output power. If the post test investigations include optical measurements not performed during the test procedure, the measurements shall also be performed on the control group. This may include measurements of insertion loss and backward loss as a function of signal wavelength.

A control group is used in the construction analysis to be able to compare the devices that have been exposed to environmental and mechanical loads with a "fresh" sample.

14.2.3.5 Post test investigations

The standard test procedures given in Chapter 14 Part 3 often specify that after the exposure to mechanical or environmental load is completed, some measurements should be made to look for permanent changes in one or more critical properties. In the evaluation programme there are in many cases specified additional tests to analyse the failure mechanisms, but also to reveal whether the load has induced changes not observed directly during the tests or revealed by the standard post test investigations. An example of such a test would be testing of the strength of fibre or cable entry after the test with respect to temperature extremes, to investigate whether temperature extremes have affected the materials in the fibre attachment in such a way that the strength is reduced.

14.2.4 Inspection

The purpose of the inspection is to make sure that the samples are suited for testing. All samples shall be inspected.

14.2.4.1 Visual inspection

The visual inspection shall be carried out in accordance with ESA/SCC Basic Specifications No. 20500.

14.2.4.2 Dimensions

Test method: 14.1.1

14.2.4.3 Mass

Test method: 14.1.2

14.2.4.4 Marking

All samples shall be marked in accordance with the standard procedure of the manufacturer.

14.2.5 Initial measurements

The purpose of the initial measurements is to determine the initial values of the most important optical parameters. The result from these initial measurements will be used as a basis for the evaluation of later tests. Further, one wants to ascertain that the various samples meet the specified requirements and to get a picture of the spread in values. The spread in values will give an indication of the production control and be a valuable input to, for instance, the lot acceptance testing programme.

The initial measurements shall be performed on all samples.

14.2.5.1 Insertion loss

The measurement shall be performed over the specified wavelength range.
Test method: 14.2.1/14.2.5

14.2.5.2 Backward loss

The measurement shall be performed over the specified wavelength range.
Test method: 14.2.3

14.2.5.3 Return loss

Test method: 14.2.4

14.2.5.4 Polarization dependence

Test method: 14.2.2

14.2.5.5 Susceptibility to ambient light coupling

Test method: 14.2.6

14.2.6 Mechanical tests

The main mechanical properties to test are strength of attachment of fibre which includes tests for pulling, axial compression, flex and torsion. The component should also be tested with respect to mechanical loads such as crush, impact, drop and acceleration.

The insertion loss is measured before, during and after the tests.

14.2.6.1 Strength of attachment of fibre

The test with respect to strength of attachment of fibre includes pulling, axial compression, flex and torsion tests. In some commercial devices input and output ports of the isolator are connectors. In such a case these connectors should be tested for mechanical strength and durability as given by Chapter 7.

14.2.6.1.1 *Pulling*

In this test the fibres constituting the input and output ports of the component is subjected to increasing load until the fibre attachment breaks. The number of samples is chosen to get a picture of the spread in values. For each component each fibre attachment shall be tested on an individual basis.

Number of samples: 2

The tensile force shall be applied smoothly and controlled, the magnitude of the force shall be increased at a specified rate. The tensile force shall be increased until the fibre breaks.
Test method: 14.3.8

14.2.6.1.2 *Axial compression*

The fibre leads shall be subjected to axial compression to establish the ability of the retention means to withstand axial compression. The number of samples is chosen to get a picture of the spread in values. For each component each fibre attachment shall be tested on an individual basis.

Number of samples: 2

The axial compression shall be applied smooth and controlled, the magnitude of the force shall be applied with the specified rate. The axial compression shall be increased until the fibre breaks.
Test method: 14.3.8

14.2.6.1.3 *Flex*

The test is intended to determine the ability of the fibre interface and strain relief to withstand flexing. For each component each fibre attachment shall be tested on an individual basis.

Number of samples: 2
Start load: as specified
The load shall be increased in steps of 20% of the initial value until the fibre breaks.
Test method: 14.3.8

14.2.6.1.4. *Torsion*

The test is intended to determine the ability of the fibre attachment to withstand torsion of the fibre. Each fibre shall be tested on an individual basis.

Number of samples: 2

The torque shall be increased until the fibre breaks.
Test method 14.3.8

14.2.6.2 Acceleration

Number of samples: 3
Start acceleration: as specified
The acceleration shall be increased until the component has failed or has suffered physical destruction.
Test method: 14.3.3

14.2.6.3 Impact

Number of samples: 3
Start energy: as specified
The energy in the impact shall be increased in steps of 20 % of the specified value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 14.3.5

14.2.6.4 Crush resistance

Number of samples: 3
Start force: as specified
The force shall be increased in steps of 20 % of the specified value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 14.3.4

14.2.6.5 Drop

Number of samples: 3

Start height: as specified
The height shall be increased in steps of 20 % of the initial value. The load shall be increased until the component has failed or suffered physical destruction.
Test method: 14.3.6

14.2.6.6 Bump

Number of samples:	3
Number of bumps:	4000 at each level of acceleration
Start acceleration:	40 g

The acceleration shall be increased in steps of 10 g. The load shall be increased until the component has failed or suffered physical destruction.

Test method: 14.3.7

14.2.7 Environmental tests

14.2.7.1 Temperature extremes

The change in insertion loss and backward loss shall be measured as a function of wavelength at each temperature. The starting temperatures are chosen to be moderate in order to fully characterise the isolator with respect to temperature dependence.

Number of samples:	3
Thermal cycling:	first low, then high
Low temperature:	sufficient to induce component failure, but not below - 70°C.
High temperature:	sufficient to induce component failure, but not above 150°C.
Low starting temperature:	20°C
High starting temperature:	30°C
Step change in temperature:	10°C
Duration of stay at each temperature:	1 hour
Test method:	14.4.2

14.2.7.1.1 *Post test investigation*

The post test investigation include a repetition of the measurement of insertion loss and backward loss after the component has reached room temperature. A visual inspection and dimensional check shall be performed on each device to check any changes in material appearance. One of the samples used in the temperature test shall be subjected to constructional analysis. The remaining samples shall be tested with respect to fibre attachment to ensure that the materials in the fibre attachment are not influenced by temperature extremes.

Insertion loss	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Dimensions,	ref: 14.2.4.2
Strength of fibre attachment, pulling strength.	ref: 14.2.6.1.1
Constructional analysis	ref: 14.2.9

14.2.7.2 Rapid change of temperature

The change in insertion loss and the backward loss shall be measured as a function of wavelength immediately before and after the temperature change. The insertion loss shall be monitored during the change of temperature.

Number of samples:	3
High temperature:	10°C below high temperature limit established in 14.2.7.1

Low temperature:	10°C above low temperature limit established in 14.2.7.1
Rate of change of temperature:	as specified
Test method:	14.4.3

14.2.7.2.1 *Post test investigation*

The insertion loss and backward loss shall be measured when the component has reached room temperature after the test is finished. A visual inspection shall be performed on the devices. One of the samples shall be subjected to a constructional analysis to investigate whether rapid change of temperature has changed the internal structure of the device.

Insertion loss,	ref: 14.2.5.1
Backward loss,	ref:14.2.5.2
Visual inspection	ref: 14.2.4.1
Constructional analysis	ref: 14.2.9

14.2.7.3 Condensation

The change in insertion loss and backward loss shall be measured each time the test conditions/temperature are changed.

Number of samples:	3
Test conditions:	as specified in IEC 68.2.38
Test method:	14.4.5

14.2.7.3.1 *Post test investigation*

The insertion loss and backward loss shall be measured after the component has reached room temperature. The devices shall be subjected to a visual inspection and a dimensional check to look for changes in material structure and appearance. Constructional analysis is included in the post test investigation to find out whether combined humidity/heat would change any of the internal materials. The remaining samples shall be tested with respect to strength of fibre attachment to investigate the effect on the materials in the fibre mounting.

Insertion loss	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Dimensions,	ref: 14.2.4.2
Strength of fibre attachment, pulling strength,	ref: 14.2.6.1.1
Constructional analysis	ref: 14.2.9

14.2.7.4 Sensitivity to external magnetic fields

The change in insertion loss and backward loss shall be measured at each step in the measurement procedure.

Number of samples: 3
Starting strength of magnetic field: as specified
Increase the magnetic field in steps of 20% of the initial value until the component has failed or the strength of the magnetic field is twice the specified value.
Test method: 14.4.13

14.2.7.4.1 *Post test investigation*

The post test investigation shall include measurement of insertion loss and backward loss after the magnetic field has been removed.

Insertion loss,	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2

14.2.7.5 Vibration

The change in insertion loss shall be monitored during the test.

Number of samples:	3
Vibration frequency:	100-2000 Hz
Starting acceleration:	as specified
The increase in acceleration:	steps of 20% of specified level until the level has reached 30 g or the component has failed
Duration:	90 minutes
Test method:	14.3.1

14.2.7.5.1 *Post test investigation*

The insertion loss and backward loss shall be measured when the device has settled after the test. The device shall be subjected to a visual inspection to look for changes in structure or appearance. Vibration may induce mechanical fractures not possible to reveal by visual inspection and optical measurements. One of the samples is therefore subjected to a condensation test. In this test condensed water may freeze in possible cracks and increase the crack. Another sample is subjected to constructional analysis to investigate whether vibration induce any changes in the internal structure of the device.

Insertion loss,	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection	ref: 14.2.4.1
Condensation	ref: 14.2.7.3
Constructional analysis	ref: 14.2.9

14.2.7.6 Shock

The change in insertion loss shall be monitored during the test.

Number of samples:	3
Pulse duration:	0.5 ms
Starting acceleration:	as specified
The increase in acceleration:	steps of 20% of specified level until the level has reached 2000 g or the component has failed.
Test method:	14.3.2

14.2.7.6.1 *Post test investigation*

The insertion loss and backward loss shall be measured when the device has settled after the test. The device shall be subjected to a visual inspection to look for changes in structure or appearance.

Shock may induce mechanical fractures not possible to reveal by visual inspection and optical measurements. One of the samples is therefore subjected to a condensation test. In this test condensed water may freeze in possible cracks and increase the crack. Another sample is subjected to constructional analysis to investigate whether shock induce any changes in the internal structure of the device.

Insertion loss	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection	ref: 14.2.4.1
Condensation	ref: 14.2.7.3
Constructional analysis	ref: 14.2.9

14.2.7.7 Rapid depressurisation

The change in insertion loss shall be measured during the rapid depressurisation.

Number of samples:	3
Test method:	14.4.15

14.2.7.7.1 *Post test investigation*

The post test investigation shall include measurement of insertion loss and backward loss. If any of the components fail, a failed sample shall be subjected to constructional analysis to investigate whether rapid depressurisation may have influenced the internal structure of the isolator. If all components pass the test, they shall be used in the test with respect to vacuum operation (14.2.7.7)

Insertion loss,	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Constructional analysis,	ref: 14.2.9

14.2.7.8 Vacuum operation

The insertion loss is not measured during the vacuum test, because any changes is expected to be permanent.

Number of samples:	3
Vacuum:	10^{-3} Pa or less
Temperature:	125°C or high temperature limit established in 14.2.7.1, whichever is lower
Duration:	24 hour
Test method:	14.4.4

14.2.7.8.1 *Post test investigation*

The post test investigation shall include measurement of the insertion loss and backward loss. The device shall be subjected to visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to investigate whether vacuum operation influenced the internal structure of the device.

Insertion loss	ref: 14.2.5.1

Backward loss,	ref: 14.2.5.2
Visual inspection	ref: 14.2.4.1
Constructional analysis	ref: 14.2.9

14.2.7.9 Ionizing radiation

The change in insertion loss and backward loss shall be measured at regular intervals during the exposure.

Number of samples:	3
Temperature:	Room temperature
Optical power:	As specified
Wavelength:	As specified
Dose rate:	5 rad(Si)/s
Duration:	The irradiation shall last until the component has failed or the total dose has reached 3 Mrad.
Test method:	14.4.10

14.2.7.9.1 *Post test investigation*

The insertion loss and backward loss shall be measured when the exposure has been removed. One of the samples shall be subjected to constructional analysis to investigate whether ionizing radiation has influenced the internal structure.

Insertion loss	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection	ref: 14.2.4.1
Constructional analysis,	ref: 14.2.9

14.2.7.10 Solar radiation

The change in insertion loss and backward loss shall be measured at regular intervals during the test.

Number of samples:	3
Temperature:	Room temperature
Radiation source:	source with representative spectral output
Duration:	until the component has failed or the maximum anticipated total dose has been reached
Test method:	14.4.11

14.2.7.10.1 *Post test investigation*

The insertion loss and backward loss shall be measured after the test is completed. The device shall be subjected to a visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to check whether solar radiation has influenced the materials inside the component.

Insertion loss	ref: 14.2.5.1
Backward loss	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Constructional analysis,	ref: 14.2.9

14.2.7.11 UV radiation

The change in insertion loss and backward loss shall be measured at regular intervals during the exposure.

Number of samples:	3
Temperature:	room temperature
Radiation source:	representative UV source
Duration:	until the component has failed or the maximum anticipated total dose has been reached.
Test method:	14.4.9

14.2.7.11.1 *Post test investigation*

The insertion loss and backward loss shall be measured after the test procedure is completed. The device shall be subjected to a visual inspection to look for changes in structure or appearance. One of the samples shall be subjected to constructional analysis to check whether the materials inside the component has changed during exposure.

Insertion loss,	ref: 14.2.5.1
Backward loss,	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Constructional analysis,	ref: 14.2.9

14.2.7.12 Resistance to solvent and contaminating fluids

Number of samples: 3

The components shall be subjected to the appropriate solvents and fluids. Reference is made to ESA/SCC Generic Specification No. 3901, paragraph 9.21. No visible changes in component appearance shall be observed. The attenuation shall be measured after the test.

Test method: 14.4.12

<u>14.2.8 Endurance tests</u>

14.2.8.1 Ageing

The change in insertion loss and backward loss shall be measured at regular intervals during the test.

Number of samples:	3
Temperature:	20°C above specified operating temperature, but at least 10°C below high temperature limit established in 14.2.7
Duration:	Until the component has failed or the test has lasted 1000 hours.
Test method:	14.4.14

14.2.8.1.1 *Post test investigation*

The insertion loss and backward loss shall be measured after the test. The device shall also be subjected to a visual inspection and dimensional check to look for changes in the appearance and structure of the device. One of the samples shall be subjected to a constructional analysis to investigate whether long term high temperature has introduced changes in the internal structure.

Another sample shall be tested with respect to fibre attachment to investigate whether long term high temperature have influenced the materials used in the fibre attachment.

Insertion loss	ref: 14.2.5.1
Backward loss	ref: 14.2.5.2
Visual inspection,	ref: 14.2.4.1
Dimensions,	ref: 14.2.4.2
Strength of attachment of fibre, pulling strength	ref: 14.2.6.1.1
Constructional analysis,	ref: 14.2.9

14.2.8.2 Optical power handling capability

Number of samples:	3
Laser source:	as specified

Input power level shall be increased in steps and measurements made of insertion loss and backward loss

The entrance and exit surfaces shall also be examined for visual damage. Input power level shall be increased until the component has failed or visual damage has occurred. The maximum input level will very likely be limited by the available optical source.
Test method: 14.2.7

14.2.9 Constructional analysis

A sample from the control group and samples subjected to the other tests, as noted under the post test investigation, shall be subjected to constructional analysis. This involves that the package is opened and the internal structure of the device is investigated. The constructional analysis may include investigation of any fracture surfaces. It may also include an examination of the optical path of the system by means of visible light, for example a HeNe laser.

14.3 Production testing

14.3.1 Introduction

A number of non-destructive tests can be performed on a fibre optic isolator during and after production to ensure that all adjustments and other production parameters are according to specifications. The production testing includes geometrical measurements as well as control of the mass of the component. The production control also includes control of some optical properties.

14.3.2 Production control

The insertion loss and backward loss shall be measured during the assembly of the component.

The dimensions as well as the mass of all components shall be controlled prior to assembly. This applies to optical components as well as package.

14.3.3 Final production testing

The tests shall be performed according to Chart 14.2. Unless otherwise specified, all samples shall be tested. In addition to a final control of the dimensions and the mass of the device, the optical performance shall be tested. This includes insertion loss, backward loss and return loss. The polarisation sensitivity shall also be measured. The susceptibility to ambient light coupling is dependent on the optical and mechanical design. The optical design in this respect is not production dependent. Changes in mechanical structure which would change the susceptibility to ambient light coupling will probably be disclosed by the visual inspection. The component shall be temperature cycled and exposed to vibration tests to reveal any failures in mechanical alignment and mounting. The temperature test is performed before the vibration test. Any temperature induced changes in glue or screws should then be revealed by the succeeding vibration test.

14.3.3.1 Visual inspection

To be performed in accordance with ESA/SCC Basic Specification No. 20500.

14.3.3.2 Dimensions

The dimensions of the package as well as the length of the fibre leads shall be controlled.
Test method: 14.1.1

14.3.3.3 Mass

Test method: 14.1.2

14.3.3.4 Insertion loss

The insertion loss shall be measured over the wavelength range of interest. The measurement is included in the final production testing even though it is controlled in the production process to ensure that the package has no influence on the insertion loss.
Test method: 14.2.1/14.2.5

14.3.3.5 Backward loss

The backward loss shall be measured over the wavelength range of interest. The measurement is included in the final production testing even though it is controlled in the production process to ensure that the package has no influence on the backward loss.
Test method: 14.2.3

14.3.3.6 Return loss

Test method: 14.2.4

14.3.3.7 Polarisation dependence

Test method: 14.2.2

14.3.3.8 Temperature extremes

The component shall be exposed to one temperature cycle. The high and low temperature shall be chosen so that, according to specifications no permanent changes are induced in the component.
Test method: 14.4.2

14.3.3.9 Vibration

Test method: 14.3.1

14.4 Burn-in

Burn-in is not relevant for fibre optic isolators.

14.5 Qualification testing

The qualification testing shall include all tests of relevance not included in the final production testing. The test programme will therefore not include any tests just for optical characteristics since this is covered by the final production testing. The sensitivity to mechanical and environmental loads was evaluated in the evaluation test programme. Several of the characteristics of the device are dependent on design and technology rather than production parameters. It will therefore not be necessary to repeat some of the tests in the qualification test programme. This is noted, as appropriate, in the discussion of the qualification test strategy.

The qualification testing is divided in tests for endurance, mechanical and environmental properties. All samples supplied for testing shall however be exposed to a climatic sequence before it is exposed to the other tests. This climatic sequence is performed to expose mechanical mounting and glue to temperature variations and humidity before any other test is performed, which may change the properties of these components.

All samples are exposed to a condensation test at the end of the test programme. This condensation test includes humidity and temperatures below zero, which may reveal any cracks and failures induced by the mechanical/environmental test programme, but not detected by the post test investigations. A similar environmental stress sequence is also seen in other test programmes [14,15].

The environmental tests included in the qualification testing are climatic sequence, vibration, shock, sensitivity to external magnetic field and condensation. The sensitivity to external magnetic fields is dependent on internal shielding of the Faraday rotator which may have been not properly assembled. The test is performed after the tests with respect to the effects of vibration and shock in case these loads have damaged the shielding. The effects of vacuum operation, rapid depressurisation, radiation (including ionizing radiation, solar and UV radiation) have all been investigated during the evaluation process. Any effects of these loads will be related to technology and design and not to production, and it will therefore not be necessary to repeat the tests in the qualification test programme.

The tests for component endurance includes the effects of long term temperature endurance (ageing).

The mechanical tests are performed to ensure that the components meet the specified mechanical requirements. The tests include strength of fibre attachment (fibre pulling, axial compression, flex and torsion) and crush resistance. Testing with respect to drop, bump and impact is not included because this is all testing of the package. The characteristics are evaluated in the evaluation phase. Production related failures will probably be revealed by the test with respect to crush resistance. Mechanical properties which may effect the internal mounting of the component, for example acceleration, are covered by the vibration and shock tests.

Each group consists of 4 isolators. The number of samples are chosen to get an indication of the spread in values. The qualification test programme uses few devices for each test, thus all samples shall meet the requirements.

14.5.2 Environmental tests

14.5.2.1 Climatic sequence

Test method: 14.4.1

14.5.2.2 Vibration

Test method: 14.3.1

14.5.2.3 Shock

Test method: 14.3.2

14.5.2.4 Sensitivity to external magnetic fields

Test method: 14.4.13

14.5.2.5 Condensation

Test method: 14.4.5

14.5.3 Endurance tests

14.5.3.1 Ageing

In those cases were the component is intended to be used in a humid atmosphere, the component shall be exposed to humidity at a specified level together with the high temperature level. Humidity may induce changes and failures not seen in an atmosphere of dry heat.
Test method: 14.4.14

14.5.4 Mechanical tests

14.5.4.1 Strength of attachment of fibre

Test method: 14.3.8

14.5.4.2 Crush resistance

Test method: 14.3.4

14.6 Lot acceptance testing

Lot acceptance testing (LAT) shall be performed on every lot delivered by the manufacturer. The purpose of the tests which have been included in the LAT-test programme is discussed in 14.2. The sequence of the tests in each level is discussed in 14.2 and 14.5.

LAT is divided in three levels, as discussed in Chapter 4. LA2 and LA1 are considered destructive, and the tested samples shall not form part of the delivered lot.

All tested samples shall meet specifications.

The LAT shall be carried out in accordance with Chart 14.4

14.6.1 Lot acceptance level 3 testing (LA3)

All components are subjected to a detailed final production control. Measurements performed in the LA3 testing are repetition of some of these measurements, performed by different personnel to ensure the quality of the delivered item as well as a control of the routine measurements performed in the final production control.

14.6.1.1 Visual inspection

The visual inspection shall be performed according to ESA/SCC Basic Specification No 20500.

14.6.1.2 Insertion loss

The measurement shall be performed over the specified wavelength range.
Test method: 14.2.1/14.2.5

14.6.1.3 Backward loss

The measurement should be performed over the specified wavelength range.

Test method: 14.2.3

14.6.2 Lot acceptance level 2 testing (LA2)

In addition to the tests included in the LA3 testing, the LA2 is comprised of tests with respect to ageing and strength of fibre attachment. The tests are considered destructive. The test with respect to the strength of the fibre attachment is performed after the ageing test to reveal any ageing related defects.

14.6.2.1 Ageing

The test shall include humidity if required by the application.
Test method: 14.4.14

14.6.2.2 Strength of attachment of fibre

Test method: 14.3.8

14.6.3 Lot acceptance level 1 testing (LA1)

In addition to the tests included in the LA2 testing, the LA1 is comprised of tests with respect to mechanical and environmental properties. The tests are considered destructive. The sequence is discussed in 14.2 and 14.5.

14.6.3.1 Temperature extremes

Test method: 14.4.2

14.6.3.2 Vibration

Test method: 14.3.1

14.6.3.3 Sensitivity to external magnetic fields

Test method: 14.4.13

14.6.3.4 Condensation

Test method: 14.4.5

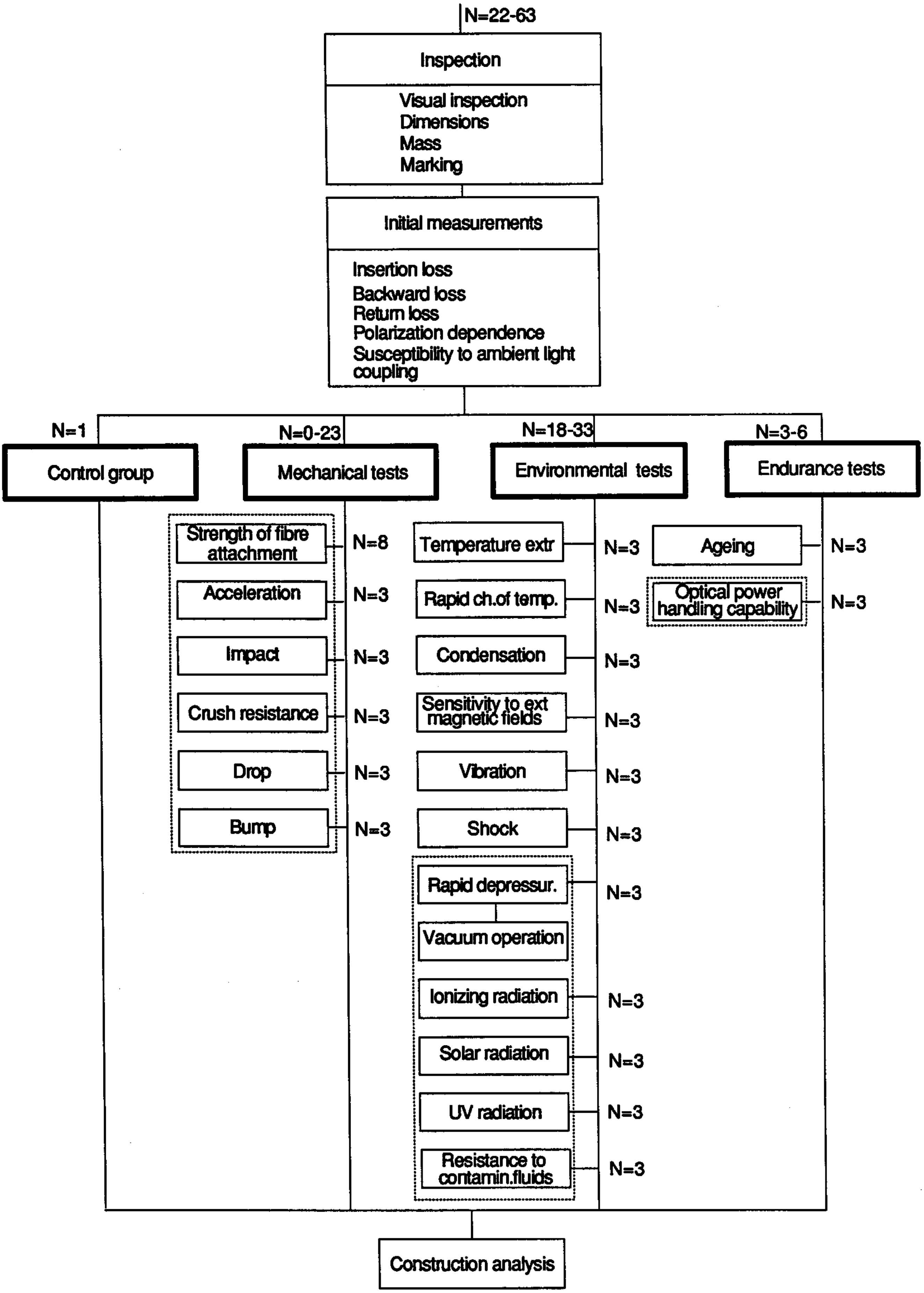

Chart 14.1 Evaluation testing for fibre optic isolators

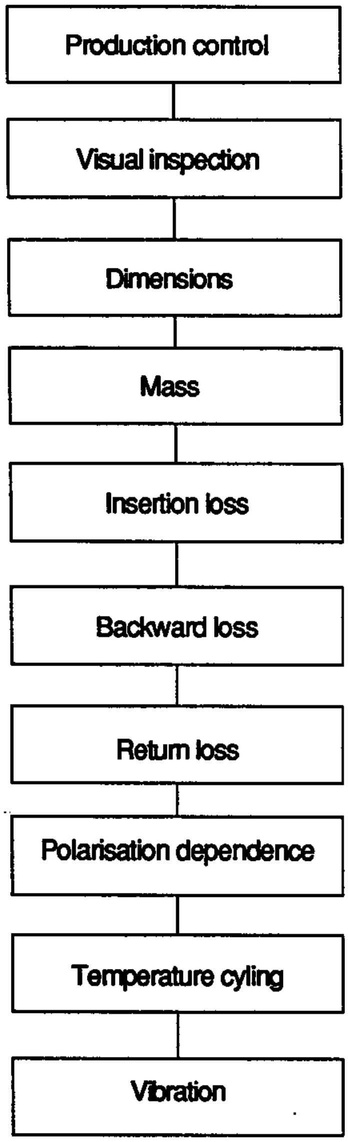

Chart 14.2 Final production testing for fibre optic isolators

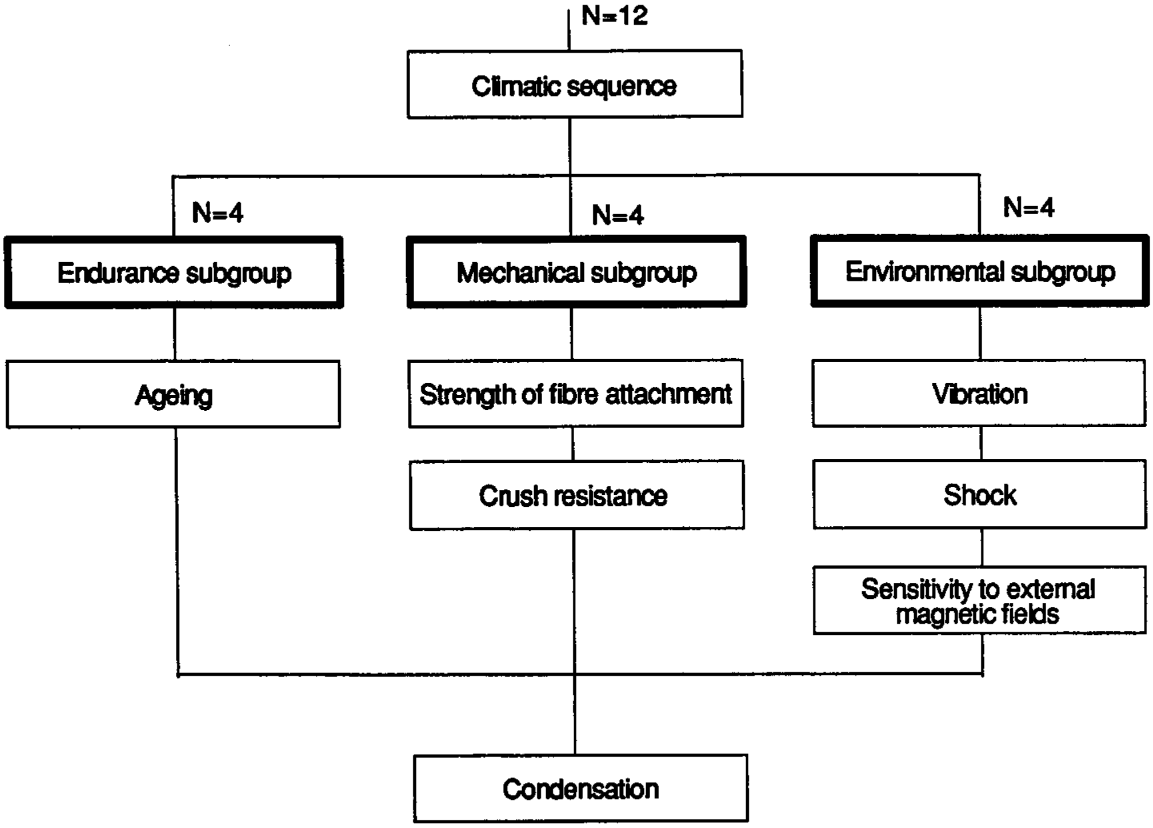

Chart 14.3 Qualification testing for fibre optic isolators

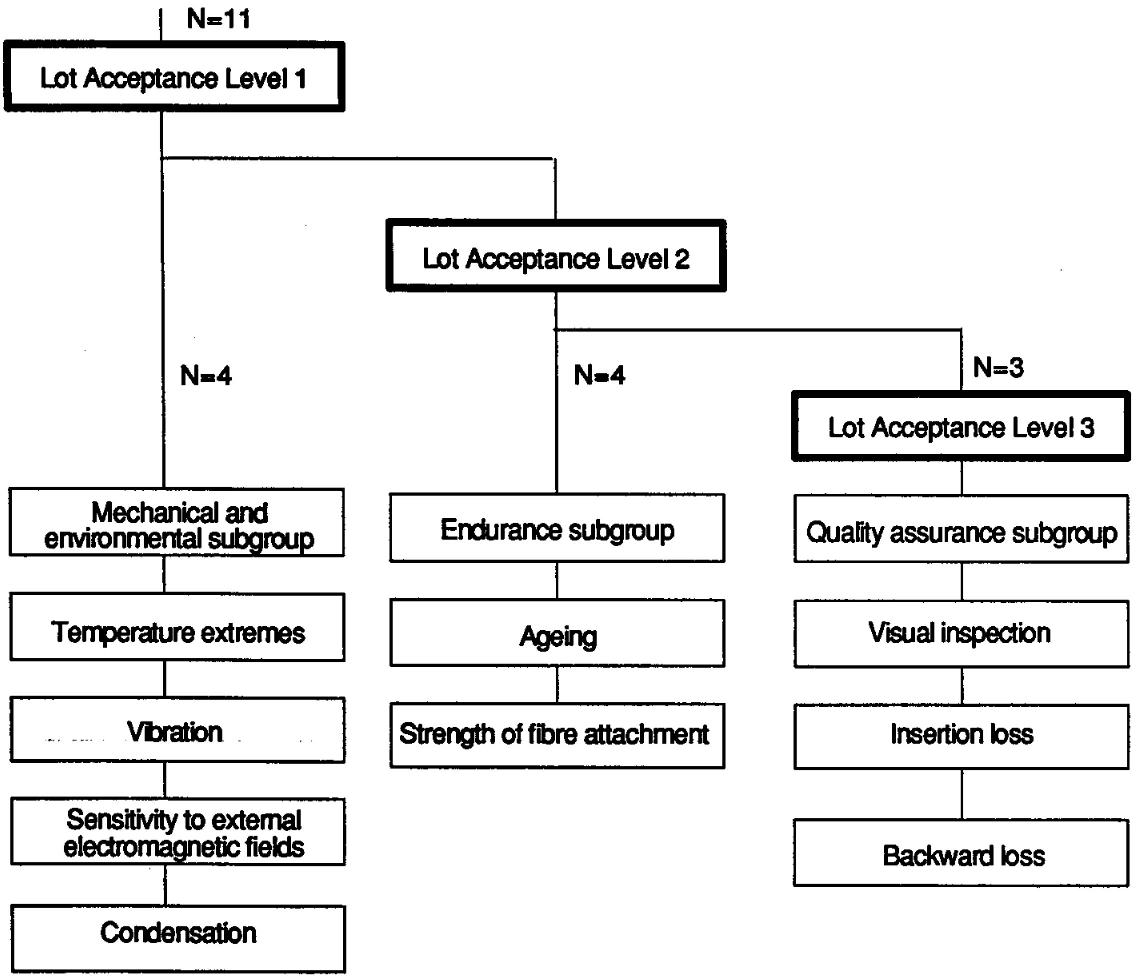

Chart 14.4 Lot acceptance testing for fibre optic isolators

15. COMBINED ELECTRIC/FIBRE OPTIC CABLE

15.1 Introduction

A combined electric/fibre optic cable can take various forms. The electrical conductors and optical fibres can be integrated into one common cable structure. A more or less complete fibre optic cable can be integrated into a larger electrical cable, or one or several electrical and optical fibre cables can be bundled together in some fashion inside a common jacket.

The reason for making a combined cable is one of convenience, f.inst. easier installation or less space needed. There are no intended interaction between the two cable types requiring a combined cable. The same functions performed by the combined cable could have been performed by two separate cables.

The combined cable must meet the same requirements as an equivalent separate electrical cable as well as the requirements for an equivalent separate optical cable. In addition the optical part must function as specified when the electrical cable is energised. The resistive heating may affect the optical cable and cause losses to be induced in the optical fibres and even damage the fibres and cable unless it is properly designed. The electrical cable will not be influenced by the optical signal.

For the combined cable a complete test programme will have to be established for both the electrical and fibre optic part. Only the optical part will be considered here but the tests will be done on the combined cable. It is assumed that appropriate test programmes exist for the various electrical cables that might be used in a combined cable, and the electrical part of the combined cable will not be considered further. Account will, however, be taken of the heating effect of the electrical cable on the optical fibre cable.

Since only the fibre optic cable will be considered, the discussion will to a large extent be a repetition of that given in Chapter 6 with respect to which tests should be included and the test strategy. However, a complete presentation will also be made of the combined cable since it has been requested that each component should be dealt with separately.

The general test strategy is described in Chapter 4 and will also be followed here. Each test method has been given a number, and these numbers are tabulated and described in Part 3 Ch.15.

15.2 Evaluation testing

15.2.1 Purpose

The purpose of the evaluation testing is to determine the operational limits of the combined electric/fibre optic cable with respect to critical mechanical and environmental parameters, to overstress specific characteristics in order to identify failure modes, demonstrate the suitability of the cable for proceeding on to qualification testing, and to get information which can be of value for a detailed planning of the test programme to be used in the procurement of the cable.

15.2.2 Properties to evaluate

The properties of interest to include in the evaluation testing are:

- mechanical properties
- tensile strength
- crush
- impact
- repeated bending
- torsion
- flexing
- snatch
- kink
- bend under tension
- bend at low temperature (cold bend)
- ability to withstand vibration
- temperature effects
- operation at high and low temperature
- ageing
- rapid temperature changes
- effects of heat generated by the electrical cable
- flammability
- effects of rapid depressurisation
- effects of operation in vacuum
- radiation effects
- ionizing radiation
- UV radiation
- solar radiation
- resistance to fluids

For coherent (single mode) transmission and sensor systems the state of polarization (SOP) of the transmitted light is for concern, and the cable will effect the SOP. However, it does not seem possible to prevent the SOP to be effected. The detection system must therefore be able to handle variations in the SOP, and appropriate methods are available [11]. Polarization preserving fibres may also be used. The effect of the combined cable on the SOP will thus not be considered.

For single mode fibres the cut-off wavelengths can change when the fibre is cabled, for example if the fibre is stranded. The cut-off wavelength must therefore be defined for the cabled fibre. But there is no purpose served by doing an evaluation testing in this respect. It can be noted that the effect of the cable on the cut-off wavelength can be simulated using an uncabled fibre.

It is assumed that the various materials used in the construction of the cable all have been tested to ensure that they are qualified for space applications, see Chapter 4. The material tests should include investigations of possible changes in mechanical properties as well as shrinkage. However, it is still considered prudent to include tests for the effects of vacuum operation and radiation on the cable. This is to ensure that the combination of various materials do not cause unexpected problems and that the changes in properties which the materials may suffer under these environmental loads, do not adversely affect the cable properties.

In the following a discussion is given why these properties are of concern.

15.2.2.1 Mechanical properties

The main purpose of the cable structure is to protect the fibre(s) against various mechanical loads. Such loads may cause losses to be induced in the fibres and even fibre breakage. The cable will probably be subjected to the most severe loads during installation when the cable may be stretched, bent, crushed and twisted, and there may also be accidental loads due f.inst. to falling objects. It is important that the cable is easy to handle, but at the same time the fibre must not be subjected to unacceptable loads during the handling.

One would expect a combined cable mainly to remain in a fixed position after installation. In such a position is could be subjected to a constant tensile load, bending, clamping and vibration. There might, however, also be cases where the cable is meant to be moved and thus subject to loads such as repeated bending, flexing and even cold bend.

The tensile strength is of special interest. In addition to know the breaking strength it is of importance to know the relationship between fibre loss and tensile force and the relationship between fibre strain and tensile force/cable elongation. As discussed in the Part 1, the fibre will be subjected to stress corrosion when under strain resulting in a time dependent breaking strength. It is thus necessary to know the relationship between fibre strain and cable tensile load to determine allowable tensile load conditions.

Vibrations can effect the performance of a cable if just a section of the cable is fastened to a support which vibrates. In such an application the cable will be strained in the transition region between the vibrating and non-vibrating part, and it is for such cases recommended to evaluate the cable's ability to withstand vibration. The possible problems encountered when the cable is attached to another component such as a connector, coupler etc. will be dealt with in the test programme for the appropriate component.

A test for abrasion has not been included. For electrical cables there is concern that the insulation can get damaged and expose the electrical conductor(s) possibly causing a short circuit and maybe also be a personnel hazard. This is not a concern with a fibre optic cable. It is, however, assumed that an evaluation of abrasion resistance will be included in the test for the electrical part of the combined cable, and it is also included in the qualification testing.

15.2.2.2 Temperature effects

The optical fibre has a much lower coefficient of thermal expansion than typical cable materials. High and low temperatures can therefore be expected to give thermally induced strain on the fibre causing macro- and microbending losses. Long term operation at high temperature can further cause ageing effects such as shrinkage of the cable materials and thus change the operational temperature range of the cable. In the combined cable account must also be taken of the heat generated by the electrical conductors, and tests will be done with an electrical load applied.

In case of rapid temperature changes thermal gradients will be set up across the cable. Depending on the difference in thermal expansion coefficient between the various cable materials, thermally induced strain could affect the cable structure.

15.2.2.3 Flammability

The flammability of the cable is a matter of great concern. The purpose of the evaluation is twofold. Firstly, to confirm the results of the flammability tests done on the individual cable materials. But in addition there may be applications where it is desirable or even required that the cable is able to function for a certain period during a fire. This latter ability should also be investigated.

15.2.2.4 Rapid depressurisation

The cable will not be compact, but have air filled sections and pockets. When the cable is subjected to rapid depressurisation, such as during launch, pressure gradients can be set up both between the outside and inside of the cable and between sections inside the cable. This could cause movement of the various cable elements and affect the fibre and possibly damage some of the cable elements.

15.2.2.5 Vacuum operation

Long term vacuum operation may affect the properties of the cable material and thus change the operational properties of the cable. Although the ability of the individual cable materials to withstand vacuum operation should have been tested, it is, recommended to investigate how the cable is effected by long term vacuum operation to confirm the previous findings.

15.2.2.6 Radiation effects

It is well known that ionizing radiation and also UV radiation will induce losses in the optical fibre. (See Part 1 and Chapter 5). The purpose of the tests proposed here is to investigate the effects of possible changes in the cable materials caused by ionizing radiation, UV radiation and solar radiation on the operational properties of the cable. In particular, it is of interest to determine if additional fibre losses are induced.

15.2.2.7 Resistance to fluids.

Potential cable materials may be damaged by certain fluids used in connection with assembly, launch and operation of spacecrafts. If it expected that the cable may come in contact with such fluids during installation or when in use, the resistance of the cable to the appropriate fluids should be investigated.

15.2.3 Sample distribution and test programme sequence

15.2.3.1 Sample distribution

The length of combined electric/fibre optic cable procured for a certain space vehicle will very likely be short, probably only a few hundred meters. The number of cable lengths to be tested will reflect this fact.

Number of cable lengths:	2
Length of each cable:	2 lengths, 550 m - 1600 m depending on number of fibres in cable.

The two cable lengths should come from two different production runs to get a picture of possible variation in properties from run to run. Two lengths for control purposes will be cut from these lengths after the initial measurements.

Each cable spool must be marked for identification.

The needed cable length will depend on the number of fibres in the cable. For many of the tests a certain fibre length is required to get sufficient accuracy. For multi-fibre cables this can be achieved by looping several fibres in the test sample.

To carry out the various tests samples of various lengths (a few m to max 200 m) will be cut from each cable length.

Generally, it is recommended to increase a load until the cable has suffered physical destruction or a substantial deterioration in performance, as appropriate. However, in the environmental tests the test levels have been limited to the most severe loads expected (see Chapter 4) with a suitable margin. If more severe loads are expected, the test levels should be increased accordingly. The results from the tests of the optical and electrical part of the cable should be compared to determine which part has less resistance to a certain load.

Since all tests are or can be destructive, new samples will be needed for each test.

All results should be recorded. One should keep track of from which cable length each sample is taken and assign the results to the appropriate sample.

15.2.3.2 Test programme sequence

The specified tests are summarised in Chart. 15.1 (see end of Chapter). Some tests are shown inside a dotted box indicating that they are of interest only for some applications as discussed later. It may well be that for some of the mechanical and environmental tests the evaluation of the optical and electrical properties can be done in parallel, but this will depend on cable type and will not be considered further. However, if one compares the test programme for pertinent electrical cables (see f.inst. ESA/SCC Generic Specification No. 3401) with the programme proposed for optical cables, the mechanical tests are less comprehensive and the recommended sample lengths generally shorter for electrical than for optical cables.

The initial measurements include determination of dimensions and the attenuation of the various fibres using optical time domain reflectometry (OTDR). Although several methods exist for measuring fibre loss, the OTDR technique has been chosen since it will give information about possible loss variations along the cable. The uniformity of loss says something about the quality of the cable. It is also of importance since samples will later be cut from the two cable lengths for the various tests.

New samples will be used for each test since all tests can be destructive, see 15.2.3.1. Further, by doing tests on new samples the effects of a specific load can more easily be discerned. Since new samples are used, the test order is of no importance for the results. It is generally recommended that those tests which are considered easiest and the least expensive to perform are done first and the more complicated and expensive tests are done at the end. Should the cable not show satisfactory results in the more simple tests, the test programme can be stopped before a large expense has been incurred.

It is recommended that the mechanical tests are done first. The tests are relatively simple to do requiring standard test equipment for cables. But the mechanical properties are of importance for installation, operation and ease of handling. The first test is for tensile strength. The ability of the cable to withstand tensile loading without inducing unacceptable fibre losses and fibre strain, is a good measure of how well the cable is designed and if it has met its design goals.

Resistance to crush and impact are tested next to study how well the fibre is protected inside the cable structure. Tests with respect to repeated bending, torsion, flexing, snatch, kink, and bend under tension are related to the ease of handling and how installation friendly the cable is. The test for cold bend is deemed necessary only in case the cable is intended to be bent or could possible be bent at low temperatures. Finally, the vibration is necessary only in cases where just a section of the cable is attached to a vibrating support, see 15.2.2.1.

The environmental tests are generally more complicated, expensive and time consuming to do than the mechanical tests. The high/low temperature test is done first. It is an important property of a properly designed cable that it can operate over a large temperature range. The test is thus a good measure of how well the cable is designed and produced. The ageing test is listed after the temperature test since the test results from the latter may be required for determining the test parameters in the ageing test. A new temperature test is, however, done as part of the post test investigation to establish any permanent change in operational temperature range. The test with respect to rapid change in temperature is also done after the high/low temperature test since the results from the latter are used to establish the test parameters of the former. The tests at high temperature and ageing will be done with maximum load on the electrical cable.

The flammability test is done next since it is regarded simpler to do than the other remaining tests. The vacuum related tests follow. The rapid depressurisation is done first since there is no purpose to the vacuum test if the cable cannot tolerate a rapid depressurisation. The two tests can be done on the same samples.

The purpose of the remaining tests are all to confirm the results from the material tests. As noted before, the ionizing and UV radiation will induce losses in the fibre. The purpose of these tests is to investigate if radiation induced changes in the cable materials and cable structure can induce losses in the fibres. The test for ionizing radiation is listed first of the three tests. A cable used in space will always be subjected to such radiation. The two remaining tests are listed in dotted boxes, see Chart. 15.1, since the cable might in some applications be shielded from UV and solar radiation removing the need for the tests. The test with respect to resistance to fluids should be carried out if this is deemed necessary for the intended application. The range of fluids will depend on the application.

The tested samples shall be subjected to a construction analysis to determine the failure modes.

15.2.3.3 Use of a control group

In the proposed tests the transmitted power is measured while the cable is subjected to the various loads, and an important object of the test programme is to determine how the transmitted power and thus loss is effected by the load in question.

Where appropriate a transmission measurement is also done after the load is removed as part of the post test investigation. It is important that some means are provided to ensure stability of the source or alternatively that the source output is monitored. Use of a control group would here serve no purpose since the control measurement would have to be made with a different set of equipment. A cable length is, however, included as a control group to be used for comparison purposes in the construction analysis.

15.2.4 Inspection

The purpose of the inspection is to make sure that the cables lengths are suited for testing. All cables should be inspected.

15.2.4.1 Visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specification No. 20500. It should be ensured that there is good access to both cable ends for later optical transmission measurements.

15.2.4.2 Marking

All cable lengths must be marked in accordance with the standard procedure of the manufacturer and the requirements stated in 15.2.3.1. The length of each cable length should be indicated.

15.2.5 Initial measurements

The purpose of the initial measurements is to determine the cable dimensions and the actual value of the fibre attenuation in the cable. These values will be used as base line data for the later measurements. Further, one can ascertain that the various cable lengths actually meet the specifications, and one can determine the spread in values which is a good indication of how well the production process is being controlled.

The initial measurements should be done on all cable lengths. It is important to keep track of the results being obtained for each fibre.

15.2.5.1 Cable dimension

The test is done so as to be able to compare cable dimensions (cross-section) before and after various tests. It also allows a check to be made of cable dimensions and uniformity. The measurement should be done on 3 positions at each end of the cable lengths. Each position should be at least one meter apart.
Test method: 15.1.3

15.2.5.2 OTDR measurement

The attenuation of each fibre in the cable should be determined at the anticipated operational wavelength. The measurement should be made on the complete cable length.
Test method: 15.2.3

15.2.6 Mechanical tests

In all these tests, except for kink, the optical transmission is measured as a function of the load. For multifibre cables several fibres can be looped together for the transmission measurement so as to be able to monitor several fibres simultaneously and also to increase the length of fibre being subjected to the load. The load should increase until fibre break or until the load has exceeded the value stated in the test description. One might expect the optical fibres to break before the electrical conductors although this would depend on cable design and type. But the results of the mechanical tests should be compared to the results of similar tests for the electrical part to determine the maximum allowable load for the combined cable.

15.2.6.1 Tensile strength

Number of samples: Two. One from each length
Sample length: at least 50 m

Increase load until fibre break. Optical transmission shall be measured at the operational wavelength and induced loss versus tensile load determined. The induced strain versus tensile load shall be measured for one or several looped fibres.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.1

15.2.6.2 Crush

Number of samples: Four. Two from each length
Sample length: A few meters
Starting load: Specified value
Duration: 1 minute
Step increase in load: 20% of specified value

Measure optical transmission versus load. The cable shall be visually inspected after each load to look for cracks or other damage to the cable sheath.
Continue load increase until fibre breaks.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.3

15.2.6.3 Impact

Number of samples: Four. Two from each lengths.
Sample lengths: A few meters
Starting energy: Specified level
Number of impacts per energy level: 5 or until break
Increase in energy per step: 20% of specified level

Measure optical transmission versus load. Continue load increase until fibre-break. The cable shall be visually inspected after each load to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.4

15.2.6.4 Repeated bending

Number of samples:	Four. Two from each length
Sample length:	A few meters
Bending radius:	Specified value for bend diameter
Load:	As specified or 10% of breaking load
Number of bends:	Until fibre-break, but maximum 1000

Measure optical transmission versus number of bends. The cable shall be visually inspected after each 100 bends to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.5

15.2.6.5 Torsion

Number of samples:	Four. Two from each length
Sample of length:	As specified (Typically a few meters)
Load:	As specified

Number of cycles (clockwise and anticlockwise): to fibre-break, max. 50 or twice specified value whichever is higher.

Measure optical transmission versus load. The cable shall be visually inspected after end of the test to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.6

15.2.6.6 Flexing

Number of samples:	Four. Two from each length
Sample length:	As specified (Typically a few meters)
Pulley diameter:	As specified
Load:	As specified

Carrier speed:	10 cycles per min or as specified
Number of cycles:	To fibre-break, max. 1000 or twice specified value whichever is higher.

The optical transmission shall be measured as a function of the number of cycles. The cable shall be visually inspected after the completion of the test to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres.

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.7

15.2.6.7 Snatch

Number of samples:	Four. Two from each length
Sample length:	A few meters
Starting weight:	As specified
Number of cycles per weight:	10 or to break
Weight increase per step:	20% of starting weight

The optical transmission shall be measured as a function of load. The cable shall be visually inspected after completion of the test with each weight to look for cracks or other damage to the cable sheath.

Fibres to include in measurement:

Cables with 1 - 6 fibres: all fibres
Cables with 7 - 20 fibres: at least 6 fibres
Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.3.8

15.2.6.8 Kink

Number of samples: Four. Two from each length
Sample length: A few meters
Decrease diameter until kink (break) is formed.
Test method: 15.3.9

15.2.6.9 Bend under tension

The purpose of this test is to determine the cable's ability to withstand bending around a cylindrical mandrel.

Number of samples:	Four. Two from each length
Sample length:	A few meters
Starting mandrel diameter:	As specified
Number of turns:	To fibre-break, but max. six or twice specified whichever is greater
Number of cycles for one diameter:	To fibre-break, but max. ten or twice the specified value whichever is greater
Decrease in mandrel diameter per step:	1 cm for starting diameter less than 10 cm 2 cm for starting diameter larger than 10 cm
Load:	as specified

The optical transmission shall be measured as a function of load. The cable shall be visually inspected after the completion of the test for each diameter to look for cracks or other damage to the cable sheath.

Fibres to include in the measurement:

Cables with 1 - 6 fibres:	all fibres
Cables with 7 - 20 fibres:	at least 6 fibres
Cables with 21 or more fibres:	at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.

Test method: 15.3.10

15.2.6.10 Cold bend

This is a test similar to that in 15.2.6.9, but the test shall be performed at a low temperature.

Mandrel diameter:	as specified
Starting temperature:	as specified
Step change in temperature:	10 °C
Low temperature:	sufficient to cause fibre-break or break of cable sheath, but not lower than -70 °C.

For other test conditions, see 15.2.6.9.

Test method: 15.3.12

15.2.6.11 Vibration

Number of samples:	Two. One from each length
Sample length:	25 m unless otherwise specified
Vibration frequency:	100-2000 Hz
Starting acceleration:	as specified
Step increase in acceleration:	20% of specified level until the level has reached 30 g or until fibre-break
Duration:	90 minutes

The optical transmission shall be measured during the test.

Fibres to include in the measurement:

Cables with 1 - 6 fibres:	all fibres
Cables with 7 - 20 fibres:	at least 6 fibres

Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped for the measurement.
The cable shall be visually inspected after the test.
Test method: 15.3.11

15.2.7 High and low temperature test

The purpose of this test is to determine the highest and lowest short term operational temperature. The optical transmission at the anticipated operational wavelength should be monitored during the tests. Several fibres may be looped for the transmission measurement. The electrical cable shall be run at max. load at the high temperature.

15.2.7.1 Temperature test

Number of samples:	Two. One from each cable length
Sample length:	Sufficient to get at least 200 m of looped fibre. Min. cable length: 50 m.
Thermal cycle:	First low, then high
Low starting temperature:	Lowest specified operating temperature or -40 °C if not known
Low temperature:	Sufficient to give an induced loss of 2 dB/km, but not lower than -70 °C
High starting temperature:	Highest specified operating temperature or +90 °C if not given
High temperature:	Sufficient to give an induced loss of 2 dB/km, but not higher than 150 °C. The electrical cable should be run at max. rated load at the high temperature.
Step change in temperature:	10 °C

Duration of stay at each temperature: Until cable temperature has stabilised, but at least 1 hour

Fibres to include in test:

Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.1

15.2.8 Ageing

Long term operation at a high temperature can affect the properties of the cable materials which to a great extent will be various types of plastics. One potential problem is shrinkage which can cause macrobend losses to be induced in the fibre. The mechanical properties of the cable material may also be affected.

15.2.8.1 Ageing test

Number of samples:	Two. One from each cable length
Sample length:	Sufficient to get at least 200 m of looped fibre. Min. cable length: 50 m.
Temperature:	20 °C above specified operational temperature, but at least 10 °C below high temperature limit established in 15.2.7.1

Duration: Until loss has increased to 2 dB/km or visual changes are clearly evident. Maximum duration: 1000 hours.
Load on electrical cable: Max. rated load

The optical transmission should be measured during the test at the anticipated operational wavelength.

Fibres to include in test:
Cables with 1 - 4 fibres: all the fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.8

15.2.8.2 Post test investigation

At the end of the ageing test a test should be done to determine if the test has caused the operational temperature range of the cable to change. The cable should be exposed to the following temperature cycle:

Max. temperature: Max. specified operating temperature
Min. temperature: Min. specified operating temperature
Temperature at end of cycle: 20 ± 5°C
Experimental conditions as in 15.2.7.1, otherwise.

At the end of the temperature cycle the following tests should be done:
Visual inspection
Cable dimensions (cross-section), see 15.2.5.1.

15.2.9 Rapid change in temperature

The purpose of the test is to investigate if thermal gradients across the cable will affect the cable structure.

15.2.9.1 Test for rapid change in temperature

Number of samples: Two. One from each cable length
Sample length: 50 m
High temperature: 10 °C below high limit established in 15.2.7.1
Low temperature: 10 °C above low limit established in 15.2.7.1
No load on electrical cable.

The optical transmission should be measured during the test at the anticipated operational wavelength.

Fibres to include in the test:

Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.2

15.2.9.2 Post test investigation

The transmission should be measured after the cable has been brought back to room temperature. This should be followed by a visual inspection.

In case the cable has failed to meet its specifications, a construction analysis should be done, see 15.2.15.

15.2.10 Flammability resistance

Number of samples:	Two. One from each cable length
Sample length:	A few meters

Unless otherwise specified the test conditions (flame temperature, duration) shall be as described in ESA/SCC Generic Specifications No. 3901, Para. 9.20.

Duration of first test cycle:	as specified for cable or as specified in ESA/SCC Generic Specification No. 3901, Para 9.20
Step increase in duration, subsequent test cycles:	Increase duration of time burner is applied by duration of first cycle
Number of cycles:	Until fibre-break, but max. duration five times original cycle.

The optical transmission shall be measured during the test. A visual inspection shall be made of the cable after each test cycle and its condition noted.

Fibres to include in the measurement:
- Cables with 1 - 6 fibres: all fibres
- Cables with 7 - 20 fibres: at least 6 fibres
- Cables with 21 or more fibres: at least 30% of fibres

The fibres shall be selected at random. For multifibre cables several fibres may be looped and the transmission measured through the loop.
Test method: 15.4.7

15.2.11 Rapid depressurisation

The purpose of this test is to investigate if rapid depressurisation can induce losses in the fibres or cause damage to the cable structure.

15.2.11.1 Rapid depressurisation test

Number of samples:	Two. One from each cable length.
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m.

The optical transmission should be measured during the test.

Fibres to include in test:
- Cables with 1 - 4 fibres: all fibres
- Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
The cable is regarded to have failed if it does not meet the specified requirement with respect to rapid depressurisation.
Test method: 15.4.9

15.2.11.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 15.2.16
In case of failure the cable shall also be subjected to a construction analysis, see 6.2.15

15.2.12 Vacuum operation

The purpose of the test is mainly to confirm that any changes in the properties of the cable materials will not affect the cable properties in an adverse way. After completion of the test a visual inspection should be made of the cable. In addition, a temperature cycling test similar to the one specified in 15.2.8.2 should be performed. The purpose of the latter test is to determine if the possible changes in material properties (f.inst. shrinkage) have affected the operating temperature range. The proposed test conditions are similar to those used in the vacuum test of materials, see PSS-01-702.

15.2.12.1 Vacuum test

Number of samples:	Two. One from each cable length. Sample from 15.2.11 can be used
Sample length:	Sufficient length to get at least 200 m looped fibre. Min. cable length: 50 m
Vacuum:	10^{-3} Pa or less
Temperature:	125 °C, but not above max. operating temperature
Duration:	24 hours, unless otherwise specified

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres: all the fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.3

15.2.12.2 Post test investigations

Visual inspection
Cable dimensions (cross-section), see 15.2.5.1
Temperature cycling test, see 15.2.8.2

15.2.13 Ionizing radiation

The purpose of this test to determine if the ionizing radiation has affected the cable materials in such a way as to induce losses in the fibres. Since the ionizing radiation will induce losses in the fibres directly, it will be difficult to distinguish between the two loss mechanisms unless the cable induced losses are significant with respect to the losses induced directly in the fibres. It must be assumed that the optical fibres used in the cable are so well characterised that the losses induced directly in the fibres can be estimated with confidence.

The only post test investigations proposed are to make a visual inspection and to measure cable dimensions.

15.2.13.1 Test for ionizing radiation

Number of samples:	Two. One from each cable length
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Temperature:	Room temperature
Incident optical power:	Ca. 1 µW
Wavelength:	Expected operational wavelength
Dose rate:	5 rad(Si)/s
Duration:	The irradiation should last until a) The induced loss from the cable is equal that induced directly in the fibre or b) The total dose has reached 3 Mrad

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres:	all fibres
Cables with 5 or more fibres:	at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.6

15.2.13.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 15.2.5.1

15.2.14 Solar radiation including UV radiation

As noted in Chapter 5 UV radiation can induce losses in optical fibres. It seems, however, reasonable to assume that the cable sheath etc. will protect the fibre from UV radiation. Any fibre induced losses observed in the tests should thus be caused by changes in the cable due to the UV/solar radiation. As discussed in 15.2.3.2 these tests are of interest only if the cable is exposed to UV and solar radiation.

15.2.14.1 Solar radiation

Number of samples:	Two. One from each cable length
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Radiation source:	Source with representative spectral output
Duration:	Until induced loss increase to 5 dB/km or visible damage to the cable or twice specified dose

The optical transmission should be measured during the test.

Fibres to include in test:

Cables with 1 - 4 fibres: all the fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped and the transmission measured through the loop.
Test method: 15.4.4

15.2.14.2 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 15.2.5.1

15.2.14.3 UV radiation

Number of samples:	Two. One from each cable length
Sample length:	Sufficient length to get at least 200 m of looped fibre. Min. cable length: 50 m
Radiation source:	representative UV source
Duration:	The irradiation shall last until a) The induced loss is 5 dB/km or b) Twice specified dose has been reached

The optical transmission should be measured during the test.

Fibres to include test:

Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

The fibres may be looped, and the transmission measured through the loop.
Test method: 15.4.5

15.2.14.4 Post test investigation

Visual inspection
Cable dimensions (cross-section), see 15.2.5.1

15.2.15 Resistance to fluids

The test should be carried out using the same procedure as for electrical cables. A range of fluids is listed in the description of the test method. Which fluids to include in the test will depend on the application.

A visual inspection should be made after the immersion of the cable in the fluid.

Number of samples:	Two. One from each cable length
Sample length:	1 - 2 m
Test method:	15.4.10

15.2.16 Construction analysis

A number of post test investigations have already been proposed in connection with the environmental measurements. In addition the damaged cable sections from the mechanical measurements should be cut open and compared to similar sections from the control cable in an attempt to identify failure mechanisms.

15.3 Production testing

15.3.1 Introduction

The measurements that are practical and desirable to make during the production process are highly dependent on the cable design and the steps in the production process. It is thus possible only to give some general rules with regard to the production control. In the final production test both optical and geometrical measurements can be made. The optical measurements are non-destructive. For the geometrical measurements short samples will have to be cut from the produced length. In addition to these measurements it is proposed to do a temperature test.

15.3.2 Production control

The cable diameter (cross-section) shall be controlled within the specified limit during the various steps of the cable production process.

If the cable design and production process allows, measurements should be made of the fibre attenuation after the completion of key steps in the process. In case the optical part of the cable is a more or less complete fibre optic cable, it should be subjected to a production control as described in 6.3.2 and a final production testing (see 6.3.3.) before being incorporated into the combined cable.

In case the cable design is based on the fibre having a certain excess length with respect to the cable, means should be provided to control the excess length during the production process.

The cable length shall be measured, and the length marked on each spool.

15.3.3 Final production testing

Measurements are to be made on each cable length or on samples from each cable as appropriate. The tests shall be done in accordance with Chart. 15.2. The tests are independent of each other. The order in which the tests are done is thus not critical.

The visual inspection and marking are done first to assure that the cable has no obvious fault and is ready for testing. Measurement of mass and outer dimensions are simple tests to do and give the first indications that the cable has been produced according to specifications. The fibre attenuation is measured next to assure that the cabling process has not induced unacceptable losses in the fibres. Finally, a temperature test is done. Such a test gives a good check on the successfulness of the cable production process. It is proposed that the temperature test is done on the complete cable length and not just on a sample since it is assumed the procured length(s) will be somewhat limited. The test should be done over the temperature range specified to give no permanent losses. Finally, for single mode fibres the cut-off wavelength should be measured. This test can also be done on uncabled fibres.

All produced lengths shall meet specifications.

15.3.3.1 External Visual Inspection

To be performed in accordance with ESA/SCC. Basic specification no. 20500. It should be assured that there is good access to both cable ends since this is necessary for the later measurements.

15.3.3.2 Marking

The cable and spool shall be marked according to specifications.

15.3.3.3 Mass

Samples should be taken from each cable length
Test method: 15.1.5

15.3.3.4 Outer dimensions

Samples should be taken from each cable length.
Test method: 15.1.3

15.3.3.5 Attenuation

Measurement should be made on all fibres and on the complete cable length and at the specified wavelength(s).
Test method: 15.2.1 or 15.2.2 or 15.2.3

15.3.3.6 Thermal cycling

The measurement shall be done on the complete length and at the specified wavelength.

Max. temperature:	Max. temperature specified not to give permanent loss
Min. temperature:	Min. temperature specified not to give permanent loss
Number of cycles:	One
Electrical load:	Max. rated load at high temperature

The optical transmission shall be measured during the test.

Fibres to include in the test:

Cables with 1 - 4 fibres: all fibres
Cables with 5 or more fibres: at least 4 fibres selected at random

Several fibres may be looped, and the transmission measured through the loop.
Test method: 15.4.1

15.3.3.7 Cut-off wavelength

A sample should be taken from every cable length. The cut-off wavelength should be measured for all fibres. This test applies only to single mode fibres. The test can also be simulated using uncabled fibres.
Test method: 15.2.4

15.4 'Burn-in'

No additional measurements needed in addition to the Final Production Testing

15.5 Qualification testing

The qualification test programme should include all tests of relevance not already done in the final production test. Optical and geometrical parameters have been measured in the final production test. It is assumed that the necessary tests of the additional optical and geometrical parameters related to the fibres themselves have been performed on the fibres before cabling. The qualification testing will thus be concerned with mechanical and environmental characteristics. The tests shall be performed in accordance with Chart 15.3.

Tests for all the mechanical properties are included in the qualification testing since they can be effected by the production process. The quality of the cable jacket materials is dependent on how well the various extrusion parameters are controlled. The incorporation of the fibre(s) in the cable by stranding or some other method is also a critical process and can affect how well the cable is able to protect the fibres from mechanical loads. Finally, the adhesion or friction between the various layers in the cable will effect its mechanical properties.

The proposed environmental tests are limited to those related to temperature. The temperature characteristics of the cable may be effected by the production process for much the same reasons as the mechanical properties. Tests for flammability, vacuum operation, radiation related effects and resistance to fluids have not been included. These properties are related to the choice of materials used in the cable and the basic cable design, and any problems in this respect should have been discovered in the evaluation testing.

One cable length shall be used for the qualification testing. The required length will depend somewhat on whether or not the complete test programme is to be performed. To carry out the complete programme at least 450 m is needed, as indicated in Chart 15.3.

All samples should meet the specifications for the cable type being tested.

15.5.1 Mechanical tests

The mechanical tests are all done on samples from the cable and mostly the samples are only 3 - 5 meter in length. It is recommended that all tests be done on fresh samples. If we leave out the tensile test, the other tests are related to loads which, when the cable is in use, will be applied locally to a short section of the cable. It seems rather unlikely that the same short section would be exposed to several of the various types of loads in an actual application. It thus seems more realistic to use fresh samples and not use the same samples for several tests. In the tensile test the sample is stressed to break, and the sample is thus damaged.

Since fresh samples are used, the sequence of tests is not critical. The order shown in Chart. 15.3 is based on the importance of the various test. Reference is made to 15.2.3.2. for a further discussion. The test for vibration is regarded necessary only if in the intended application a section of the cable is attached to a support which vibrates with respect to the remaining part of the cable.

It may be noted that no test is included for strippability. Generally, in the specifications for fibre optic cables only some general remarks are made with respect to ease of stripping the cable. The main concern is with the fibre, and the strippability of the fibre is considered in the tests for fibres, see Chapter 5. It is assumed that a test for stripping will be included in the qualification test programme for the electrical part.

The sample length recommended for the various tests are given in Chart 15.3 unless otherwise stated in the detailed specifications. Two samples should be used in each test, one sample from each end.

15.5.1.1 Tensile strength

The fibre loss and elongation should be measured as a function of tensile load. The cable should be stressed to break.
Test method: 15.3.1.

15.5.1.2 Crush

Test method: 15.3.3

15.5.1.3 Impact

Test method: 15.3.4

15.5.1.4 Repeated bending

Test method: 15.3.5

15.5.1.5 Torsion

Test method: 15.3.6

15.5.1.6 Flexing

Test method: 15.3.7

15.5.1.7 Snatch

Test method: 15.3.8

15.5.1.8 Kink

Test method: 15.3.9

15.5.1.9 Bend under tension

Test method: 15.3.10

15.5.1.10 Abrasion

This test can likely be combined with the abrasion test with respect to electrical properties.
Test method: 15.3.2

15.5.1.11 Vibration

Test method: 15.3.11

15.5.2 Environmental tests

As discussed before, only tests related to temperature are included. The tests involve measuring temperature induced losses, and the tests must therefore be done on sufficient lengths to allow any change in loss to be measured with the required accuracy. In addition, a certain cable length is required to get information about possible variations in properties along the cable. A minimum length of 200 m is recommended, see Chart. 15.3. For multifibre cables several fibres may be looped together for the transmission measurements.

A test to check the temperature operating range is included in the production test. The qualification test is started with an ageing test followed by a temperature cycling test to see if the ageing test has affected the temperature operating range, f.ex. due to shrinkage of the cable jacket. The cycling test should be done with maximum rated load on the electrical conductor.
The temperature cycling test can be done as a continuation of the ageing test. It is therefore done before the test for rapid change in temperature which requires a different test set-up.

Two mechanical tests are proposed after the temperature test, one for bending at room temperature and one for cold bend to see if the ageing process has affected the cable jacket.If the cable should be subjected to bend in space, this could well be after it has been subjected to high and low temperatures. However, one would expect a fibre optic cable to be subjected to bend only in some special applications. The test should be done on two short samples taken from each end of the samples used in the temperature tests. Separate samples are used for the two tests.

The cable will likely be subjected to the heaviest mechanical loads during installation, and this should be before it has been exposed to ageing. It should thus not be necessary to do any additional mechanical tests on the sample which has undergone the ageing test.

15.5.2.1 Ageing

Maximum rated load on electrical conductors.
Test method: 15.4.8

15.5.2.2 Temperature cycling

Maximum rated load on electrical conductors at high temperature.
Test method: 15.4.1

15.5.2.3 Rapid change in temperature

Test method: 15.4.2

15.2.2.4 Bend under tension

Test method: 15.3.10

15.5.2.5 Cold bend

Test method: 15.3.12

15.6 Lot Acceptance Testing

Lot acceptance testing (LAT) shall be performed on every lot delivered by the manufacturer. The purposes of the tests to be included in the various LAT-levels have been discussed in Chapter 4.

The tests proposed for LAT3 can be done on a complete cable length. The tests are non-destructive, and the cable length can be delivered.

The proposed tests for LAT1 and LAT2 require that samples of various lengths be cut from a longer cable length. The tests are or may be destructive. The samples cannot be delivered.

The LAT shall be carried out in accordance with Chart. 15.4.

15.6.1 Lot Acceptance Level 3 Testing (LA3)

All optical and geometrical characteristics have been measured in the Final Production Testing of the cable or the fibre. As a check of the measurement of attenuation, the most important optical characteristic, it is proposed that the attenuation be measured on one of the cable lengths to be delivered. Further, a visual inspection should be made.

The cable must meet all tested specifications including the loss specifications for all fibres in the cable.

15.6.1.1 External visual inspection

The inspection should be carried out in accordance with ESA/SCC Basic Specification No. 20500.

15.6.1.2 Attenuation

The measurement should be made on the whole cable length on all fibres and at the specified wavelength(s). It is recommended that the measurement be made using OTDR (optical time domain reflectometry) since this will allow the uniformity of the loss along the cable to be checked.
Test method: 15.2.3

15.6.2 Lot Acceptance Level 2 Testing (LA2)

LA2 encompasses LA3 and the environmental/endurance subgroup. The proposed tests are for ageing, temperature cycling and when appropriate, bend under tension and cold bend. The temperature tests are included since they give a very good indication of how successful the production process has been. As noted before, the fused silica fibres have a much smaller coefficient of thermal expansion than other typical cable materials. Variation in temperature may therefore cause micro- and macrobending of the fibres resulting in added losses unless the cable is properly designed and fabricated.

The sequence of test and needed test lengths were discussed in 15.5.2.

All tested samples shall meet specifications.

15.6.2.1 Ageing

Maximum rated load on electrical conductors.

Test method: 15.4.8

15.6.2.2 Temperature cycling

Maximum rated load on electrical conductors at high temperature.
Test method: 15.4.1

15.6.2.3 Bend under tension

Test method: 15.3.10

15.6.2.4 Cold bend

Test method: 15.3.12

15.6.3 Lot Acceptance Level Testing (LA1)

LA1 encompasses LA3 and LA2 and the mechanical subgroup. The proposed tests are for tensile strength, crush, impact and flexing. The test for tensile strength gives a good indication of how successful the production has been with respect to an important design goal. By measuring the fibre loss and fibre strain versus tensile load, a good check is obtained on how successfully the fibres have been incorporated into the cable structure. The test with respect to crush resistance gives some of the same information and also tells how well the various cable layer have been put together. The tests with respect to impact and flexing gives information on the quality of the cable jacket as well as the cable structure and the positioning of the fibres in the cable. A successful outcome of the four proposed tests in the mechanical subgroup together with the tests in LA2 and LA3 should thus give a good assurance that the production process is under proper control.

The sequence of tests is discussed in 15.5.1

The recommended sample lengths are given in Chart. 15.4 unless otherwise stated in the detailed specification. Two samples should be used in each test, one sample from each cable end.

All tested samples shall meet specification.

15.2.3.1 Tensile strength

Test method: 15.3.1

15.6.3.2 Crush

Test method: 15.3.3

15.6.3.3 Impact

Test method:15.3.4

15.6.3.4 Flexing

Test method: 15.3.7

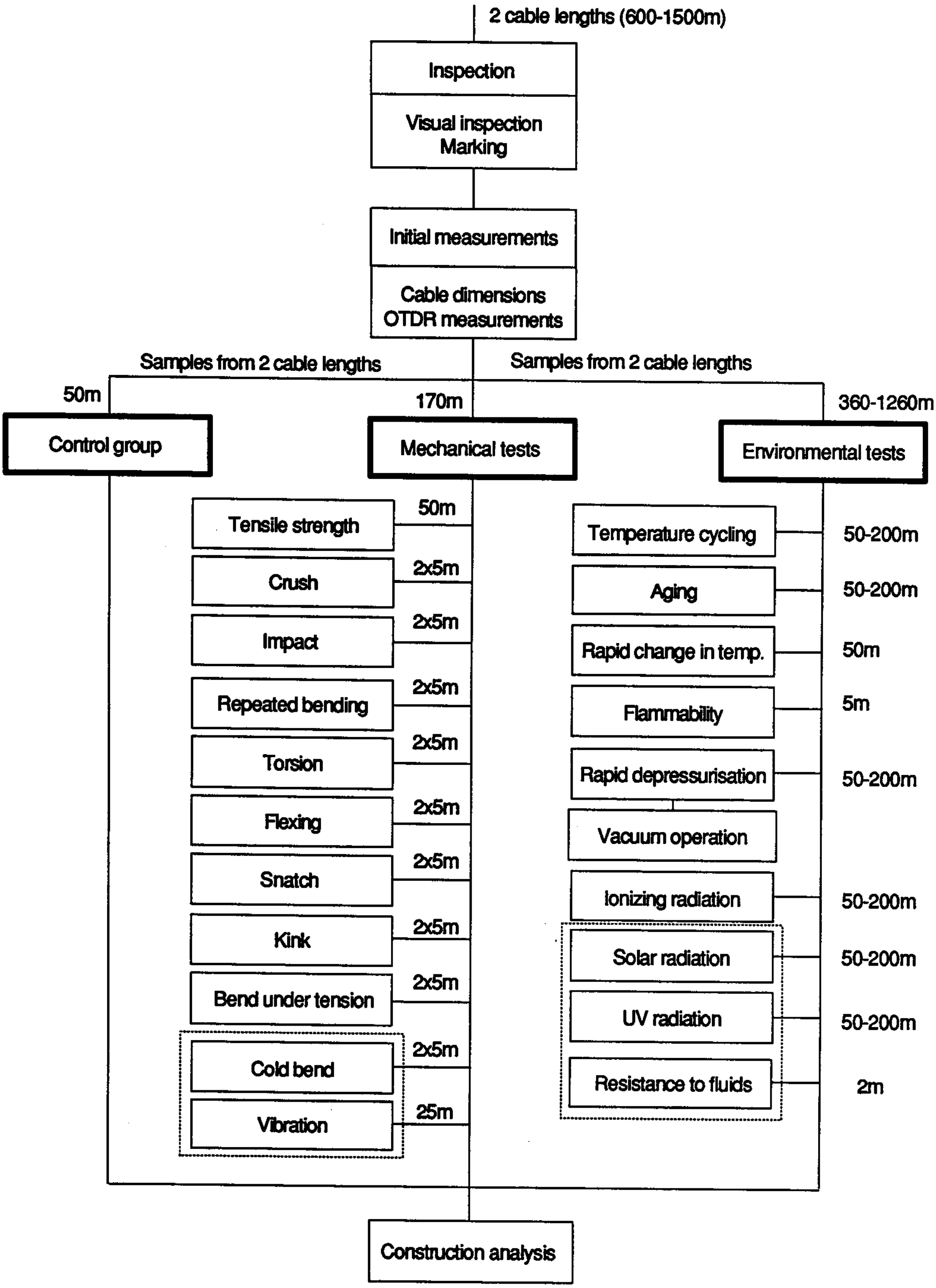

Chart 15.1 Evaluation testing, combined electric/fibre optic cables.

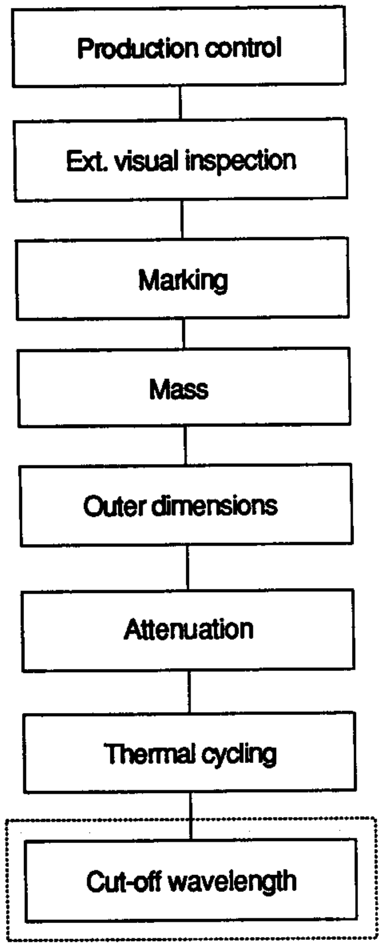

Chart 15.2 Final production testing, combined electric/fibre optic cables

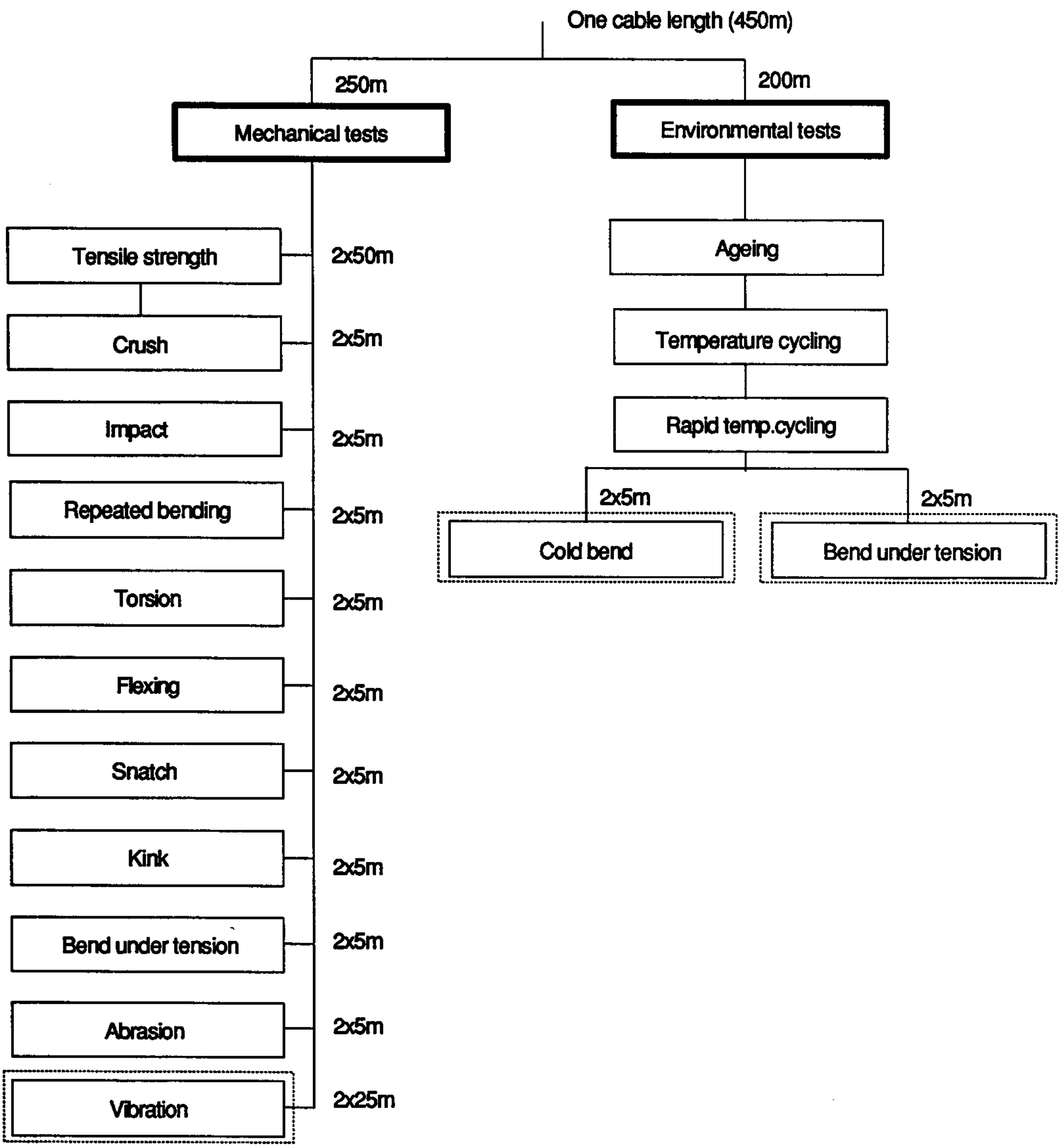

Chart 15.3 Qualification testing, combined electric/fibre optic cables

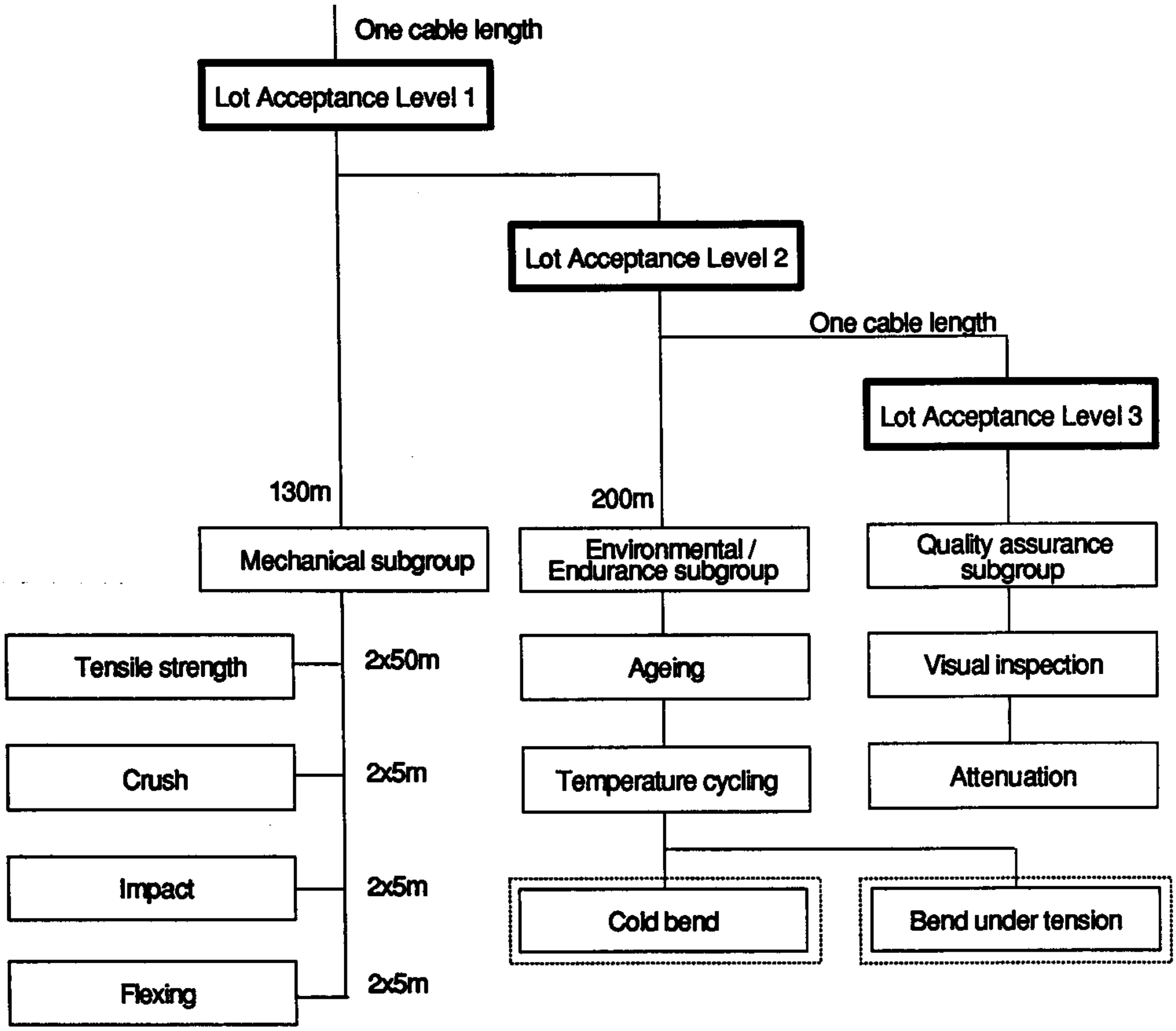

Chart 15.4 Lot acceptance testing, combined electric/fibre optic cables

16. APPENDICES

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1. INTRODUCTION

This Part contains Task Report No.3 of the ESTEC Contract No.8906/90/NL/PM(SC).

2. OBJECTIVE OF WORK TASK 3

The objective of this Task has been to work out a detailed description of new test methods giving a complete description of all environmental, mechanical, optical standard test methods for passive optoelectronic components, taking as guidelines the existing standards in the SCC system for electric cables and electric connectors, i.e.:

- Evaluate existing standard test methods.
- Decide if and when these existing test methods are applicative.
- Work out new methods and modify existing where and when considered necessary.

3. DOCUMENTATION

The work has been performed in accordance with the specific articles listed in the Contract. Besides the work is based on additional documentation received from ESTEC and other relevant references listed in Part 1. Literature references have been listed in Chapter 18.1. References used have been given in brackets e.g. [A4].

4. GENERAL

4.1 Introduction

In this Chapter, a general description of the testing procedures will be given. The strategies for testing of optoelectronic components have been described in Part 2.

In Part 1 the following passive fibre optic components were determined to be of interest for space applications:

- Optical fibre
- Optical fibre cables
- Fibre optic connectors
- Fibre optic splices
- Splice organisers
- Fibre optic attenuators
- Fibre optic branching devices (couplers)
- Fibre optic switches
- Fibre optic wavelength multiplexers/demultiplexers
- Fibre optic isolators
- Combined electric/fibre optic cable

All these components have already found extensive use in various terrestrial applications. At the present, technical standards covering almost every important property of these components are available. For a number of years national and international standard organisations have been working at establishing test methods applicable to determine the quality of fibre optic components. The International Electrotechnical Commission (IEC) has issued several standards, see Chapter 3 in Part 1, and new and revised documents are steadily being published. Among the national organisations the Electronic Industry Association (EIA) in the US has been particularly active. A large number of fibre optic test procedures (FOTP) have been worked out and published in Recommended Standard EIA/TIA-455. The US Military Standards for fibre optic components also seem to a large degree to rely on the EIA test methods.

A fibre optic component used in space will perform the same function, be based on the same physical principles and in general have similar or equal properties as other fibre optic components. Even though the parameter severities may be different from terrestrial applications, it may be assumed that the established test methods also are suitable for components intended for space operation. However, some additional tests related to environment tests will be needed to be established.

4.2 Testing of passive fibre optic components for space applications

In Part 2 the test strategy was established for evaluation, production, qualification and lot acceptance testing for all the relevant components. All the tests to which the various components shall be subjected were identified and listed.

In this part we will start out with the list of tests. Each component will be treated in a separate Chapter. Where existing test methods are considered applicable, only a reference will be given. Where existing test methods need modifications, the required modifications will be described. New test methods will be described in full detail. The procedures are based on the existing procedures described in the ESA/SCC specifications, e.g. No.20100.

If test methods from several standard bodies are considered applicable, IEC Standards will be preferred followed by those from EIA. In some cases the IEC Standards only exist as a draft document at present. Reference will then be given to the draft. It is expected that the drafts will be issued as official standards in the near future.

The test methods for the basic optical and geometrical properties will not depend on the environment. The existing test methods should thus be applicable, and the methods will in general not be described, only referenced. However, a few optical test methods have as of yet not been considered by the standard organisations. In these cases we have proposed a test method. It is however, recommended that as test methods are established by the standard organisations for the optical properties in question, such methods are adopted by ESTEC.

The test methods for mechanical properties will in general also be the same whether the component is intended for terrestrial or space application. The main difference could be in the severity of the test parameter(s). These tests will only be discussed in case modifications are needed. Tests for some of the environmental conditions met in space applications have, however, not be addressed by standard organisations. In these cases new or modified test methods have been worked out where required.

4.3 Testing conditions and parameter severities

In space applications, and particularly in the pre-orbit and on-station phase, the components will be subjected to environmental loads which are quite different from that normally met in terrestrial applications. This topic was discussed at length in the Task 1 Report.

The following environmental parameters and conditions were found to be of special concern for the passive optical fibre components used in space applications:

- ionizing radiation,
- rapid depressurisation,
- operation in vacuum,
- temperature extremes,
- rapid temperature cycling,
- vibrations,
- mechanical shock.

To base a decision on results obtained in laboratory or factory testing, the test itself must be relevant to the environment and strains the component is supposed to endure in actual service condition, and to the criticality of the component's function. An important aspect is that in normal working condition the components are exposed to combination of parameters. It is not possible to design a test taking care of all the varying parameters. It is therefore normal to carry out several single tests in series, and to evaluate the result of each before starting the next and at the end of the series testing. The succession of tests is to be selected with confidence that all testing carried out is equivalent actual service conditions.

Besides, a component may be unaffected to an extreme condition when it is new, but may fail when it is subjected to the same condition after being used for a long period due to aging. This must be taken into consideration upon designing the test and interpreting the testing results.

A general discussion of severities was given i Part 1. Component qualification testing should normally not be performed at more severe conditions than the specified operating range. On the other hand, evaluation testing will be performed at more severe conditions than the specified operating range in order to determine the operational limits.

4.4 Selection of specimens

Unless the whole lot shall be subjected to testing, the sample must be representative of the whole lot. To find that sample the total quantity and the production process are important variables.

Besides, all components must be structurally similar. The term structurally similar components defines those components of style and variants that may be grouped together for the purpose of qualification approval and quality conformance inspection. The components are considered similar provided that they:

- are of common design and application and performance level,
- are such that the results of a given test, carried out on one of these components, can be regarded as valid for other structurally similar components,
- are produced by one manufacturer with essentially the same materials, processes, methods and at approximately the same time.
- utilise the same fibre retention technology
- utilise the same cable retention technology
- utilise the same alignment technic
- may accept various fibre or cable sizes

4.5 Test programme

The test normally fall into two broad categories: functional design criteria and performance criteria. Functional criteria are compared to the general design and stated features of the fibre optical components. Performance criteria are compared against the ability of the components to demonstrate their capabilities of minimising changes in the signal transmission, e.g. fibre attenuation, when subjected to physical and operational conditions.

The complete testing procedures shall describe: the purpose of testing, quality assurance measures, test methods, preparations, selection of specimen, testing equipment, succession of tests, severity of test parameters, duration, observations to be made, failure criteria and reporting. The testing strategies were discussed in the Part 2.

General procedures in connection with testing, such as requirements to the laboratory, measuring equipment, measurement accuracy, statistical analysis technique based on mathematical laws of probability to determine the size of the sample, are examples of aspects that have not been treated in this Report as they considered to be general to all testing activities going on in the ESA/SCC programme.

Visual inspection

The purpose of this test is to ensure that the specimen conforms to design, construction and marking requirements of the relevant specification. Optical inspections instruments may be used as appropriate.

The specimen is examined to ensure that it contains the proper number and types of components, that the workmanship is satisfactory and that the marking is correct.

Preconditioning

The relevant specification shall specify the preconditioning procedures.

Cleaning the optical surfaces is permitted as part of test preconditioning and recovery unless otherwise specified in the detail specification. Cleaning shall be in accordance with the instructions for use.

Standard conditions

The standard atmospheric conditions, including specimen recovery should be according to IEC 68-1. The relevant specification shall specify the preconditioning and recovery procedures.

All tests shall be performed at room temperature of 25°C ±5°C unless otherwise specified. The test instrumentation will be allowed to stabilise prior to any test measurement.

Post test investigations

The relevant specification shall specify the recovery procedures. In general a visual inspection shall be carried out after the specific test. The purpose of this inspection is to ensure that the specimen conforms to design, construction and marking requirements of the relevant specification, and to examine a specimen for change which may result from an environmental test. Optical inspections instruments may be used as appropriate. The specimen shall show no evidence of broken, deformed, or displaced parts. There shall neither be evidence of cracks, chips, or other damage which might be detrimental to normal operation of the specimen.

Only those parameters which have been specified in the detail specification and which were tested can be assumed to be within the specified limits. It should not be assumed that unspecified parameters will be uniform and unchanged from one component to another. If it should be necessary to control parameters, other than those specified, a new more extensive detail specification shall be written and used. The additional test method(s) shall be described and appropriate performance limits and assessment levels specified.

Failure criteria

No damage shall occur to the component that impairs the functional capabilities. A component shall be considered as failed if it exhibits one or more of specified failure modes given in the detail specification. In cases where a failed component can be allowed, this should be explicitly specified.

5.0 OPTICAL FIBRES

The various applicable test methods have been categorised as geometrical, optical, mechanical and environmental tests and are listed in Tables 5.1 through 5.4, respectively.

5.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
5.1.1 5.1.2 5.1.3	Diameter of core	IEC-793-1-A1 IEC-793-1-A2 IEC-793-1-A3	Refracted near field Near field light distrib. Four concentric circles
5.1.4 5.1.5 5.1.6 5.1.7	Diameter of cladding	IEC-793-1-A1 IEC-793-1-A2 IEC-793-1-A3 IEC-793-1-A4	As above " " Mechanical
5.1.8 5.1.9	Diameter of primary coating and buffers	IEC-793-1-A2 IEC-793-1-A4	As above "
5.1.10 5.1.11 5.1.12 5.1.13	Non-circularities	IEC-793-1-A1 IEC-793-1-A2 IEC-793-1-A3 IEC-793-1-A4	As above " " "
5.1.14 5.1.15 5.1.16	Concentricity errors	IEC-793-1-A1 IEC-793-1-A2 IEC-793-1-A3	As above " "
5.1.17	Length of fibre	IEC-793-1-A6	Delay of transmitted and/or reflected pulse

Table 5.1 Tests for geometrical characteristics of an optical fibre

The appropriate IEC tests have been found applicable. It can be noted that method IEC-793-1-A3, Four concentric circles, cannot be used for an accurate determination of dimensions. The purpose of the test is to determine if the fibre dimensions are within the specified limits (including tolerances).

Length of fibre can also be determined by standard mechanical measurement methods, and such methods will be most suitable for short fibre lengths. The method listed can be used to determine the length of fibre on a spool without unwinding.

5.2 Test methods for optical properties

Test	Characteristics	Test method	Remarks
5.2.1 5.2.2 5.2.3	Attenuation	IEC 793-1-C1A IEC 793-1-C1B IEC 793-1-C1C	Cut back Insertion loss Backscattering (OTDR)
5.2.4 5.2.5 5.2.6	Bandwidth	IEC 793-1-C2A IEC 793-1-C2B IEC 793-1-C5	Impulse response Frequency response Pulse delay, phase shift
5.2.7	Continuity	IEC 793-1-C4	
5.2.8 5.2.9	Change in optical transmittance	IEC 793-1-C10A IEC 793-1-C10B	Transmission Backscattering
5.2.10	Polarization cross-coupling	See 5.2.4	
5.2.11	Beat length	See 5.2.5	
5.2.12	Numerical aperture	IEC 793-1-C6	
5.2.13	Cut off wavelength	IEC 793-1-C7	
5.2.14	Mode field diameter	IEC 793-1-C9	
 5.2.15 5.2.16	Bending sensitivity: Macrobending Microbending	 EIA-455-62 IEC 793-1-C3	 In draft form
5.2.17	Optical power handling capability	See 5.2.6	

Table 5.2 Test methods for optical characteristics of an optical fibre

5.2.1 Attenuation

Test methods IEC 793-1-C1A (cut-back) and IEC 793-1-C1B (insertion loss) are suitable for both spectral loss measurements and measurements at one or several discrete wavelengths. Method IEC 793-1-C1C (backscattering) will usually in practice be limited to determining the attenuation in the wavelength regions of 850 nm, 1300 nm and 1550 nm where suitable semiconductor laser sources needed in the measurement apparatus, are easily available. Applicable laser sources for other wavelengths do, however, exist.

5.2.2 Bandwidth

In principle, all three methods listed can be used for determining the bandwidth of both multimode and singlemode fibres. However, methods IEC 793-1-C2A and IEC 793-1-C2B are most suitable for multimode fibres, and method IEC 793-1-C5 is most suitable for singlemode fibres.

5.2.3 Continuity/change in optical transmittance

These methods are auxiliary test methods used in the mechanical and environmental tests to look for fibre break or change in transmission loss during or after the fibre is subjected to the applicable load. They will be used when such measurements are to done.

5.2.4 Polarization cross-coupling

The recognised standards bodies have as of yet not considered a method for determining the polarization cross-coupling in a birefringent fibre. The method described here is the method generally used by those working with birefringent fibres [1, 2].

Test method for determining cross-coupling in birefringent fibres

Purpose
To determine the amount of coupling of light from one axis to the other axis in a birefringent fibre.

Test arrangement
A schematic of the test arrangement is shown in Fig. 5.1.

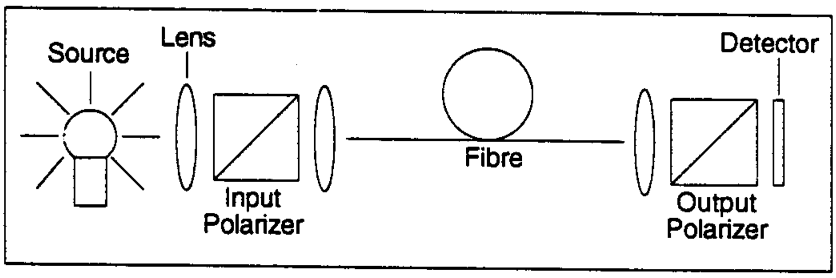

Figure 5.1 Schematic of test arrangement [2]

Test sample
If not otherwise specified, the sample length should be sufficient to achieve a measurable cross-coupling. However, the length need not be longer than the length required for the intended application. The sample can be coiled or loosely wound on a drum. Minimum diameter 30 cm, unless otherwise specified.

Procedure
Linearly polarized light at the specified wavelength is coupled in along one of the fibre axis and the direct and cross-coupled power is measured at the output end by rotating the output polarizer for maximum and minimum transmission. The measurement should be made for light input at both axes (x- and y-axis).

The degree of cross-coupling can be given either as

a) The extinction ratio = $P_{min} / (P_{min} + P_{max})$

where P_{min} and P_{max} are minimum and maximum output power when the output polarizer is rotated 360 degrees.

b) The h-parameter where $h = 1/L \tanh^{-1} (P_y / P_x)$

where L is the fibre length, P_x the power exiting in the axis to which it was coupled and P_y the power exiting in the other axis.

Results
The following data shall be given:
- Fibre length.
- Diameter of spool or coil.
- Wavelength.
- Type of light source.
- Extinction ratio and/or h-parameter.

5.2.5 Beat length

The beat length is defined as

$$\text{Beat length} = 2\pi / (\beta_1 - \beta_2)$$

where β_1 and β_2 are the propagation constants of the two polarization modes in a birefringent fibre.

No method has of yet been recommended by the recognised standards organisations for measuring beat length. Several methods exist and the one being proposed here is regarded as the simplest one. It is based on the fact that the amplitude of the radially scattered light depends on the polarization of the transmitted light [3].

Test method for determining beat length in a birefringent fibre

Purpose
To determine the beat length of the fibre.

Test arrangement
A linearly polarized monochromatic light source and means for coupling the light into the fibre is needed. The light source should preferably operate at the wavelength for which the beat length is specified. But a light source operating at another wavelength may be used and the result converted to the specified wavelength. A convenient light source may be a HeNe laser operating at 6328Å.

Test sample
Sufficient fibre length to achieve at least ten beat lengths if not otherwise specified.

Procedure
The linearly polarized light is launched into the fibre at an angle of 45° to the principle transverse axis. The radially scattered light is observed, and the distance between adjacent light minima is

measured. This distance is equal to the beat length.

If the measurement is not made at the specified wavelength, the beat length at the specified wavelength, λ_s, can be found from:

$$\text{Beat length } (\lambda_s) = \lambda_s/\lambda_m \times \text{Beat length } (\lambda_m)$$

Here λ_m is the measurement wavelength.

Results
The following data shall be given:
- Fibre length.
- Measurement wavelength.
- Type of light source.
- Number of minima over which the measurement was made.
- Measured (and converted) beat length.

5.2.6 Optical power handling capability

As discussed in the Part 2 several effects may limit the power handling capability of a fibre. High power levels may cause physical damage to the fibre, and non-linear optical effects may cause signal distortion and/or conversion of signal to other wavelengths. No method has of yet been recommended by recognised standards organisations.

Test method for optical power handling capability

Purpose
To determine if the fibre can handle the specified input optical power.

Test arrangement
A schematic of the test arrangement is shown in Fig. 5.2.

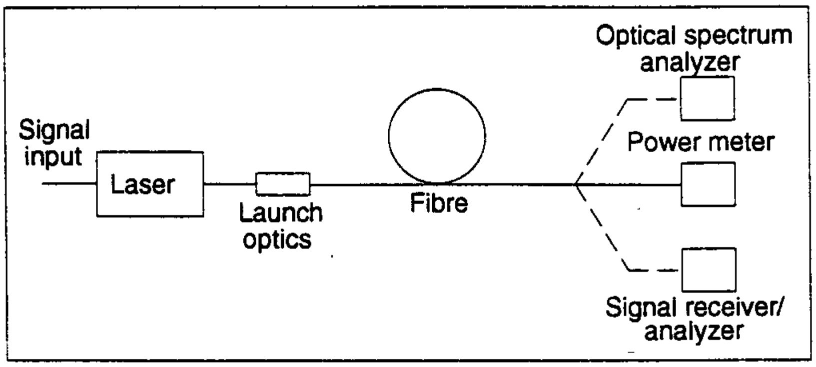

Figure 5.2 Arrangement to test optical power handling capability

The laser source should operate on the same wavelength and have the same spectral character as the source in the intended application. Available input power must be at least equal to specified maximum power handling level for the fibre. The necessary equipment on the output side will depend on the application and specification of the fibre. If the fibre is being used just for conducting optical power, the optical output power and the spectral character of the output should be measured unless otherwise specified. If the fibre is used for signal transmission, any power dependent signal distortion should also be determined.

Test sample
The fibre length should be representative for the application or as specified.

Procedure
The input power to the fibre should be increased in steps to the specified power level and measurements made as appropriate of:
- Output power versus input power.
- Spectral character of output signal versus input power.
- Bit error rate/signal to noise ratio versus input power.

The entrance and exit surfaces should be examined for any physical damage.

Results
The following data should be given if not otherwise specified:
- Fibre length.
- Specification of laser source (wavelength, bandwidth, continuous, pulsed).
- Output power versus input power.
- Spectral character of output power versus input power.
- Signal distortion (bit error rate/signal to noise ratio as appropriate) versus input power (if required).
- Any damage to entrance and exit surfaces and the input power level at which damage was observed.

5.3 Test methods for mechanical properties

Test	Characteristics	Test method	Remarks
5.3.1	Tensile strength	IEC 793-1-B2A	Short lengths. Long lengths under consideration.
5.3.2	Bending	IEC 794-1-E11	
5.3.3	Proof test	IEC 793-1-B1	
5.3.4	Strippability	See 5.3.1	
5.3.5	Abrasion	EIA-455-66	For buffers and coatings
5.3.6	Crush	IEC 794-1-E3	
5.3.7	Impact	IEC 794-1-E4	
5.3.8	Torsion	IEC 794-1-E7	
5.3.9	Flexing	IEC 794-1-E8	
5.3.10	Snatch	IEC 794-1-E9	
5.3.11	Kink	IEC 794-1-E10	

Table 5.3 Test methods for mechanical characteristics of an optical fibre

5.3.1 Strippability

The IEC has issued a draft document with respect to determining optical fibre strippability. Reference: Committee 86A, Document 112. It is recommended this test method be used until the approved test method is published.

5.3.2 Bending, Crush, Impact, Torsion, Flexing, Snatch, Kink

The test methods recommended for these properties are the same as for fibre optic cables.

As discussed in the Part 2, tests for these properties are usually not performed for uncabled fibres. One exception being plastic fibres which will probably not be used in space due to their susceptibility to damage from ionizing radiation. IEC has in a draft document for plastic fibres specified the same test methods as for fibre optic cables for the properties being considered here.

In these tests measurements are usually made to determine if there is a fibre break and/or change in transmission loss, see 5.2.3.

5.4 Test methods for environmental properties

Test	Characteristics	Test method	Remarks
5.4.1	Temperature cycling	IEC 793-1-D1	
5.4.2	Vacuum test (including temperature cycling)	See 5.4.1	
5.4.3	Solar radiation	See 5.4.2	
5.4.4	UV radiation	See 5.4.3	
5.4.5	Ionizing radiation	See 5.4.4	
5.4.6	Ageing	See 5.4.5	

Table 5.4 Test methods for environmental characteristics of an optical fibre

5.4.1 Thermal vacuum test

Purpose
To determine how the exposure to vacuum and temperature cycling affect the performance of the optical fibre.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre to 125°C or as specified.
- Measurement equipment for determining the fibre attenuation at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer (if required)).
- A microscope or other suitable means for measuring coating diameter.

Test sample
A fibre length of at least 200 m or as specified.

Procedure
The outer diameter of the fibre with coating shall be measured on both sample ends. The attenuation of the fibre shall also be measured before the start of the test at the specified wavelength(s). The sample is then placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. The set temperature(s), stay time at each temperature and number of cycles shall be as specified in the detailed specification.

After completion of the test cycles, the sample shall be removed from the chamber and the attenuation measurement repeated. The outer diameter shall be measured at both sample ends, and a visual inspection shall be made to look for any damage or change in the fibre coating.

Results

The following data shall be given.

- Fibre length.
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Attenuation before and after test at the specified wavelength(s).
- Coating diameter before and after test.
- Result of visual inspection.

5.4.2 Solar radiation test

Purpose

To determine that the fibre can withstand exposure to the specified solar radiation level.

Test arrangement

The following equipment is needed:

- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample

A fibre length of at least 200 m or as specified.

Procedure

The fibre sample is placed in the test chamber and the fibre ends connected to the measurement equipment which is located outside the chamber. The fibre must be spread out so that the whole length is exposed to uniform radiation.

The fibre is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or change in the fibre coating.

Results

The following data shall be given:

- Fibre length.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

5.4.3. UV radiation test

Purpose

To determine that the fibre can withstand exposure to the specified UV radiation level.

Test arrangement

The following equipment is needed:

- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre ends to be connected to the measuring equipment outside the chamber.
- Measurement equipment for determining the change in transmission loss and spectral attenuation (if required) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample

A fibre length of at least 200 m or as specified.

Procedure

The spectral attenuation of the fibre shall be measured before the start of the test (if required). The sample is then placed in the chamber and the fibre ends connected to the transmission loss measurement equipment. The fibre must be spread out so that the whole length is exposed to uniform radiation. The fibre is then subjected to the specified irradiance level for the specified time. The transmitted power at the specified wavelength is monitored continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and the spectral attenuation measured (if required). Further, a visual inspection shall be made to look for any damage or change in the fibre coating.

Results

The following data shall be given:

- Fibre length.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Spectral attenuation curves before and after the test (if required).
- Result of visual inspection.

5.4.4 Test for ionizing radiation

It is recommended that test IEC 793-1-D3 be used, but with a few modifications. Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

5.4.5 Ageing test [5]

Purpose
To simulate long term (life time) degradation processes by subjecting the fibre to an extended exposure at a high temperature.

Test arrangement
The following equipment is needed:
- A temperature test chamber capable of maintaining a stable temperature over a long period. Max. temperature at least as specified for the test. The chamber must have appropriate ports to allow the fibre ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), power meter to monitor the transmitted power and launching optics.
- A microscope or other suitable means to measure coating diameter (if specified).

Test sample
A fibre length of at least 200 m or as specified

Procedure
The outer diameter of the coated fibre shall be measured at both ends before the test (if specified). The fibre sample is then placed in the chamber, and the fibre ends connected to the measurement equipment outside the chamber. The fibre is then heated to a temperature 10°C above maximum specified operating temperature if not otherwise specified and maintained at that temperature for 240 hours or as specified. (The results from the evaluation test of the particular component in question should be taken into account when determining test temperature and duration of test). The test is performed in dry air if not otherwise specified. The transmitted power at the specified wavelength is monitored continuously during the test. After the test is completed, the outer diameter of the coated fibre is again measured (if specified), and the fibre is visually inspected for damage or change in the fibre coating.

Results
The following data shall be given:
- Fibre length.
- Temperature and duration of test.
- Coating diameter before and after test (if required).
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

6.0 OPTICAL FIBRE CABLES

The various applicable test methods are categorised as geometrical, optical, mechanical and environmental tests and are listed in Tables 6.1 through 6.4 respectively.

6.1 Test methods for geometrical characteristics

Test	Characteristics:	Test method:	Remarks:
6.1.1	Length of cable	See 6.1.1	
6.1.2	Thickness of sheath	IEC publication 189, 540	Mechanical test method
6.1.3	Overall dimensions	IEC publication 189, 540	Mechanical test method
6.1.4	Fibre geometrises for cabled fibres are measured using the same methods as for the uncabled fibres, see 5.1.		
6.1.5	Mass		Measured as appropriate

Table 6.1 Test methods for geometrical characteristics of an optical fibre cable

6.1.1 Measuring of cable length

The cable length can be measured by various mechanical means. The fibre length in the cable can be measured by Test 5.1.17. The fibre length can, however, be longer than the cable length, depending on the cable design. This is the case for cables where the fibres are stranded and for cables where the fibres have purposely been given a so-called excess length. For such cables the measured fibre length has to be adjusted to arrive at the correct cable length.

6.2 Test methods for optical characteristics

Test	Characteristics:	Test method:	Remarks:
6.2.1 6.2.2 6.2.3	Attenuation	IEC 793-1-C1A IEC 793-1-C1B IEC-1-C1C	Cut back Insertion loss Backscattering (OTDR)
6.2.4	Cut-off wavelength	IEC 793-1-C7	
6.2.5	Continuity	IEC 793-1-C4	
6.2.6 6.2.7	Change in optical transmission	IEC 793-1-C10A IEC 793-1-C10B	Transmission Backscattering

Table 6.2 Test methods for optical characteristics of an optical fibre cable

Of the optical characteristics only the attenuation and cut-off wavelength will be significantly affected by the cabling process. Methods for determining the other optical characteristics of the fibres are given in Ch. 5. These methods are of course also applicable to cabled fibres.

6.2.1 Attenuation

Test method IEC 793-1-C1A (cut back) and IEC 793-1-C1B (insertion loss) are suitable for both spectral loss measurements and measurements at one or more discrete wavelengths. Method IEC 793-1-C1C (backscattering) is for practical purposes limited to determining the attenuation in the wavelength regions of 850 nm, 1300 nm and 1550 nm due to availability of equipment.

6.2.2. Continuity/change in optical transmission

These test methods are to be used when it is required to measure change in transmission including possible fibre break, in the various mechanical and environmental tests.

6.3 Test methods for mechanical characteristics

Test	Characteristics:	Test method	Remarks:
6.3.1	Tensile strength	IEC 794-1-E1	
6.3.2	Abrasion	IEC 794-1-E2	In draft form
6.3.3	Crush	IEC 794-1-E3	
6.3.4	Impact	IEC 794-1-E4	
6.3.5	Repeated bending	IEC 794-1-E6	
6.3.6	Torsion	IEC 794-1-E7	
6.3.7	Flexing	IEC 794-1-E8	
6.3.8	Snatch	IEC 794-1-E9	
6.3.9	Kink	IEC 794-1-E10	
6.3.10	Bend under tension	IEC 794-1-E11	
6.3.11	Vibration	EIA-455-11A	
6.3.12	Cold bend	IEC 794-1-E11 Clause 20.7	

Table 6.3 Test methods for mechanical characteristics of an optical fibre cable.

6.3.1 Test severities

In the listed test methods recommended severity classes are sometimes given. These might not always be applicable to space applications, and the test severities should be as stated in the detail specifications.

6.3.2 Abrasion

The test listed is quite similar to the one being used for electrical cables, see ESA SCC Generic Specification 3901, Para. 9.23. The cable surface is abraded by a steel needle. Another test which more simulate a rubbing action can be found in MIL-SPEC DOD-C-00850458 (EC), para. 4.7.33. The IEC-test has been chosen so that the fibre optic cables are subjected to a similar test as electrical cables.

6.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks:
6.4.1	Temperature cycling	IEC 794-1-F1	
6.4.2	Rapid change of temperature	See 6.4.1	
6.4.3	Vacuum test (including temperature cycling)	See 6.4.2	
6.4.4	Solar radiation	See 6.4.3	
6.4.5	UV radiation	See 6.4.4	
6.4.6	Ionizing radiation	See 6.4.5	
6.4.7	Flammability	MIL-STD DOD-STD-1678 Test method 5010	See 6.4.6
6.4.8	Ageing	See 6.4.7	
6.4.9	Rapid depressurisation	See 6.4.8	
6.4.10	Resistance to fluids	MIL-STD DOD-STD 1678 Test method 8030	

Table 6.4 Test methods for environmental characteristics of an optical fibre cable.

6.4.1 Rapid change of temperature

The recommended test method is EIA/TIA-455-71 with the following modifications:

- The temperatures of the two chambers, one at high and one at low temperature, shall be as specified.
- The transfer time between the two chambers at high and low temperature shall be as specified.
- The transmitted power at the specified wavelength shall be recorded continuously throughout the test including during the transfer between chambers.

6.4.2 Thermal vacuum test

Purpose
To determine the ability of the optical cable to operate in vacuum under varying temperatures.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the cable to 125°C or as specified. The test chamber must have appropriate ports (feed-throughs) to allow the fibre ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength f.inst. a stabilised LED, optical power meter to monitor the transmitted power and launching optics.
- Means for measuring cable diameter and sheath thickness.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The outer diameter and cable sheath thickness shall be measured before the test. The cable sample is then placed in the chamber and the fibre ends connected to the measurement equipment located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable ends shall be located inside the chamber, unless otherwise specified, and connected to the outside via short fibre lengths. It must be ensured that no losses are induced in the feedthroughs or in any splices located inside the chamber during the test.The chamber is evacuated and the sample subjected to the specified temperature cycles. The transmission through the fibre loop(s) shall be measured continuously during the test. The set temperature(s), stay time at each temperature and number of cycles shall be as specified in the detailed specification.

After the completion of the test cycles, the sample shall be removed from the chamber. The cable diameter and cable sheath thickness shall be measured, and a visual inspection made to look for any damage or change in cable structure and cable materials.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Change in attenuation during the test at the specified wavelength.
- Cable diameter and cable sheath thickness before and after the test.
- Result of visual inspection.

6.4.3 Solar radiation test

Purpose
To determine that the cable can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the cable to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The cable sample is placed in the test chamber and the fibre ends connected to the measurement equipment which is located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable must be spread out so that the whole length is exposed to uniform radiation. Splices and fibre(s) should be shielded from the sun radiation to avoid any risk of radiation induced losses.

The cable is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or change in the outer cable jacket.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

6.4.4 UV radiation test

Purpose
To determine that the cable can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating UV radiation and capable of emitting sufficient power in the specified spectral range to expose the cable to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The cable sample is placed in the test chamber and the fibre ends connected to the measurement equipment which is located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable must be spread out so that the whole length is exposed to uniform radiation. Splices and uncabled fibres should be shielded from the UV radiation to avoid UV induced losses.

The cable is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or change in the outer cable jacket.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

6.4.5 Test for ionizing radiation

It is recommended that test IEC 793-1-D3 be used, but with a few modifications. Two somewhat different test procedures are described in the IEC test, one for low level of radiation (background radiation) one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed, but with a different total dose/dose rate combination. Unless otherwise specified one of the following total dose/dose rate combinations are recommended [4]:

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Several fibres in the cable may be looped for the transmission loss environment. The total fibre length should be at least 200 m. The cable length should not be less than 50 m.

The cable dimension (outer diameter, sheath thickness etc.) shall be measured before and after the exposure. In addition a visual inspection shall be made of the cable after the test.

It should be noted that the ionizing radiation can be expected to induce losses in the fibres. If the purpose of the test is to determine losses caused by radiation induced changes in the cable materials or structure, the losses induced directly in the fibre must be subtracted.

6.4.6 Flammability test

The recommended test method is quite similar to the one specified for electrical cables, see ESA SCC Generic Specification No., 3901, Para. 9.20. It has also been used in a recent NASA study of fibre optic cables for space use [6]. The purpose of the test is to determine the flammability of the cable, and if the cable when subjected to a flame, will cause sparking, sputtering or dripping of flaming particles.

Should there also be a requirement for measuring the optical transmission properties of the cable during the test, a somewhat longer cable specimen (specified length is 600 mm) may be needed or some type of tubing may be required at the sample ends to protect the fibres from the flame.

6.4.7 Ageing test [7]

Purpose
To simulate long term (life time) degradation processes by subjecting the cable to an extended exposure at a high temperature.

Test arrangement
The following equipment is needed:
- A temperature test chamber capable of maintaining a stable temperature over a long period. Max. temperature at least as specified for the test. The chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), power meter to monitor the transmitted power and launching optics.
- Means for measuring cable diameter and sheath thickness.

Test sample
A cable length of at least 50 m, but sufficient to give a looped length of at least 200 m, or as specified.

Procedure
The cable diameter and sheath thickness shall be measured at both ends before the test. The sample is then placed in the chamber, and the fibre ends connected to the measurement equipment outside the chamber. For multifibre cables several fibres can be looped, and when applicable, at least four fibres shall be included in the test.

The cable is then heated to a temperature 10°C above maximum specified operating temperature if not otherwise specified and maintained at that temperature for 240 hours or as specified. (The results from the evaluation test of the particular component in question should be taken into account when determining test temperature and duration of test). The test is performed in dry air if not otherwise specified. The transmitted power at the specified wavelength is monitored continuously during the test. After the test is completed, the outer cable diameter and sheath thickness is again measured, and the cable is visually inspected for damage or change in the cable structure.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Temperature and duration of test.
- Cable diameter and sheath thickness before and after test.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

6.4.8 Rapid depressurisation test

Purpose
To determine the performance of the fibre optic cable when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power and launching optics.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The outer dimensions shall be measured at both ends of the cable samples before the test starts. The sample is then placed in the test chamber and the fibre ends connected to the measurement equipment located outside the chamber. For multifibre cables several fibres can be looped, and when applicable, at least four fibres shall be subjected to the test. The cable ends shall be located inside the chamber, unless otherwise specified, and connected to the outside via short fibre lengths spliced to the fibre(s) under test.

The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The transmitted power at the specified wavelength shall be recorded continuously during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the cable is removed from the chamber, the outer dimensions of the cable measured, and a visual inspection made to look for any damage or change in the cable structure.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.

- Rate of pressure fall and minimum pressure.
- Change in attenuation during the test at the specified wavelength.
- Outer cable dimensions before and after the test.
- Result of visual inspection.

6.4.9 Resistance to fluids

The proposed test method is quite similar to the one used for electrical cables, see ESA SCC Generic Specification No. 3901, para. 9.21. The type of fluids, temperature and duration of immersion shall be as given in the detail specification. A representative list can be found in the just referenced para. 9.21.

7.0 FIBRE OPTIC CONNECTORS

7.1 Test methods for geometrical characteristics

Test	Characteristics:	Test method:	Remarks:
7.1.1	Outside diameter of cylindrical object	IEC-874-1 clause 26.1	
7.1.2	Inside diameter of cylindrical object	IEC-874-1 clause 26.2	
7.1.3	Outside diameter of rectangular object	IEC-874-1 clause 26.3	
7.1.4	Inside diameter of rectangular object	IEC-874-1 clause 26.4	
7.1.5	Mass		As appropriate

Table 7.1 Test methods for geometrical characteristics of a fibre optic connector

The test methods referenced include different methods to measure inside and outside dimensions, of which one method describes how to assess the shape deviation from an ideal circle or rectangle, as appropriate.

7.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
7.2.1	Insertion loss	IEC 874-1 clause 27.1	See 7.2.1
7.2.2	Cross talk	IEC 874-1 clause 27.2	
7.2.3	Susceptibility to ambient light coupling	IEC 874-1 clause 27.3	
7.2.4	Return loss	IEC 874-1 clause 27.4	
7.2.5	Modal distribution	See. 7.2.2	
7.2.6	Spectral loss	IEC 874-1 clause 27.6	
7.2.7	Optical power handling capability	See 7.2.3	

Table 7.2 Test methods for optical characteristics of a fibre optic connector.

7.2.1 Insertion loss

The referenced tests include several methods for measuring the insertion loss of a fibre optic connector depending on the configuration of the connector supplied for the test. The connectors could be supplied as individual components which are to be mounted to a fibre/cable as part of the test procedure, or the connectors could be mounted to a fibre/cable with a bare fibre or another connector in the other end.

7.2.2 Modal distribution

In multimode fibre optic connectors the insertion loss may depend on the modal distribution in the fibre. The dependence on modal distribution may be a function of mechanical tolerances, but also be affected by mode-mixing in the connector, for instance in connectors based on lens coupling. The standards organisations have not yet suggested a test for dependence on modal distribution. The method suggested here will give an indication of the difference in loss when all modes are excited in the fibre and when the modal distribution is at its so-called equilibrium. These two situations may occur in short and long line length systems respectively.

Modal distribution test

Purpose
The purpose of the test is to determine how the insertion loss varies for two different modal distributions (fully filled and equilibrium) of the incoming light. The test is only applicable to multimode fibres.

Test arrangement
An appropriate method for measuring the insertion loss of a connector is chosen according to Test 7.2.1. The measurement equipment shall include means for achieving equilibrium and fully filled mode distribution. The measurements shall be performed at the specified wavelength(s)

Test procedure
- Launch light into the fibre to achieve the fully filled mode distribution
- Use one of the methods described in Test 7.2.1 to measure the insertion loss, but mate and remate the connector 10 times, or as specified, to get an indication of the variations in insertion loss before the absolute insertion loss is measured
- Repeat the procedure for equilibrium mode distribution

Results
The following data shall be recorded unless otherwise specified.
- Light source (peak wavelength, line width).
- Description of arrangement for launching light into the fibre.
- Method used to measure insertion loss.
- The absolute insertion loss at each mode distribution.
- The variation in insertion loss at each mode distribution.

7.2.3 Optical power handling capability

Excessive levels of optical power may induce failures in a fibre optic connector due to heat generated by the absorbed radiation. A test method for optical power handling capability has not yet been considered by recognised standards organisations.

Optical power handling capability test

Purpose
To determine if the connector can handle the specified input optical power.

Test arrangement
The following equipment is needed:
- A laser source which should operate on the same wavelength and have the same spectral character as the source in the intended application. Available input power must be at least equal to specified maximum power handling level for the connector.
- Means to monitor output power versus input power to observe any variations in insertion loss.

Test sample
The connector should be representative for the application or as specified.

Procedure
The input power to the connector should be increased in steps to the specified power level and measurements made of output power versus input power. The entrance and exit surfaces should be examined for any physical damage.

Results
The following data should be given if not otherwise specified:
- Specification of laser source (wavelength, bandwidth, continuous, pulsed).
- Output power versus input power.
- Any damage to entrance and exit surface and the input power level at which damage was observed.

7.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
7.3.1	Fibre or ferrule retention	IEC 874-1 clause 28.4	
7.3.2	Static load	IEC 874-1 clause 28.5	
7.3.3	Engagement and separation force	IEC 874-1 clause 28.6	
7.3.4	Strength of cable retention and cable entry - pulling - torsion - flex/bending/nutation	 IEC 874-1 clause 28.7.2 IEC 874-1 clause 28.7.3 IEC 1073-1 clause 3.6.8	 See 7.3.2
7.3.5	Strength of coupling mechanism	IEC 874-1 clause 28.8	
7.3.6	Gauge retention force	IEC-874-1 clause 28.3	
7.3.7	Bending moment	IEC 874-1 clause 28.9	
7.3.8	Crush resistant	IEC 874-1 clause 28.12	
7.3.9	Bump	IEC 874-1 clause 28.10	
7.3.10	Axial compression	IEC 874-1 clause 28.13	
7.3.11	Impact	IEC 874-1 clause 28.14	
7.3.12	Acceleration	IEC 874-1 clause 28.15	
7.3.13	Connector drop (with cable)	IEC 874-1 clause 28.17	
7.3.14	Vibration	IEC 874-1 clause 28.2	
7.3.15	Shock	IEC 874-1 clause 28.11	

Table 7.3 Test methods for mechanical properties of a fibre optic connector

7.3.1 Test severities

The mechanical test methods referenced include preferred combinations of test parameters (level of vibration, shock, acceleration, impact etc.). In those cases where these levels do not fulfil the requirements in the detail specification, the test severities should be adjusted accordingly. This will not, however, change the test procedures.

7.3.2 Strength of cable retention, cable entry

A test for cable bend/flex/nutation is not included in IEC 874. We have chosen to apply the recommended test for cable bending for fibre optic splices. This test covers the same characteristics for fibre optic connector as for fibre optic splices (or any other fibre optic component with cable attachment). In this way the same standard test procedure for cable attachment is used for all components.

7.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
7.4.1	Climatic sequence	IEC 874-1 clause 29.5	
7.4.2	Temperature extremes	IEC 874-1 clause 29.5	See 7.4.1
7.4.3	Rapid change in temperature	IEC 874-1 clause 29.7	See 7.4.2
7.4.4	Vacuum test (including temperature cycling)	See 7.4.3	
7.4.5	Condensation	IEC 874-1 clause 29.6	
7.4.6	Corrosive atmosphere	IEC 874-1 clause 29.9	not considered applicable
7.4.7	Dust	IEC 874-1 clause 29.10	not considered applicable
7.4.8	Flammability	IEC 874-1 clause 29.12	
7.4.9	Sealing	IEC 874-1 clause 29.8	
7.4.10	Solar radiation	See 7.4.4	
7.4.11	UV radiation	See 7.4.5	
7.4.12	Ionizing radiation	See 7.4.6	
7.4.13	Mechanical endurance	IEC 874-1 clause 30	
7.4.14	Rapid depressurisation	See 7.4.7	
7.4.15	Ageing	IEC 874-1, clause 31	
7.4.16	Intermateability	See 7.4.8	
7.4.17	Resistance to solvents and contaminating fluids	IEC 874-1 clause 32	See 7.4.9

Table 7.4 Environmental characteristics of a fibre optic connectors.

7.4.1 Temperature extremes

The recommended test method is the same as for climatic sequence, but with the test sequence adapted to the temperature extreme test requirements. The temperature and duration of stay at each temperature should be specified by the detail specification.

7.4.2 Rapid change in temperature

The recommended test procedure is applicable with the following modifications:
- The change in transmittance shall be monitored during the whole test, including during the transfer between the two chambers of high and low temperatures.
- High and low temperature, temperature change rate and number of cycles should be given in detail specification.

7.4.3 Vacuum test (including temperature cycling)

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the connector.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic connector to 125°C or as specified.
- Measurement equipment for determining the insertion loss at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer (if required)).

Test sample
A fibre optic connector representative for the application or as specified.

Procedure
The dimensions of the connector and the dimension of any strain relief mechanism etc. shall be measured prior to evacuation. The insertion loss of the fibre optic connector shall also be measured before the test to verify the performance of the connector.

The sample is placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. The insertion loss is measured after the test is completed. The dimensions shall be measured and a visual inspection made to look for any damage or change in appearance.

The set temperature(s), duration of test at each temperature and number of cycles shall be as specified in the detail specification.

Results
The following data shall be given
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Insertion loss before and after test cycle.
- Result of visual inspection/geometrical control.

7.4.4 Solar radiation

A test with respect to solar radiation is described by IEC (IEC 874-1, clause 29.15). We have, however, not found this test quite suitable to cover all aspects of testing with respect to solar radiation. We propose the following test procedure:

Solar radiation test

Purpose
The purpose of the test is to determine that the fibre optic connector can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic connector to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A fibre optic connector representative for the application or as specified.

Procedure
The insertion loss is measured prior to irradiation at the specified wavelength(s). The fibre optic connector sample is placed in the test chamber and the pigtails connected to the measurement equipment which is located outside the chamber.

The fibre optic connector is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or changes in appearance.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss before test.
- Change in transmission during the test at the specified wavelength.
- Result of visual inspection.

7.4.5. UV radiation test

Purpose
To determine that the fibre optic connector can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic connector to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber

- Measurement equipment for determining the change in transmission loss and spectral attenuation (if required) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample
A fibre optic connector representative for the application or as specified.

Procedure
The insertion loss shall be measured at the specified wavelength(s) prior to irradiation. Spectral loss shall be measured before the start of the test if required. The sample is then placed in the chamber and the fibre ends connected to the transmission loss measurement equipment. The sample is then subjected to the specified irradiance level for the specified time. The transmitted power at the specified wavelength(s) is monitored continuously during the exposure. After completion of exposure the sample shall be removed from the chamber and the spectral loss measured (if required). Further, a visual inspection shall be made to look for any damage or changes in appearance.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss before exposure.
- Change in transmission during the test at the specified wavelength(s).
- Spectral insertion loss curves before and after the test (if required).
- Result of visual inspection.

7.4.6. Ionizing radiation

No test method exist for testing with respect to ionizing radiation. The test recommended for optical fibres (IEC 793-1-D3) could be used with a few modification. These modifications are:

Dose rate/total dose level
Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample
A connector representative for the application or as specified. The fibre attached to the connector should be characterised with respect to ionizing radiation in advance to be able to separate the effects of ionizing radiation related to the connector from the effects related to the fibre.

Measurements
The insertion loss shall be measured at the specified wavelength(s) before the sample is irradiated. If required the spectral loss shall be measured. During irradiation the transmission shall be monitored at the specified wavelength(s). If required the spectral loss shall also be measured after the irradiation. The connector shall be visually inspected before and after irradiation to look for changes in structure or appearance.

7.4.7 Rapid depressurisation

Purpose
To determine the performance of the fibre optic connector when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow the pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED). Optical power meter to monitor the transmitted power and launching optics.

Test sample
A fibre optic connector representative of the application or as specified.

Procedure
The connector is visually inspected and the geometrical dimensions are measured before depressurisation. The insertion loss is also measured. The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The transmitted power at the specified wavelength(s) shall be recorded continuously during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the connector is removed from the chamber, the geometrical dimensions of the connector are measured, and a visual inspection made to look for any damage or change in appearance or structure.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Insertion loss prior to depressurisation.
- Change in transmitted power during the test at the specified wavelength.
- Geometrical dimensions before and after test.
- Result of visual inspection.

7.4.8. Intermateability test

Purpose
The purpose of the test is to determine whether or not the connector can be mated with connectors of the same type, but manufactured by other producers or in another production batch.

Test arrangement

The following equipment is needed:

- Preferable a sample of the fibre optic connector used as a reference standard. If this is not available, fibre optic connectors of the same type from other manufacturers.
- Equipment to measure the engagement and separation forces and insertion loss.

Test sample

A connector representative of the application or as specified.

Test procedure

The connector under test shall be mated with the reference connector and the engagement forces measured. The insertion loss shall be measured at the specified wavelength(s) and the connectors separated. The connectors shall be visually inspected to look for damage or changes in appearance or structure. The test shall be repeated the specified number of times. The procedure shall be repeated for all reference connectors.

Results

The following data shall be recorded.

- Type of reference connector(s).
- Engagement and separation forces.
- Insertion loss at specified wavelength(s).
- Number of matings.
- Result of visual inspection.

7.4.9 Resistance to solvents and contaminating liquids

The referenced test is applicable with the following modification:

- The type of fluids, temperature and duration of immersion shall be as specified in detail specification.

7.4.10 Test severities

In the referenced test methods preferred combinations of parameter severities and duration of load are usually given. These combinations may not be adequate for space application and the values specified in detail specification should be used.

8 FIBRE OPTIC SPLICES

8.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
8.1.1	Outline dimensions	IEC 1073-1 clause 3.4	Measured according to detail specifications or as appropriate
8.1.2	Mass		Measured as appropriate

Table 8.1 Test methods for geometrical characteristics of a fibre optic splice.

8.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
8.2.1	Insertion loss	IEC 1073-1 clause 3.5.1	See 8.2.1
8.2.2	Return loss (reflected power)	IEC 1073-1 clause 3.5.4	
8.2.3	Crosstalk	IEC 1073-1 clause 3.5.2	For multiple splices only
8.2.4	Susceptibility to ambient light coupling	IEC 1073-1 clause 3.5.3	
8.2.5	Spectral dependence of insertion loss	IEC 1073-1 clause 3.5.6	
8.2.6	Optical power handling capability	See 8.2.2	
8.2.7	Monitoring technique	IEC 1073-1 clause 3.5.7	

Table 8.2 Test methods for optical characteristics of a fibre optic splice.

8.2.1 Insertion loss

The referenced test includes several methods for measuring the insertion loss of fibre optic splices. The method should be chosen on basis of type of splice supplied for test, desired accuracy and number of splices to measured successively in a fibre link. It should be noted that the IEC have included a method to measure insertion loss based on bidirectional OTDR (Optical Time Domain Reflectrometry), which allows a non-destructive measurement to be made.

8.2.2 Optical power handling capability

Excessive levels of optical power may induce failures in a fibre optic splice due to heat generated by the absorbed radiation. A test method for optical power handling capability has not been considered by recognised standards organisations.

Optical power handling capability test

Purpose
To determine if the fibre optic splice can handle the specified input optical power.

Test arrangement
The following equipment is needed:
- A laser source which should operate on the same wavelength and have the same spectral character as the source in the intended application. Available input power must be at least equal to specified maximum power handling level for the splice.
- Means to monitor output power versus input power to observe any variation in insertion loss.

Test sample
The splice should be representative for the application or as specified.

Procedure
A visual inspection shall be made prior to the test. The input power to the splice should be increased in steps to the specified power level and measurements made of output power versus input power. A visual inspection shall be made at each step in optical power to look for damage or change in appearance or structure.

Results
The following data should be given if not otherwise specified:
- Specification of laser source (wavelength, bandwidth, continuous, pulsed).
- Output power versus input power.
- Result of visual inspection.

8.2.3 Monitoring technique

The referenced test method is used when the parameter of interest is the variation or change in insertion loss and not the absolute value. The method is used to monitor the transmitted power during various environmental and mechanical tests.

8.3 Test method for mechanical characteristics

Test	Characteristics	Test method	Remarks
8.3.1	Tensile strength/proof test	IEC 1073-1 clause 3.6.3	
8.3.2	Effectiveness of clamping device against - fibre/cable pulling - fibre/cable bending - fibre/cable torsion	 IEC 1073-1 clause 3.6.8.2 IEC 1073-1 clause 3.6.8.4 IEC 1073-1 clause 3.6.8.3	 See 8.3.2 " "
8.3.3	Vibration	IEC 1073-1 clause 3.6.2	
8.3.4	Shock	IEC 1073-1 clause 3.6.10	
8.3.5	Acceleration	IEC 1073-1 clause 3.6.14	
8.3.6	Crush resistance	IEC 1073-1 clause 3.6.11	
8.3.7	Impact	IEC 1073-1 clause 3.6.13	
8.3.8	Drop	IEC 874-1 clause 28.17	See 8.3.3
8.3.9	Bump	IEC 1073-1 clause 3.6.9	
8.3.10	Axial compression	IEC 1073-1 clause 3.6.12	

Table 8.3 Test methods for mechanical characteristics of a fibre optic splice.

8.3.1 Test severities

The mechanical test methods referenced include preferred combinations of test parameters (level of vibration, shock, acceleration, impact etc.). In those cases where these levels do not fulfil the requirements in the detail specification, the test severities should be adjusted accordingly. This will not, however, change the test procedures.

8.3.2 Strength of cable/fibre entry

In those cases where the splice has separate fibre and cable retention, IEC specifies a separate test method for strength of fibre entry (IEC 1073-1 clause 3.6.4). This method is however the same as for strength of cable entry with the exception that the force/torque/bending moment is applied to the fibre entry instead of the cable entry.

8.3.3 Drop

The IEC does not propose any test for drop of splice. The test method used for fibre optic connectors could, however, also be used for drop testing of fibre optic splices.

8.4 Test method for environmental characteristics

Test	Characteristics	Test method	Remarks
8.4.1	Climatic sequence	IEC 1073-1 clause 3.7.5	
8.4.2	Temperature extremes	IEC 1073-1 clause 3.7.5	See 8.4.1
8.4.3	Rapid change in temperature	IEC 1073-1 clause 3.7.7	See 8.4.2
8.4.4	Vacuum test (including temperature cycling)	See 8.4.3	
8.4.5	Condensation	IEC 1073-1 clause 3.7.6	
8.4.6	Corrosive atmosphere	IEC 1073-1 clause 3.7.8	not considered applicable
8.4.7	Dust	IEC 1073-1 clause 3.7.9	not considered applicable
8.4.8	Flammability	IEC 1073-1 clause 3.7.11	
8.4.9	Solar radiation	See 8.4.4	
8.4.10	UV radiation	See 8.4.5	
8.4.11	Ionizing radiation	See 8.4.6	
8.4.12	Resistance to solvents and contaminating fluids (as required)	IEC 1073-1 clause 3.9	See 8.4.7
8.4.13	Ageing	IEC 1073-1 clause 3.8	
8.4.14	Rapid depressurisation	See 8.4.8	

Table 8.4 Test methods for environmental characteristics of a fibre optic splice.

8.4.1 Temperature extremes

The recommended test method is the same as for climatic sequence, but with the test sequence adapted to the temperature extreme test requirements. The temperature and duration of stay at each temperature should be specified by the detail specification.

8.4.2 Rapid change in temperature

The recommended test procedure is applicable with the following modifications:

- The change in transmittance shall be monitored during the whole test, including during the transfer between the two chambers of high and low temperatures.
- High and low temperature, temperature change rate and number of cycles should be given in detail specification.

8.4.3 Vacuum test (including temperature cycling)

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the splice.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic splice to 125°C or as specified.
- Measurement equipment for determining the insertion loss at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer (if required)).

Test sample
A fibre optic splice representative for the application or as specified.

Procedure
The dimensions of the splice and the dimensions of any strain relief mechanism etc. shall be measured prior to evacuation. The insertion loss of the fibre optic splice shall also be measured before the test to verify the performance of the splice.

The sample is placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. The insertion loss is measured again after the test. The dimensions shall also be measured and a visual inspection made to look for any damage or change in appearance.

The set temperature(s), duration of test at each temperature and number of cycles shall be as specified in the detail specification.

Results
The following data shall be given
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Insertion loss before and after test cycle.
- Result of visual inspection/geometrical control.

8.4.4 Solar radiation

A test with respect to solar radiation is described by IEC (IEC 1073-1, clause 3.7.14). We have, however, not found this test quite suitable to cover all aspects of testing with respect to solar radiation. We therefore propose the following test procedure:

Solar radiation test

Purpose
The purpose of the test is to determine that the fibre optic splice can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic splice to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A fibre optic splice representative for the application or as specified.

Procedure
The insertion loss is measured prior to irradiation at the specified wavelength(s). The fibre optic splice sample is placed in the test chamber and the pigtails connected to the measurement equipment which is located outside the chamber.

The fibre optic splice is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or changes in appearance.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss before test.
- Change in transmission during the test at the specified wavelength.
- Result of visual inspection.

8.4.5. UV radiation test

Purpose
To determine that the fibre optic splice can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic splice to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber
- Measurement equipment for determining the change in transmission loss and spectral attenuation (if required) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample
A fibre optic splice representative for the application or as specified.

Procedure

The insertion loss shall be measured at the specified wavelength(s) prior to irradiation. Spectral loss shall be measured before the start of the test if required. The sample is then placed in the chamber and the fibre ends connected to the transmission loss measurement equipment. The sample is then subjected to the specified irradiance level for the specified time. The transmitted power at the specified wavelength(s) is monitored continuously during the exposure. After completion of exposure the sample shall be removed from the chamber, and the spectral loss measured (if required). Further, a visual inspection shall be made to look for any damage or changes in appearance.

Results

The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss before exposure.
- Change in transmission during the test at the specified wavelength(s).
- Spectral insertion loss curves before and after the test (if required).
- Result of visual inspection.

8.4.6 Ionizing radiation

No test method exists for testing with respect to ionizing radiation. The test recommended for fibre (IEC 793-1-D3) could be used with a few modification. These modifications are:

Dose rate/total dose level

Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample

A splice representative for the application or as specified. The fibre attached to the splice should be characterised with respect to ionizing radiation in advance to be able to separate the effects of ionizing radiation related to the splice from the effects related to the fibre.

Measurements
The insertion loss shall be measured at the specified wavelength(s) before the sample is irradiated. If required the spectral loss shall be measured. During irradiation the transmission shall be monitored at the specified wavelength(s). If required the spectral loss shall also be measured after the irradiation. The splice shall be visually inspected before and after irradiation to look for changes in structure or appearance.

8.4.7 Resistance to solvents and contaminating fluids

The proposed test method is applicable with the following modification:

- The type of fluids, temperature and duration of immersion shall be as specified in the detail specification.

8.4.8 Rapid depressurisation

Purpose
To determine the performance of the fibre optic splice when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:

- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED). Optical power meter to monitor the transmitted power and launching optics.

Test sample
A fibre optic splice representative of the application or as specified.

Procedure
The splice is visually inspected and the geometrical dimensions are measured before depressurisation. The insertion loss is also measured. The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The transmitted power at the specified wavelength(s) shall be recorded continuously during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the splice is removed from the chamber, the geometrical dimensions of the splice are measured, and a visual inspection made to look for any damage or change in appearance or structure.

Results
The following data shall be given:

- Rate of pressure fall and minimum pressure.
- Insertion loss prior to depressurisation.
- Change in transmitted power during the test at the specified wavelength.
- Geometrical dimensions before and after test.
- Result of visual inspection.

8.4.9 Test severities

In the referenced test methods preferred combinations of parameter severities and duration of load are usually given. These combination may not be adequate for space application and the values given in the detail specifications should be used.

9. SPLICE HOLDERS, ORGANISERS AND CLOSURES

The tests fall into two broad categories: functional design criteria and performance criteria. Functional criteria are compared to the general design and stated features of the splice organiser assembly. Performance criteria are compared against the ability of the splice organiser assembly to demonstrate its capability of minimising changes in fibre attenuation when subjected to physical and operational conditions.

The test assembly shall be composed of the following components:

a) Splice closure
b) Splice organiser assembly
c) Splice holder
d) Optical fibre cables
e) Fibre splices

The selection of a particular splice closure, as part of the test assembly, should be determined on the basis of whether the manufacturer produces an associate closure (to be used with the splice organiser assembly) or if the manufacturer of splice organiser assemblies recommends a particular closure. As the performance of the subject components including the fibre cable is very much dependent on type of fibre cable, the test should be carried out with a relevant type of cable installed. The cabinet housing, if required as part of the test assembly, will be based on whether the manufacturer supplies the splice organiser assembly as an integral part of the cabinet housing or, if the manufacturer recommends a particular housing for the splice organiser assembly. The splice organiser assembly consists of a housing or frame (if applicable), splice organiser tray(s), splice holder(s) and the necessary assembly and mounting hardware. Fusion spliced fibres shall be used, unless otherwise specified. The use of fusion splices is intended to minimise the variations in power loss that may occur as a result of environmental and mechanical testing.

The term 'closure assembly' refers to a splice closure including the above mentioned splice organiser(s), tray(s) and holder(s), that has been completely assembled, and if required, using shield bonding apparatus, ground wires and even filled with an encapsulating compound.

For some environmental and mechanical tests, an optical measurement is used to evaluate the performance of the components. When optical measurements are required for a particular test, the number of fibre splices per cable is to be based on the minimum of one fibre per buffer tube or channel, depending on the particular cable design. Where the cable employs a single fibre bundle design, a minimum of six fibres are to be randomly selected. The cable lengths used with the splice closure must be adequate to permit monitoring the fibre before, during and after each test as required.

In the following it is assumed that minimum two fibre cables have been installed in the closure assembly, each cable with a length of minimum 4 m. Refer to Fig. 9.1. When no optical measurements are required, the closure is to be installed over unspliced optical fibre cable, unless otherwise specified. If, however, tests are to be carried out on discrete parts or without the fibre cables installed, e.g. on splice closures or splice organisers alone, modified test methods must be established. It has not been considered necessary to describe such tests in detail as they normally will be sub-sets of the complete test method for the closure assembly.

Closures intended for use with cables having metallic elements, such as shields and strength members shall meet specific requirements. The splice closure assembly shall in such instances provide the necessary hardware for bonding the metallic elements of the cable prior to the splicing operation. Once established, the continuity shall not be affected by subsequent re-entries into the closure. The splice closure assembly shall provide appropriate hardware and installation procedures for extending the electrical continuity of all metallic elements to an effective electrical ground. An electrical conductive test may be perfomed to verify the capacity of the grounding (e.g. 1000 Amps applied for 20 seconds.) No damage shall occur to the closure or bonding components that impairs the functional capabilities of the closure system.

The test setup used to measure the change in optical transmission can assume a variety of options. The use of a reference fibre for monitoring the light source is normally required.

- Install the splice organiser assembly into a splice closure (or cabinet housing), if applicable, and install the cable per the manufacturer's instructions.

- After assigning identification numbers to each of the fibres, install the fibres by loading the splice organiser to its maximum capacity. The exception to this procedure is the fibre assembly/disassembly test. If the splice organiser handles less than 24 splices, the use of for instance two organiser is acceptable.

- Splice the fibres between cable No.1 and cable No.2 and place the fusion splices in their respective splice holder locations.

- Measure the light transmission at the specified wavelength for each of the fibres and record their values.

- Subject the splice closure assembly to the specified test.

- Remeasure the optical transmission at the specified wavelengths of the individually fibres, and determine the optical transmission loss.

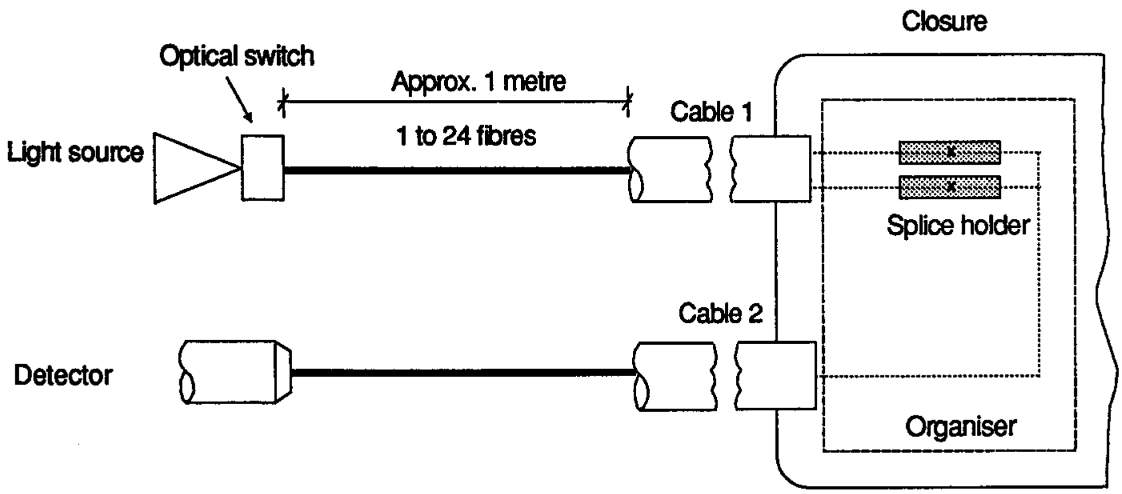

Figure 9.1 Splice closure test assembly

The various applicable test methods are categorised as geometrical, mechanical and environmental tests and are listed in Tables 9.1 through 9.4, respectively. For the majority of test methods a reference to IEC 86B(Secretariat) 172 has been given. This standard is, however, only in a draft form. It is expected that the draft will be issued as an official standard in the near future.

9.1 Test methods for geometrical characteristics

The purpose of the tests is to ensure that the specification conforms to dimensional requirements given in the relevant specification. These measurements may be used as a reference to evaluate changes of characteristics during or after a certain other test.

Test	Characteristics	Test method	Remarks
9.1.1	Outline dimensions	IEC 86B(Sec.)172, clause 4.4.2	Measured according to detailed specifications or as appropriate
9.1.2	Mass		Measured as appropriate

Table 9.1 Geometrical characteristics of splice holders, organisers and closures.

The referenced IEC test method has been found applicable.

9.2 Test methods for optical characteristics

The purpose of the test is to measure the change in insertion loss which may result from an environmental or mechanical test.

Test	Characteristics	Test method	Remarks
9.2.1	Insertion loss after assembling of fibre splices in closure is completed	IEC 86B(Sec.)172, clause 4.4.7	

Table 9.2 Optical characteristics of splice holders, organisers and closures.

The referenced IEC test method has been found applicable.

9.3 Test methods for mechanical characteristics

The purpose of the test is to ensure that the specimen will withstand mechanical loads likely to be applied during installation and in normal service. The closure assembly shall not cause an increase in fibre attenuation greater than specified.

Test	Characteristics	Test method	Remarks
9.3.1	Effectiveness of clamping device against fibre or cable pulling, cable torsion, cable bending	See 9.3.1	
9.3.2	Vibration	See 9.3.2	
9.3.3	Shock	See 9.3.3	
9.3.4	Crush resistance	IEC 86B(Sec.)172, clause 4.5.6	
9.3.5	Impact	IEC 86B(Sec.)172, clause 4.5.8	
9.3.6	Bump	IEC 86B(Sec.)172, clause 4.5.4	
9.3.7	Axial compression	IEC 86B(Sec.)172, clause 4.5.7	
9.3.8	Acceleration	IEC 86B(Sec.)172, clause 4.5.9	

Table 9.3 Mechanical characteristics of a splice holder, a splice organiser and a splice closure.

The referenced IEC test methods have been found applicable.

9.3.1 Effectiveness of clamping device against fibre or cable pulling, cable torsion, cable bending

Purpose
To ensure that the captivation or attachment of the fibre and/or cable to the specimen will withstand mechanical loads likely to be applied during installation and in normal service. The clamping, attached to the cables, shall not cause an increase in fibre attenuation greater than specified (typically 0.05 dB/splice).

Test arrangement
Two cables used in a closure configuration shall have individual test fibres checked for optical transmission prior to and after final assembly, to determine the effects of the clamping on the optical transmission of the fibres.

The number of fibres measured shall be based on a minimum of one fibre per buffer or channel depending on the particular cable design. The cables shall be installed in the splice closure.

The specimen is to be fixed to the test bench and load is to be applied to the fibre or cable.

The optical transmission for each selected test fibre shall be measured and recorded. The cables shall then be assembled into position, per the manufacturer's instructions, using the cable clamping associated with the closure. After installation the optical fibre measurements shall be repeated and compared against the initial values.

The apparatus consists of:
- A force generator capable of smoothly applying the load at the specified rate.
- A suitable clamping device for the fibre or cable.
- A fixed clamping device for the specimen.
- A light source and optical switch
- A reference fibre
- A detector/power meter

Procedure
- Install the cables in the splice closure without using the clamping device(s).
- Measure the optical transmission.
- Assemble cables in position using the clamping device(s).
- Measure the optical transmission.
- Securely fix the specimen to the fixed clamping device.
- Clamp the fibre or cable at the point of application specified in the relevant specification, and smoothly apply the tensile load to cable. Maintain the load for a specified period of time (e.g.10 seconds minimum).
- Measure the optical transmission.
- Repeat the test by application of cable bending. The cable shall be subjected to a specified number of bending cycles and the sample examined for damage to the cable, closure, and cable to closure seal and hardware. A bending cycle shall consist of a bend in one direction followed by an equal bend in the opposite direction and a return to the original position.
- Repeat the test by application of cable torsion. Apply the specified number of torque cycles.

Results
The following data shall be given:
- Magnitude and rate of application of the load i.e.:
  - magnitude and rate of application of tensile load,
  - number , magnitude and direction of the cable bends,
  - number of torque cycles, magnitude of torque or degree of rotation applied to the cable.
- Point of application of the load.
- Specimen optically functioning or nonfunctioning.
- Preconditioning procedure.
- Recovery procedure
- Initial measurements and performance requirements
- Measurements during test and performance requirements
- Final measurements and performance requirements.
- Deviations.

9.3.2 Vibration

Purpose
To evaluate the effects of vibration on specimens at predominant frequency ranges and magnitudes that may be encountered during launching and orbiting. Most vibration encountered in normal service is not of a simple harmonic nature. However, tests based on vibrations of this type have

proven to satisfactorily simulate actual field service. The test is applicable to closure assemblies including fibre cables installed, and to closures and splice organisers alone.

Test arrangement
A specimen is mounted to a vibration generator and vibrated with a sinusoidal motion. The specimen is exposed to vibration in three mutually perpendicular directions, one of which is parallel to the optical axis. The vibration amplitude is specified in terms of constant displacement and/or constant acceleration. The apparatus shall be in accordance with the MIL-STD 750, No.2056 or IEC 68-2-5. The severity is determined by the combination of frequency range, vibration amplitude, and endurance per axis. The severity shall be specified in the detail specification.

Example of severity:

Frequency range:	100-2000 Hz
Peak acceleration:	20 g.
Cross-over:	50 Hz
Endurance per axis:	30 minutes

Procedure
Conduct the test in accordance with the relevant standard. The specimen shall be vibrated in three mutually perpendicular axis, one of which is the optical axis. The vibration endurance shall be performed by sweeping rather than at fixed frequency.

Results
The following data shall be given:
- Frequency range
- Vibration amplitude
- Endurance duration per axis
- Specimen optically functioning or nonfunctioning
- Preconditioning procedure
- Recovery procedure
- Initial measurements and performance requirements
- Measurements during test and performance requirements
- Final measurements and performance requirements
- Deviations

9.3.3 Shock

Purpose
To reveal mechanical weakness and/or degradation of specimens when subjected to non-repetitive mechanical shocks. It simulates infrequent non-repetitive shocks likely to be encountered in launching, orbiting and in the installation phase. The test is applicable to closure assemblies including fibre cables installed, and to closures and splice organisers alone.

Test arrangement
The test to be carried out in accordance with MIL-STD 750, No.2016.2 or IEC 68-2-27.
The severity is determined by the combination of peak acceleration and number of shocks. The severity shall be specified in the detail specification.

Procedure
The specimen is fastened to the table of a shock testing machine and is subjected to half-sine shock pulses.

Example of test severity:
Peak acceleration: 1500 g
Pulse duration: 0.5 s
Number of shocks: 5

Results:
The following data shall be given:
- Peak acceleration
- Number of shocks
- Specimen optically functioning or nonfunctioning
- Preconditioning procedure
- Recovery procedure
- Initial measurements and performance requirements
- Measurements during test and performance requirements
- Final measurements and performance requirements
- Deviations

9.4 Test methods for environmental characteristics

The purpose of the tests is to determine the suitability of specimens for use and/or storage under adverse environmental conditions. The referenced IEC test methods have been found applicable.

Test	Characteristics	Test method	Remarks
9.4.1	Climatic sequence	IEC 86B(Sec.)172, clause 4.5.14	
9.4.2	Temperature extremes	IEC 68-2-1 Test Ab IEC 86-2-2 Test Bb	See 9.4.1
9.4.3	Rapid change in temperature	See 9.4.2	
9.4.4	Vacuum test (including temperature cycling)	See 9.4.3	
9.4.5	Condensation	IEC 86B(Sec.)172, clause 4.5.15	
9.4.6	Corrosive atmosphere	IEC 86B(Sec.)172, clause 4.5.17	
9.4.7	Dust	IEC 86B(Sec.)172, clause 4.5.18	
9.4.8	Flammability	IEC 86B(Sec.)172, clause 4.5.28 IEC 695-2-2	
9.4.9	Sealing	IEC 86B(Sec.)172, clause 4.5.26	
9.4.10	Solar radiation	See 9.4.4	
9.4.11	UV radiation	See 9.4.5	
9.4.12	Ionizing radiation	IEC 86B(Sec.)172, clause 4.5.22	See 9.4.6
9.4.13	Resistance to solvents and contaminating fluids	IEC 86B(Sec.)172, clause 4.5.25	See 9.4.7
9.4.14	Mechanical endurance (separable components)	IEC 86B(Sec.)172, clause 4.5.23	
9.4.15	Assembly and disassembly of closures	IEC 86B(Sec.)172, clause 4.5.30	
9.4.16	Ageing	See 9.4.8	
9.4.17	Rapid depressurisation	See 9.4.9	

Table 9.4 Environmental characteristics of a splice holder, a splice organiser and a splice closure.

9.4.1 Temperature extremes

Purpose
To determine the suitability of specimens for use and/or storage under conditions of high and low temperatures.

The procedure relates to gradual increase/decrease in temperature and is for specimens which are subjected to high/low temperature for a time long enough for the specimen to achieve temperature stability. The specimen need to be in operation during temperature variations, otherwise the test change of temperature should be used.

Test arrangement
The apparatus consists of:

- An environmental chamber in accordance with the IEC recommendations.
- Measurement equipment determining the optical attenuation of the transmission at specified wavelength(s) by using a reference fibre.

The specimen is placed in a chamber at ambient temperature. The temperature is then raised/lowered to test temperature at a rate not to exceed 1°C per minute and maintained at that temperature for the specified duration. At the end of the period, the specimen remains in the chamber while the temperature is lowered/raised to ambient. It is then allowed to attain temperature equilibrium at ambient temperature before optical measurements are carried out.

Procedure
The procedure shall be conducted in accordance with IEC 68-2-2 Test Bb for high temperature respectively IEC 68-2-1 Test Ab for low temperature.

The severity is determined by the combination of the temperature and duration of exposure. The severity shall be specified in detail specification.

As a reference, the following minimum/maximum temperatures are anticipated when the components are in operation on-station. Refer to Part 1:

Outside: -55/+125°C
Inside: -30/+70°C

Results
The following data shall be given:
- Temperature
- Duration of exposure
- Specimen optically functioning or nonfunctioning
- Preconditioning procedure
- Recovery procedure
- Initial measurements and performance requirements
- Measurements during test and performance requirements
- Final measurements and performance requirements
- Deviations

9.4.2 Rapid change in temperature

Purpose

To determine the suitability of a component to withstand the effects of change of temperature or a component to withstand the effects of change of temperature or a succession of change of temperature.

The specimen is first subjected to one extreme of temperature for a given period of time. It is then subjected to the other extreme of temperature for an equal period of time. The difference of these two tests is the manner and time of change over between temperatures.
The tests should be carried out in accordance with IEC 68-2-14, Na or Nb.

Test Na subjects the specimen to extremes of temperature with a very short change-over time, in essence, subjecting the specimen to a series of thermal shocks.

Test Nb subjects the specimen to a more gradual variation of temperature which stresses but does not shock the specimen.

Optical measurements shall be carried out while the temperature changes.

Test arrangement

The apparatus consists of:
- Suitable environmental chamber(s) described in IEC 68-2-14.
- Measurement equipment determining the optical attenuation of the transmission at specified wavelength(s) by using a reference fibre.

Procedure

The tests should be carried out in accordance with IEC 68-2-14, Test Na or Nb.

The specimen is first subjected to one extreme of temperature for a given period of time. It is then subjected to the other extreme of temperature for an equal period of time.

The severity is determined by the combination of low temperature, high temperature, duration, changeover time or rate of change of temperature and number of cycles.

As a reference, the following temperatures gradients are anticipated when the components are in operation on-station. Refer to Part 1:

$\Delta T/\Delta t = 0.4°C/s$
$\Delta T/\Delta L = 20°C/m$ near equipment
$\Delta T/\Delta L = 5°C/m$ for other locations

Results

The following data to be given:
- Test Na or Nb
- High temperature
- Low temperature
- Duration extreme temperature
- Cycles
- Specimen optically functioning or non-functioning

- Preconditioning procedure
- Recovery procedure
- Initial measurements and performance requirements
- Measurements during test and performance requirements
- Final measurements and performance requirements
- Deviations

9.4.3 Vacuum test (including temperature cycling)

Purpose
To determine the ability of the closure assembly to operate in vacuum under varying temperatures.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the closure assembly to 125°C or as specified.
- Measurement equipment determining the optical attenuation of the transmission at specified wavelength(s) by using a reference fibre. The measuring equipment may be located outside the vacuum chamber.

Procedure
The fibre cable(s) shall be installed, and the closure completely assembled. The specimen shall be placed in the thermal vacuum chamber. The measurement equipment can be placed in the thermal vacuum chamber if appropriate. Initial measurement shall be made and recorded. The chamber shall be evacuated and the specimen subjected to the specified temperature cycles.

The set temperature(s) stay time at each temperature and number of cycles shall be as specified in the detailed specification. The optical measurements shall be performed at intervals or continuously during the temperature cycling. After completion of the test cycles, the sample(s) shall be re-measured, and a visual inspection shall be made to check for physical damage.

Results
The following data shall be given:
- Pressure in the vacuum chamber
- Intervals of optical measurements
- Temperature cycle diagram including number of cycles
- Attenuation before, during and after the test at specified wavelength(s)
- Results of visual inspection.

9.4.4 Solar radiation

Purpose
To assess the effects of solar radiation on the materials of a specimen, and to determine that the closure assembly can withstand the specified solar radiation.

Test arrangement
The following equipment is needed:
- A test chamber with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre to the specified level of irradiance. Reference is made to ESA PSS-01-706 'The particle and ultraviolet (UV) radiation testing of space materials' with regard to typical levels and spectral content. The test chamber

must have appropriate ports to allow the two fibre cables to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at specified wavelength, optical power meter to monitor the transmitted power.

Procedure

The specimen to be place in the test chamber and the fibre cables connected to the measuring equipment. In order to radiated all sides of an object, the specimen should be suspended in the chamber and the light should be directed to all sides.

The specimen is then subjected to specified irradiance for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to check for any damage or change in the exterior.

Results

The following data to be given:
- Irradiance level and spectral character of radiation
- Duration of exposure
- Change in attenuation during the test at specified wavelength
- Result of visual inspection

9.4.5 UV radiation

Purpose

To assess the effects of UV radiation on the materials of a specimen, and to determine that the closure assembly can withstand the specified UV radiation.

Test arrangement

The following equipment is needed:
- A test chamber with suitable lamps for simulating UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre to the specified level of irradiance. Reference is made to ESA PSS-01-706 'The particle and ultraviolet (UV) radiation testing of space materials' with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the two fibre cables to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at specified wavelength, optical power meter to monitor the transmitted power.

Procedure

The specimen to be place in the test chamber and the fibre cables connected to the measuring equipment. In order to radiated all sides of an object, the specimen should be suspended in the chamber and the light should be directed to all sides.

The specimen is then subjected to specified irradiance for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber an da visual inspection made to check for any damage or change in the exterior.

Results

The following data to be given:

- Irradiance level and spectral character of radiation
- Duration of exposure
- Change in attenuation during the test at specified wavelength
- Result of visual inspection

9.4.6 Ionizing radiation

It is recommended that the test conditions described in IEC 793-1-D8 should be used, but with a few modifications. The IEC test describes two different test levels viz. one for low level radiation (background radiation) and one high level (adverse nuclear environments). It is recommended that the procedure for adverse nuclear radiation environment to be followed but with different total dose and dose rate combination. The following total dose and dose rate combinations have been recommended, other levels should be used whenever specified:

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Optical measurements are considered not relevant. A check of closure dimensions and a visual inspection to be carried out after the test.

9.4.7 Resistance to solvents and contaminating fluids (as required)

It is recommended that the test IEC 86B(Sec.)172, 4.5.25 should be used, but with a few modifications. In App. C a list of active chemical substances has been given. It is suggested that the list of chemicals given in the IEC test is reviewed in light of relevant chemicals and liquids.

9.4.8 Ageing

Purpose
The purpose is to simulate long term (life time) degradation by subjecting the closure assembly to elevated temperature.

Test arrangement
The following equipment is needed:
- A temperature chamber capable of maintaining the specified endurance temperature with specified tolerance (e.g. ±5°C). The chamber shall be such that the specimen is not subjected to direct radiation from the heating of the chamber. The chamber must have ports to allow the fibre ends to be connected to measuring equipment outside the chamber
- A suitable optical power source operating at specified wavelength. power meter to monitor the transmitted power

Procedure

The closure's dimensions shall be verified and recorded. The fibre cable(s) shall be installed, and the closure(s) completely assembled. The specimen(s) shall be placed in the thermal chamber. Initial measurement shall be made and recorded. The sample(s) subjected to the specified temperature. This temperature can be 10°C above the maximum specified operating temperature if not otherwise specified. The temperature should be maintained for at least 240 hours or as specified. (The results from the evaluation test of the particular component in question should be taken into account when determining test temperature and duration of test. The test is specified in dry air if not otherwise specified.) The transmitted power at the specified wavelength(s) is monitored continuously during the test. After the test is completed, the sample(s) shall be re-measured, and a visual inspection shall be made to check for physical damage on the structure of the closure.

Results

The following data shall be given:
- Temperature and duration of test
- The dimensions before and after the test
- Change in attenuation
- Result of visual inspection.

9.4.9 Rapid depressurisation

Purpose

To determine the effect of reduced pressure such as might be encountered in the launch phase.

The test arrangement

The following equipment is needed:
- A vacuum chamber in which the pressure may be reduced to minimum 10 Torr in less than 5 seconds, or as specified
- Measurement equipment determining the optical attenuation of the transmission at specified wavelength(s) by using a reference fibre.

Procedure

The fibre cable(s) shall be installed, and the closure completely assembled. The specimen shall be placed in the vacuum chamber. The measurement equipment can be placed in the vacuum chamber if appropriate. Initial measurement shall be made and recorded. The chamber shall be rapidly depressurised and pressurised.

The optical measurements shall be performed at intervals or continuously during the temperature cycling. After completion of the test cycles, the sample(s) shall be re-measured, and a visual inspection shall be made to check for physical damage.

Results

The following data shall be given:
- Pressure in the vacuum chamber
- Intervals of optical measurements
- Depressurisation cycle diagram including number of cycles
- Attenuation before, during and after the test at specified wavelength(s)
- Results of visual inspection.

10.0 FIBRE OPTIC ATTENUATORS

A generic specification for fibre optic attenuator has been published by the IEC (IEC 869-1, issued 1988). This document describes a number of applicable test procedures with respect to optical and environmental parameters, but does not contain any mechanical test procedures at all. A revision of this document is under preparation, and a draft for the revised issue exists (document reference No. 86B(Secretariat)229). This draft contains some additional test methods which have been found applicable. These test procedures are referenced with the clause number they are given in this draft document. The draft document was issued in May 1991 and it is expected that a revised version of the generic specification for fibre optic attenuators will become available within a year.

10.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
10.1.1	Outline dimensions		Measured according to detail specifications or as appropriate
10.1.2	Mass		Measured as appropriate

Table 10.1 Test methods for geometrical characteristics of a fibre optic attenuator

10.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
10.2.1	Attenuation	IEC 869-1 clause 27.1 and clause 27.2	See 10.2.1
10.2.2	Return loss	IEC 869-1 clause 27.3	
10.2.3	Spectral loss	IEC 869-1 clause 27.4	
10.2.4	Polarisation dependence	See 10.2.2	
10.2.5	Modal distribution	See 10.2.3	
10.2.6	Susceptibility to ambient light coupling	See 10.2.4	
10.2.7	Maximum input power	clause 4.3.9	See 10.2.5
10.2.8	Change in transmittance	clause 4.3.8	See 10.2.6

Table 10.2 Test methods for optical characteristics of a fibre optic attenuator

10.2.1 Attenuation measurement

Several measurement configurations are described in the recommended test method depending on whether the attenuator is delivered with fibre pigtails, connectorized fibre pigtails or connectors.

10.2.2 Test for polarisation dependence test

Purpose
The purpose of the test is to establish the dependence of attenuation and return loss (if specified) on state of polarisation of incoming light.

Test arrangement
The following equipment is needed:
- Means for measuring change in transmittance as described for Test 10.2.8.
- Means for generating a linearly polarised beam whose direction of polarisation can be rotated 360°.

Test sample
An attenuator representative for the application or as specified.

Test procedure
The change in transmittance is measured as the direction of polarisation of the incoming light is rotated 360°. The reference signal is measured simultaneously such that it would reflect any change in input signal as the direction of polarisation is rotated (this requires a polarisation independent coupler). A similar measurement is also done for the return loss (if specified).

The procedure is repeated at each wavelength of interest. In those cases where the attenuator is variable, the measurements shall be performed at the attenuation value settings specified in the detail specification.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of means for achieving a rotatable linearly polarised beam.
- Change in transmittance as a function of direction of polarisation.
- Change in return loss as a function of direction of polarisation (if specified).

10.2.3 Test for dependence on modal distribution

In multimode fibre optic attenuators the attenuation may be dependent on the mode distribution of the input light. The standards organisations have not yet suggested a test for the dependence on mode distribution. The method suggested here will give an indication of the modal dependence as it measures the difference in insertion loss with fully filled and equilibrium mode distribution, corresponding to short and long line length systems respectively.

Purpose
To determine the difference in attenuation and return loss (if specified) for fully filled and equilibrium mode distribution.

Test arrangement
The following equipment is needed:
- Equipment for attenuation measurement as described for Test 10.2.1.
- Equipment for return loss measurement as described for Test 10.2.2.
- Means for launching light with the specified mode distribution into the fibre optic attenuator.

Test sample
A fibre optic attenuator representative of the application or as specified.

Test procedure
- Launch light into the fibre in such a way that fully filled mode distribution is achieved.
- Measure the attenuation for that particular mode distribution, see Test 10.2.1. If required the return loss shall also be measured, see Test 10.2.2.
- Repeat the procedure for the equilibrium mode distribution.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of arrangement for launching light into attenuator.
- The attenuation at each mode distribution.
- The return loss at each mode distribution (if specified).

10.2.4 Test for susceptibility to ambient light coupling

Purpose
The purpose of the test is to determine the susceptibility of the attenuator to ambient light coupling.

Test arrangement
The test arrangement for measuring the susceptibility to ambient light coupling is described in detail in other IEC documents, for example IEC 875-1 clause 17.2. This test arrangement could also be used for fibre optic attenuators.

Test sample
A fibre optic attenuator representative of the application or as specified.

Test procedure
- Turn on equipment and allow about 1 hour to reach a stable state.
- Place attenuator in integrating sphere as specified in the description of the test arrangement.
- Connect attenuator fibre leads to cable.
- Measure light level in sphere, P_o
- Measure light level in fibre from the attenuator, P_f

Outside light immunity, IL, is given by:

$$IL = -10\log(\frac{P_f}{P_o})$$

In those cases where the attenuator is variable, the outside light immunity is measured for the settings of attenuator given in the detail specification.

Results
The following shall be recorded:
- Light source (wavelength range, power)
- Outside light immunity at each attenuation value of interest.

10.2.5 Maximum input power

The referenced test is applicable with a few modifications. The light source should operate at the same wavelength and have the same spectral character as the intended application. The power level shall be increased in steps to the specified level.

10.2.6 Change in transmittance

The referenced test method is used when the parameter of interest is the change in attenuation or return loss, for instance during various environmental and mechanical tests.

10.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
10.3.1	Vibration	clause 4.4.1	
10.3.2	Shock	clause 4.4.9	
10.3.3	Crush resistance	clause 4.4.10	
10.3.4	Impact	clause 4.4.12	
10.3.5	Drop	clause 4.4.14	
10.3.6	Acceleration	clause 4.4.13	
10.3.7	Bump	clause 4.4.8	
10.3.8	Strength of attachment of fibre - pulling - axial compression - flex/bending/nutation - torsion	 clause 4.4.4 clause 4.4.11 clause 4.4.35 clause 4.4.5	See 10.3.2

Table 10.3 Test methods for mechanical characteristics of a fibre optic attenuator.

10.3.1 Test severities

The mechanical test methods referenced include preferred combinations of test parameters (level of vibration, shock, acceleration, impact etc.). In those cases where these levels do not fulfil the requirements in the detail specification, the test severities should be adjusted accordingly. This will not, however, change the test procedures.

10.3.2 Strength of attachment of fibre

The referenced tests include methods to measure the strength of attachment of fibre. If the input and output port of the fibre optic attenuator are connectors these tests should be replaced by tests for strength of coupling mechanisms, and strength of fibre/cable attachment found for fibre optic connectors, see Chapter 7.

10.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
10.4.1	Climatic sequence	IEC 869-1 clause 29.5	
10.4.2	Temperature extremes	IEC 869-1 clause 29.5	See 10.4.1
10.4.3	Rapid change in temperature	IEC 869-1 clause 29.7	See 10.4.2
10.4.4	Vacuum test (including temperature cycling)	See 10.4.3	
10.4.5	Condensation	IEC 869-1 clause 29.6	
10.4.6	Corrosive atmosphere	IEC 869-1 clause 29.9	not considered applicable
10.4.7	Dust	IEC 869-1 clause 29.10	not considered applicable
10.4.8	Flammability	IEC 869-1 clause 29.12	
10.4.9	Sealing	IEC 869-1 clause 29.8	
10.4.10	Solar radiation	See 10.4.4	
10.4.11	UV radiation	See 10.4.5	
10.4.12	Ionizing radiation	See 10.4.6	
10.4.13	Resistance to solvents and contaminating fluids (as required)	IEC 869-1 clause 32	see 10.4.7
10.4.14	Ageing	IEC 869-1 clause 31	
10.4.15	Rapid depressurisation	See 10.4.8	

Table 10.4 Test methods for environmental characteristics of a fibre optic attenuator.

10.4.1 Temperature extremes

The recommended test method is the same as for climatic sequence, but with the test sequence adapted to the temperature extreme test requirements. The temperature and duration of stay at each temperature should be specified by the detailed procedure.

10.4.2 Rapid change in temperature

The recommended test procedure is applicable with the following modifications:
- The change in transmittance shall be monitored during the whole test, including during the transfer between the two chambers of high and low temperatures.
- High and low temperature, temperature change rate and number of cycles should be given in detail specification.

10.4.3 Vacuum test including temperature cycling

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the attenuator.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic attenuator to 125°C or as specified.
- Measurement equipment for determining the attenuation at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer (if required)).

Test sample
A fibre optic attenuator representative for the application or as specified.

Procedure
The dimensions of the attenuator and the dimensions of any strain relief mechanism etc. shall be measured prior to evacuation. The attenuation shall be measured before the test at the specified wavelength(s) to verify the performance of the attenuator.

The sample is placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. The attenuation is measured after the test is completed. The dimensions shall also be measured and a visual inspection shall also be made to look for any damage or change in appearance.

The set temperature(s), duration of test at each temperature and number of cycles shall be as specified in the detail specification.

If the attenuator is variable, attenuation measurements shall be performed at the attenuator settings specified in the detail specification before and after vacuum test.

Results
The following data shall be given
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Attenuation before and after test cycle.
- Result of visual inspection/geometrical control.

10.4.4 Solar radiation

A test with respect to solar radiation is described by IEC (IEC 869-1, clause 29.15.1). We have, however, not found this test quite suitable to cover all aspects of testing with respect to solar radiation. We therefore propose the following test procedure:

Solar radiation test

Purpose
The purpose of the test is to determine that the fibre optic attenuator can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic attenuator to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength(s) (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A fibre optic attenuator representative for the application or as specified.

Procedure
The attenuation is measured prior to irradiation at the specified wavelength(s). The fibre optic attenuator sample is placed in the test chamber and the pigtails connected to the measurement equipment which is located outside the chamber.

The fibre optic attenuator is then subjected to the specified irradiance level for the specified time. The change in transmittance is recorded continuously during the exposure at the specified wavelength(s). After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or changes in appearance.

If the attenuator is variable the transmission measurements shall be performed at specified intervals during the test at the attenuator value settings specified in the detailed specification.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Attenuation before test.

- Change in transmittance during the test at the specified wavelength(s).
- Result of visual inspection.

10.4.5 UV radiation test

Purpose
To determine that the fibre optic attenuator can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic attenuator to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber
- Measurement equipment for determining the change in transmittance and spectral attenuation (if required) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample
A fibre optic attenuator representative for the application or as specified.

Procedure
The attenuation shall be measured at the specified wavelength(s) prior to irradiation. Spectral loss shall be measured before the start of the test if required. The sample is then placed in the chamber and the fibre ends connected to the transmittance measurement equipment. The sample is then subjected to the specified irradiance level for the specified time. The change in transmittance at the specified wavelength(s) is monitored continuously during the exposure. After completion of exposure the sample shall be removed from the chamber, and the spectral loss measured (if required). Further, a visual inspection shall be made to look for any damage or changes in appearance.

If the attenuator is variable, transmission measurements shall be performed at specified intervals during the test at the attenuation value settings specified in the detail specification.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Attenuation before exposure.
- Change in transmittance during the test at the specified wavelength(s).
- Spectral loss curves before and after the test (if required).
- Result of visual inspection.

10.4.6 Ionizing radiation

No test method exists for testing with respect to ionizing radiation. The test recommended for optical fibres (IEC 793-1-D3) could be used with a few modification. These modifications are:

Dose rate/total dose level
Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample
A attenuator representative for the application or as specified. The fibre attached to the attenuator should be characterised with respect to ionizing radiation in advance to be able to separate the effects of ionizing radiation related to attenuator from the effects related to the fibre.

Measurements
The attenuation shall be measured at the specified wavelength(s) before the sample is irradiated. If required the spectral loss shall be measured. During irradiation the change in transmittance shall be monitored at the specified wavelength(s). If required the spectral loss shall also be measured after the irradiation. The attenuator shall be visually inspected before and after irradiation to look for changes in structure or appearance.

If the attenuator is variable, the transmission measurements shall be performed at specified intervals during the test at the attenuation value settings specified in the detail specification.

10.4.7 Resistance to solvents and contaminating fluids

The proposed test method is applicable with the following modification:
- The type of fluids, temperature and duration of immersion shall be as specified in the detailed specification.

10.4.8 Test for rapid depressurisation

Purpose
To determine the performance of the fibre optic attenuator when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED). Optical power meter to monitor the change in transmittance and launching optics.

Test sample
A fibre optic attenuator representative of the application or as specified.

Procedure
The attenuator is visually inspected and the geometrical dimensions are measured before depressurisation. The attenuation is also measured at the specified wavelength(s). If required the spectral loss is measured. The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The change in transmittance shall be monitored at the specified wavelength(s) during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the attenuator is removed from the chamber, the geometrical dimensions of the attenuator are measured, and a visual inspection made to look for any damage or change in appearance or structure.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Attenuation prior to depressurisation.
- Change in transmittance during the test at the specified wavelength.
- Geometrical dimensions before and after test.
- Result of visual inspection.

10.4.9 Test severities

In the referenced test methods preferred combinations of parameter severities and duration of load are usually given. These combination may not be adequate for space application and the values given in the detail specifications should be used.

11 FIBRE OPTIC BRANCHING DEVICES

A generic specification for fibre optic branching devices has been published by the IEC (IEC 875-1, issued 1986). This document describes a number of applicable test procedures with respect to optical, mechanical and environmental parameters, but has a limited scope compared to the test strategy described in Part 2. A revision of this document is under preparation and a draft for the revised issue exists (document reference no 86B(Secretariat)228). This draft contains some additional test methods which have been found applicable. These test procedures are referenced with the clause number they are given in this draft document. The draft document was issued in May 1991 and it is expected that a revised version of the generic specification for fibre optic branching devices will become available within a year.

11.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
11.1.1	Outline dimensions		Measured according to detail specifications or as appropriate
11.1.2	Mass		Measured as appropriate

Table 11.1 Test methods for geometrical characteristics of a fibre optic branching device.

11.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
11.2.1	Optical branching efficiency	See 11.2.1	
11.2.2	Modal distribution	See 11.2.2	
11.2.3	Polarisation sensitivity	See 11.2.3	
11.2.4	Stability of transfer coeff-icients		not considered applicable
11.2.5	Susceptibility to ambient light coupling	IEC 875-1 clause 17.2	
11.2.6	Optical power handling capability	IEC 875-1 clause 17.5	See 11.2.4
11.2.7	Change in transmittance	clause 4.3.8	See 11.2.5

Table 11.2 Test methods for optical characteristics of a fibre optic branching device.

11.2.1 Optical branching efficiency

The branching efficiency encompasses the insertion loss for the various optical paths and also the return loss from the input port. The recommended method for measuring the insertion loss is found in IEC 875-1 clause 17.1. The method for measurement of return loss can be found in the draft for the revised version, clause 4.3.5.

11.2.2 Modal distribution

In multimode fibre optic branching devices the branching efficiency may be dependent on the modal distribution in the launch fibre. The standards organisations have not yet suggested a test for the dependence on modal distribution. The method suggested here will give an indication of the modal dependence as it measures the difference in branching efficiency with fully filled and equilibrium mode distribution, corresponding to short and long line length systems respectively.

Test for dependence on modal distribution

Purpose
To determine the difference in branching efficiency for fully filled and equilibrium mode distribution.

Test arrangement
The following equipment is needed:
- Equipment needed for measurement of optical branching efficiency according to 11.2.1.
- Means for launching light with the specified mode distributions into the fibre optic branching device.

Test sample
A fibre optic branching device representative of the application or as specified.

Test procedure
- Launch light into the fibre in such a way that fully filled mode distribution is achieved.
- Measure the branching efficiency for that particular mode distribution at the specified wavelength(s) according to one of the methods described in 11.2.1.
- Repeat the procedure for the equilibrium mode distribution.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of arrangement for launching light into the branching device.
- The branching efficiency at each mode distribution.

11.2.3 Polarisation dependence

The IEC generic specification includes a method to measure polarisation sensitivity of a branching device (IEC 875-1, clause 17.6). The proposed test method is basically the same, but with a few modifications.

Polarisation sensitivity test

Purpose
The purpose of the test is to establish the dependence of branching efficiency on state of polarisation of incoming light.

Test arrangement
The following equipment is needed:
- Means for measuring change in transmittance as described for Test 11.2.7.
- Means for generating a linearly polarised beam whose direction of polarisation can be rotated 360°.

Test sample
An fibre optic branching device representative for the application or as specified.

Test procedure
The change in transmittance is measured as the direction of polarisation in the incoming light is rotated 360°. The reference signal is measured simultaneously such that it would reflect any change in input signal as the direction of polarisation is rotated (this requires a polarisation independent coupler).

The procedure is repeated at each wavelength of interest.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of means for achieving a rotatable linearly polarised beam.
- Change in transmittance as a function of direction of polarisation (and return loss (if required)

11.2.4 Optical power handling capability

The referenced test is applicable with a few modifications. The light source should operate at the same wavelength and have the same spectral character as in the intended application. The power level shall be increased in steps to the specified level.

11.2.5 Change in transmittance

The referenced test method is used when the parameter of interest is the change in optical branching efficiency under varying operating conditions, for example during mechanical and environmental loads.

11.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
11.3.1	Vibration	IEC 875-1 clause 18.2	
11.3.2	Shock	IEC 875-1 clause 18.4	
11.3.3	Acceleration	clause 4.4.13	
11.3.4	Crush resistance	clause 4.4.10	
11.3.5	Impact	clause 4.4.12	
11.3.6	Drop	clause 4.4.14	
11.3.7	Bump	IEC 875-1 clause 18.3	
11.3.8	Strength of attachment of fibre/cable - pulling - axial compression - torsion - bend/flex/nutation	 clause 4.4.4 clause 4.4.11 clause 4.4.5 clause 4.4.35	See 11.3.2

Table 11.3 Test methods for mechanical characteristics of a fibre optic branching device.

11.3.1 Test severities

The mechanical test methods referenced include preferred combinations of test parameters (level of vibration, shock, acceleration, impact etc.). In those cases where these levels do not fulfil the requirements in the detail specification, the test severities should be adjusted accordingly. This will not, however, change the test procedures.

11.3.2 Strength of fibre/cable attachment

The referenced tests include methods to measure the strength of attachment of fibre. If the input and output port of the fibre optic branching device are connectors, these tests should be replaced by tests for strength of coupling mechanisms, and strength of fibre/cable attachment found for fibre optic connectors, see Chapter 7.

11.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
11.4.1	Climatic sequence	IEC 875-1 clause 19.2	
11.4.2	Temperature extremes	clause 4.4.17 clause 4.4.18 clause 4.4.19	Cold Dry heat Damp heat
11.4.3	Rapid change in temperature	IEC 875-1 clause 19.4	See 11.4.1
11.4.4	Vacuum test (including temperature cycling)	See 11.4.2	
11.4.5	Condensation	IEC 875-1 clause 19.3	
11.4.6	Corrosive atmosphere	IEC 875-1 clause 19.6	not considered applicable
11.4.7	Dust	IEC 875-1 clause 19.7	not considered applicable
11.4.8	Flammability	IEC 875-1 clause 19.9	
11.4.9	Sealing	clause 4.4.23 clause 4.4.25	Panel/barrier sealed Hermetic sealed
11.4.10	UV radiation	See 11.4.3	
11.4.11	Ionizing radiation	See 11.4.4	
11.4.12	Solar radiation	See 11.4.5	
11.4.13	Resistance to solvents and contaminating fluids (as required)	IEC 875-1 clause 21	See 11.4.6
11.4.14	Ageing	IEC 875-1 clause 20	
11.4.15	Rapid depressurisation	See 11.4.7	

Table 11.4 Test methods for environmental characteristics of a fibre optic branching device.

11.4.1 Rapid change in temperature

The recommended test procedure is applicable with the following modifications:
- The change in transmittance at the specified wavelength(s) and in the specified optical paths shall be monitored during the whole test procedure, including during the transfer between the two chambers of high and low temperatures.
- High and low temperature, temperature change rate and number of cycles should be given in the detail specification.

11.4.2 Vacuum test (including temperature cycling)

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the fibre optic branching device.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic branching device to 125°C or as specified.
- Measurement equipment for determining the optical branching efficiency at the specified wavelength(s) and in the specified optical paths (stabilised optical source, optical detector, launching optics, spectrometer (if required)).

Test sample
A fibre optic branching device representative for the application or as specified.

Procedure
The dimensions of the branching device and the dimensions of any strain relief mechanism etc. shall be measured prior to evacuation. The branching efficiency in the specified optical paths shall be measured before the test at the specified wavelength(s) to verify the performance of the branching device.

The sample is placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. After the test is completed the optical branching efficiency shall be measured at the specified wavelength(s). The dimensions shall also be measured and a visual inspection shall also be made to look for any damage or change in appearance.

The set temperature(s), duration of test at each temperature and number of cycles shall be as specified in the detail specification.

Results
The following data shall be given
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Branching efficiency before and after test cycle.
- Result of visual inspection/geometrical control.

11.4.3 UV radiation test

Purpose
To determine that the fibre optic branching device can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic branching device to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails

to be connected to the measuring equipment outside the chamber

- Measurement equipment for determining the change in transmittance in the specified optical paths and at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample

A fibre optic branching device representative for the application or as specified.

Procedure

The optical branching efficiency shall be measured at the specified wavelength(s) prior to irradiation. The sample is then placed in the chamber and the fibre ends connected to the transmittance measurement equipment. The sample is then subjected to the specified irradiance level for the specified time. The change in transmittance at the specified wavelength(s) is monitored continuously during the exposure. After completion of exposure the sample shall be removed from the chamber. Further a visual inspection shall be made to look for any damage or changes in appearance.

Results

The following data shall be given:

- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Branching efficiency before test.
- Change in transmittance during the test at the specified wavelength(s).
- Result of visual inspection.

11.4.4 Ionizing radiation

No test method exists for testing with respect to ionizing radiation. The test recommended for optical fibres (IEC 793-1-D3) could be used with a few modification. These modifications are:

Dose rate/total dose level

Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample
A fibre optic branching device representative for the application or as specified. The fibre attached to the branching device should be characterised with respect to ionizing radiation in advance to be able to separate the effects of ionizing radiation related to branching device from the effects related to the fibre.

Measurements
The branching efficiency in the specified optical paths shall be measured at the specified wavelength(s) before the sample is irradiated. During irradiation the change in transmittance shall be monitored at the specified wavelength(s) in the specified optical paths. The branching device shall be visually inspected before and after irradiation to look for damage or changes in structure or appearance.

11.4.5 Solar radiation

A test with respect to solar radiation is described by IEC (IEC 875-1, clause 19.12). We have, however, not found this test quite suitable to cover all aspects of testing with respect to solar radiation. We therefore propose the following test procedure.

Solar radiation test

Purpose
The purpose of the test is to determine that the branching device can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:

- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the branching device to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength(s) (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A fibre optic branching device representative for the application or as specified.

Procedure
The optical branching efficiency in the specified optical path is measured prior to irradiation at the specified wavelength(s). The sample is placed in the test chamber and the pigtails connected to the measurement equipment which is located outside the chamber.

The branching device is then subjected to the specified irradiance level for the specified time. The change in transmittance in the specified optical paths is recorded continuously during the exposure at the specified wavelength(s). After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or changes in appearance.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Optical branching efficiency before test.
- Change in transmittance during the test at the specified wavelength(s).
- Result of visual inspection.

11.4.6 Resistance to solvents and contaminating fluids

The proposed test method is applicable with the following modification:
- The type of fluids, temperature and duration of immersion shall be as specified in the detail specification.

11.4.7 Test for rapid depressurisation

Purpose
To determine the performance of the fibre optic branching device when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED). Optical power meter to monitor the change in transmittance and launching optics.

Test sample
A fibre optic branching device representative of the application or as specified.

Procedure
The fibre optic branching device is visually inspected and the geometrical dimensions are measured before depressurisation. The optical branching efficiency is measured at the specified wavelength(s). The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The change in transmittance in the specified optical paths shall be monitored at the specified wavelength(s) during the test until a stable output

is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the sample is removed from the chamber, the geometrical dimensions of the branching device are measured, and a visual inspection made to look for any damage or change in appearance or structure.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Optical branching efficiency prior to depressurisation.
- Change in transmittance during the test at the specified wavelength.
- Geometrical dimensions before and after test.
- Result of visual inspection.

11.4.8 Test severities

In the referenced test methods preferred combinations of parameter severities and duration of load are usually given. These combinations may not be adequate for space application and the values given in the detail specifications should be used.

12.0 FIBRE OPTIC SWITCHES

In 1986 the IEC issued Publication 876-1, Fibre optic switches, Part 1: Generic Specification. This publication contains a number of applicable test methods, but the number of tests covered is somewhat limited. A draft for a revision of this publication has been issued, document reference no. Committee 86B (Secretariat) 227. The draft contains some additional test methods which have been found applicable. These new test methods will only be referenced with the clause number with the understanding that it refers to the draft document. It is expected the revised standard will become available within a year.

12.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
12.1.1	Outline dimensions		Measured according to detailed specifications or as appropriate
12.1.2	Mass		Measured as appropriate

Table 12.1 Test methods for geometrical characteristics of a fibre optic switch.

12.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
12.2.1	Insertion loss for the various transmission paths at the operational wavelengths	IEC 876-1 clause 17.1	
12.2.2	Crosstalk and isolation between various optical paths	IEC 876-1 clause 17.2	
12.2.3	Modal distribution	See 12.2.2	
12.2.4	Polarisation dependence	See 12.2.3	
12.2.5	Return loss	Clause 4.3.5	
12.2.6	Susceptibility to ambient light coupling	IEC 876-1 clause 17.3	
12.2.7	Switching speeds and chattering	Clause 4.3.11	
12.2.8	Stability of optical performance	See 12.2.4	
12.2.9	Optical power handling capability	Clause 4.3.10	
12.2.10	Change in transmittance	Clause 4.3.9	

Table 12.2 Test methods for optical characteristics of a fibre optic switch.

12.2.1 Insertion loss

Two measurement methods are described in the recommended test. Which method to use depends on whether the input/output ports are fibre pigtails or connectors.

12.2.2 Modal distribution

For multimode fibre switches the insertion loss and return loss will depend on the modal distribution of the incoming light. No test method has of yet been established by the recognised standards organisations with regard to determine this dependence.

A method is proposed here where the insertion loss and return loss is measured with fully filled and with equilibrium mode distribution to get a measure of the modal dependence. These two situations might occur in short and long line length systems, respectively. Reference is made to IEC Publication 793-1 Clause 32 and also Clause 4.3.4 in the draft document for a detailed discussion of these launch conditions.

Test for modal dependence of insertion loss and return loss

Purpose
To determine the insertion loss and return loss of the optical switch for two different modal distributions (fully filled and equilibrium) of the incoming light. The test is only applicable to multimode fibre switches.

Test arrangement
The test arrangement is described in Tests 12.2.1 and 12.2.5 for the insertion loss and return loss, respectively. The necessary means must be provided for achieving fully filled and equilibrium mode distribution. The measurements shall be done at the specified wavelength(s).

Test procedure
- Launch light into the input port with fully filled mode distribution. Use the appropriate methods described for Tests 12.2.1 and 12.2.5 to measure the insertion loss and return loss, respectively. The switch should be actuated a number of times to get a picture of the variation in loss before the insertion loss/return loss is measured. The test should be done for each path through the switch unless otherwise specified.
- Repeat the whole procedure with the equilibrium mode distribution.

Results
The following data shall be recorded unless otherwise specified:
- Characteristics of light source (type, wavelength, spectral width)
- Description of launching arrangement.
- Methods used to measure insertion loss and return loss.
- The value of insertion loss and return loss at the two modal distribution.
- Difference in insertion loss and return loss for the two modal distribution.

12.2.3 Polarisation dependence

The insertion loss and return loss will for some devices be dependent on the state of polarisation of the incoming light. This is particularly the case for integrated optics switches. No test methods for determining the dependence of the insertion loss and return loss on the state of polarisation has as of yet been established by the standards organisation.

Test for polarisation dependence of insertion loss and return loss

Purpose
To determine the polarisation dependence of insertion loss and return loss for a fibre optic switch.

Test arrangement
The test arrangement is the same as for the measurement of insertion loss and return loss, see Tests 12.2.1 and 12.2.5, but with a rotatable polariser incorporated into the light path of the excitation unit.

Test sample
One or more representative fibre optic switch or as specified.

Test procedure
The test is carried out following the usual procedures for measuring insertion and return loss but with the following modifications:
- Measure the transmitted signal and return signal (if specified) as a function of the direction of linear polarisation of the incident light by rotating the polariser 360°.
- Measure the input signal also as a function of the direction of linear polarisation.
- Calculate the insertion loss and return loss (if specified) as a function of the direction of linear polarisation.

Results
The following data shall be recorded unless otherwise specified:
- Characteristics of light source (type, wavelength, spectral width)
- Description of launching arrangement including arrangement for obtaining linearly polarised light.
- Method used to measure insertion loss and return loss (if specified).
- The value of insertion loss and return loss (if specified) as a function of the direction of linear polarisation, or as specified.

12.2.4 Stability of optical performance

The standards organisations have not yet established a test method for stability of optical performance. A method is proposed here based on the test method for change in transmittance, see Test Method 12.2.10.

Test method for stability of optical performance

Purpose
To determine the variation in insertion loss from switching operation to switching operation and the variation as a function time with the switch in a closed position.

Test arrangement
The test arrangement is the same as described for Test 12.2.10, but a special test chamber is not needed.

Test sample
One or more representative fibre optic switch or as specified.

Procedure
The switch is installed and then operated according to the specified sequence of openings and closings. The number of operations and time in the open and closed position after each operation shall be given in the detail specifications. The transmitted signal shall be recorded continuously during the whole test sequence. All switching paths shall be tested unless otherwise specified.

Results
The following data shall be given unless otherwise specified
- Description of test arrangement including light source, launching optics and detection system.
- Test sequence to which the switch has been subjected.
- Variation in insertion loss during the test.

12.2.5 Change in transmittance

Test 12.2.10 gives a method for measuring the change in transmittance when the switch is subjected to various loads. It is assumed used when such measurements are called for in the various mechanical and environmental tests.

12.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
12.3.1	Vibration	IEC 876-1 clause 18.2	
12.3.2	Shock	IEC 876-1 clause 18.4	
12.3.3	Acceleration	Clause 4.4.13	
12.3.4	Crush resistance	Clause 4.4.10	
12.3.5	Impact	Clause 4.4.12	
12.3.6	Drop	Clause 4.4.14	
12.3.7	Bump	IEC 876-1 clause 18.3	
12.3.8	Strength of attachment of fibre	Clause 4.4.4 Clause 4.4.11 Clause 4.4.35 Clause 4.4.5	Pulling Axial compression Flex, nutation Torsion
12.3.9	Actuating mechanism	See 12.3.2	

Table 12.3 Test methods for mechanical characteristics of a fibre optic switch.

12.3.1 Strength of attachment of fibre

The listed test methods are applicable to switches with fibre or cable input/output ports. For switches with connectorized input/output ports reference is made to Chapter 7 with respect to testing of mechanical properties.

12.3.2 Test for actuating mechanism

Purpose
To determine any variation in insertion loss, switching speed, and chattering (bounce time) when the actuation signal is varied within its specified limits.

Test arrangement
The same test arrangement as described for Test 12.2.7 (Switching speed and chattering) is to be used. In addition a reference channel or some other suitable means should be provided to monitor any variation in the source output power. All measurements are to be performed at the operational wavelength(s) of the switch.

Procedure
The insertion loss should be measured before the start of the test (Test 12.2.1) applying the nominal value of the actuation signal if not otherwise specified. The switch is then installed in the test set-up, and the transmitted signal, switching speed and chattering are recorded as appropriate for the following operations of the switch unless otherwise specified:

- engagement: actuation signal from nominal 'off' level to nominal 'on' level,
- engagement: actuation signal from nominal 'off' level to minimum specified 'on' level,
- engagement: actuation signal from nominal 'off' level to maximum specified 'on' level, (if applicable),
- disengagement: actuation signal from nominal 'on' level to nominal 'off' level,
- disengagement: actuation signal from nominal 'on' level to maximum (or minimum) specified level to disengage.

The measurment shall be performed for all switch paths unless otherwise specified.

Results
The following data shall be given unless otherwise specified:
- Description of test arrangement including light source, launching optics and detection system.
- Insertion loss at start of the test.
- Number of engagements/disengagements for the various actuating conditions.
- Change in insertion loss for the various actuation signal levels.
- Switching speed and bounce time for the various actuating conditions.

12.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
12.4.1	Climatic sequence	IEC 876-1 clause 19.2	
12.4.2	Temperature extremes	Clause 4.4.17 Clause 4.4.18	Cold Dry heat
12.4.3	Rapid change in temperature	See 12.4.1	
12.4.4	Vacuum test (including temperature cycling)	See 12.4.2	
12.4.5	Condensation	IEC 876-1 clause 19.3	
12.4.6	Corrosive atmosphere	IEC 876-1 clause 19.6	Not considered applicable
12.4.7	Dust	IEC 876-1 clause 19.7	Not considered applicable
12.4.8	Flammability	IEC 876-1 clause 19.9	
12.4.9	Sealing	Clause 4.4.23 Clause 4.4.25	Panel/barrier seals Hermetic seal
12.4.10	UV radiation	See 12.4.3	
12.4.11	Ionizing radiation	See 12.4.4	
12.4.12	Solar radiation	See 12.4.5	
12.4.13	Resistance to solvents and contaminating fluids (as required)	IEC 876-1 clause 21	See 12.4.6
12.4.14	Ageing	IEC 876-1 Clause 20	See 12.4.7
12.4.15	Rapid depressurisation	See 12.4.8	
12.4.16	Electromagnetic field (stationary and alternating)	See 12.4.9	

Table 12.4 Test methods for environmental characteristics of a fibre optic switch.

12.4.1 Test for rapid change in temperature

The recommended test is IEC 876-1, Clause 19.4 with the following modifications:

- The temperatures of the two chambers, one at high and one at low temperature,shall be as specified.

- The transfer time between the two chambers at high and low temperature shall be as specified.
- The transmitted power at the specified wavelength through the switch shall be recorded continuously during the test including during the transfer between the two chambers.
- The switch shall be actuated at least once, unless otherwise specified, while it is in transfer between the two temperature chambers.
- All paths in the switch shall be tested unless otherwise specified.

12.4.2 Thermal vacuum test

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the fibre optic switch.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and capability of heating the fibre optic switch to 125°C or as specified.
- Measuring equipment for determining insertion loss and return loss (if specified).

Test sample
One or more representative fibre optic switch or as specified.

Procedure
- Measure insertion loss and return loss (if specified) before the start of the test.
- Place the switch(s) in the chamber, evacuate and subject the sample(s) to the specified temperature cycles. The set temperature(s), stay time at each temperature and number of cycles shall be as specified in the detail specification.
- After the completion of the test cycle, the sample(s) are removed and the insertion loss and return loss (if specified) measured once more. A visual inspection shall also be made.
- All paths through the switch shall be tested unless otherwise specified.

Results
The following data shall be given:
- Description of test arrangement for measuring insertion loss and return loss (if specified) including light source, launching optics.
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Insertion loss and return loss (if specified) before and after test.
- Result of visual inspection.

12.4.3 UV radiation test

Purpose
To determine that the fibre optic switch can withstand exposure to the specified UV radiation level.

Test arrangement

The following equipment is needed:

- A test chamber equipped with suitable lamps for simulating UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic switch to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the switch to be connected to the measuring equipment and the actuating power source outside the chamber.
- A test arrangement for measuring change in insertion loss.
- Measuring equipment for determining insertion loss and return loss (if specified).

Test sample

One or more representative fibre optic switch or as specified.

Procedure

- Measure the insertion loss and return loss (if specified) before the start of the test.
- Place the switch in the chamber and connect it to the equipment for measuring change in transmission and to the actuating power source.
- Expose the switch to the specified irradiance level for the specified time. The transmission shall be measured continuously during the test, and the switch shall be actuated at specified intervals. Fibres from the switch to the outside should be shielded from the UV radiation to avoid any radiation induced losses.
- After the completion of the test remeasure the return loss (if specified). A visual inspection shall also be made.
- All paths through the switch shall be tested unless otherwise specified.

Results

The following data shall be given:

- Description of test arrangement for measuring insertion loss, return loss (if specified) and transmission loss.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss at start of test.
- Change in insertion loss during the test at the specified wavelength.
- Return loss before and after test (if specified).
- Number of times switch has been actuated and intervals between actuations.
- Report on visual inspection.

12.4.4 Test for ionizing radiation

It is recommended that the test for optical fibres (IEC 793-1-D3) be used, but with the following modifications:

Dose rate/total dose level

Two somewhat different test procedures are described in the IEC test, one for low level of radiation (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample
One or more representative fibre optic switch or as specified. One should be aware that the ionizing radiation will induce losses in the fibres connected to the switch. The fibres should have been characterised in advance with respect to the induced losses so that one may be able to separate out any loss changes occurring in the switch.

Measurement
The insertion loss and return loss (if specified) shall be measured before the sample is exposed. During exposure the change in insertion loss shall be monitored at the specified wavelength. Upon completion of the test the return loss is measured (if specified), and a visual inspection shall also be made. All paths through the switch shall be tested unless otherwise specified. The test shall be carried out at room temperature unless otherwise specified.

12.4.5 Test for solar radiation

Purpose
To determine that the fibre optic switch can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic switch to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the switch to be connected to the measuring equipment and the actuating power source outside the chamber.
- A test arrangement for measuring change in insertion loss.
- Measuring equipment for determining insertion loss and return loss (if specified).

Test sample
One or more representative fibre optic switch or as specified.

Procedure
- Measure the insertion loss and return loss (if specified) before the start of the test.
- Place the switch in the chamber and connect it to the equipment for measuring change in transmission and to the actuating power source.
- Expose the switch to the specified irradiance level for the specified time. The transmission shall be measured continuously during the test, and the switch shall be actuated at specified intervals. Fibres from the switch to the outside should be shielded from the solar radiation to avoid any radiation induced losses.
- After the completion of the test remeasure the return loss (if specified). A visual inspection shall also be made.
- All paths through the switch shall be tested unless otherwise specified.

Results
The following data shall be given:
- Description of test arrangement for measuring, insertion loss, return loss (if specified) and transmission loss.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss at start of test.
- Change in insertion loss during the test at the specified wavelength.
- Return loss before and after test, if specified.
- Number of times switch has been actuated and intervals between actuations.
- Report on visual inspection.

12.4.6 Resistance to solvents and contaminating fluids

The recommended test method lists a number of fluids which might not all be relevant for space applications. Reference is instead made to ESA/SCC Generic Specification No. 3901, para. 9.21. The type of fluids, temperature and duration of immersion shall be as given in the detailed specification.

12.4.7 Ageing

The ageing test will often be carried out above specified operating temperature. It is thus recommended that the switch not be actuated during the test unless specified.

12.4.8 Test for rapid depressurisation

Purpose
To determine the performance of the fibre optic switch when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow the switch to be connected to the measuring equipment and to the actuating power source outside the chamber.
- A test arrangement for measuring change in insertion loss.
- Measuring equipment for determining insertion loss.

Test sample
One or more fibre optic switch representative of the application or as specified.

Procedure
- Measure the outer geometrical dimensions of the switch.
- Measure the insertion loss.
- Place the switch in the chamber and connect it to the equipment for measuring change in insertion loss and to the actuating power source.
- Reduce the chamber pressure at the specified rate until a stable pressure of not more than 10 Torr, or as specified, is reached.
- Monitor the change in insertion loss continuously during the test. Continue the monitoring until the insertion loss has stabilised and the pressure has stabilised below 10 Torr.
- Actuate the switch at least once during the pressure fall between 1 atm and 10 Torr and also after the pressure has stabilised below 10 Torr, as specified.
- Bring the chamber back to 1 atm, remove the sample, measure the outer geometrical dimensions of the switch and make a visual inspection.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Insertion loss prior to depressurisation.
- Change in insertion loss during the test at the specified wavelength including the tests of the actuating function.
- Change in geometrical dimensions during test.
- Result of visual inspection.

12.4.9 Test for effects of external electromagnetic field

Purpose
To determine if the operation of the switch is affected by external electromagnetic fields. The test is only applicable to switches which can be actuated electrically or magnetically.

Test arrangement
The following equipment is needed:
- A suitable chamber equipped with the required electromagnetic sources to expose the switch to the specified electromagnetic fields. Reference is made to IEC Publications 801-1, 801-2 and 801-3 which describes methods for testing with respect to electrostatic discharges and electromagnetic radiation. The test chamber must have appropriate ports to allow the switch to be connected to the outside measurement equipment and actuating power source.
- A test arrangement for measuring change in insertion loss.

Test sample
One or more representative fibre optic switch or as specified.

Procedure
- Place the switch in the test chamber and connect it to equipment for measuring change in transmission and to the actuating power source.
- Expose the switch to the specified electromagnetic field while the switch is
  - open
  - closed
  - while being actuated

- Monitor the transmitted power during the whole test at the specified wavelength.

<u>Results</u>
The following data shall be given:
- Characteristic properties of the electromagnetic field.
- Details of the test programme to which the switch was adjusted.
- Change in insertion loss during the various test sequences.

13 FIBRE OPTIC WAVELENGTH MULTIPLEXERS/DEMULTIPLEXERS

A generic specification for fibre optic branching devices which also covers fibre optic wavelength multiplexers/demultiplexers has been published by the IEC (IEC 875-1, issued 1986). This document describes a number of applicable test procedures with respect to optical, mechanical and environmental parameters, but has a limited scope compared to the test strategy described in Part 2. A revision of this document is under preparation and a draft for the revised issue exists (document reference no 86B(Secretariat)228). This draft contains some additional test methods which have been found applicable. These test procedures are referenced with the clause number they are given in this draft document. The draft document was issued in May 1991 and it is expected that a revised version of the generic specification for fibre optic branching devices including wavelength multiplexer/demultiplexer will become available within a year.

13.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
13.1.1	Outline dimensions		Measured according to detail specifications or as appropriate
13.1.2	Mass		Measured as appropriate

Table 13.1 Test methods for geometrical characteristics of a fibre optic wavelength multiplexer/demultiplexer.

13.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
13.2.1	Optical branching efficiency	See 13.2.1	
13.2.2	Modal distribution	See 13.2.2	
13.2.3	Polarisation sensitivity	See 13.2.3	
13.2.4	Stability of transfer coeff-icients		not considered applicable
13.2.5	Susceptibility to ambient light coupling	IEC 875-1 clause 17.2	
13.2.6	Optical power handling capability	IEC 875-1 clause 17.5	See 13.2.4
13.2.7	Change in transmittance	clause 4.3.8	See 13.2.5

Table 13.2 Test methods for optical characteristics of a fibre optic wavelength multiplexer/ demultiplexer.

13.2.1 Optical branching efficiency

The branching efficiency encompasses the insertion loss for the various optical paths and also the return loss from the input port. The recommended method for measuring the insertion loss is found in IEC 875-1 clause 17.1. The method for measurement of return loss can be found in the draft for the revised version, clause 4.3.5.

In fibre optic wavelength multiplexer/demultiplexer the optical branching efficiency is purposely given a dependence on wavelength. In some cases it may therefore be necessary to measure the spectral dependence of the branching efficiency. A test method for this measurement is given in the draft for the revised version, Clause 4.3.6.

13.2.2 Modal distribution

In multimode fibre optic wavelength multiplexer/demultiplexers the branching efficiency may be dependent on the modal distribution in the launch fibre. The standards organisations have not yet suggested a test for the dependence on modal distribution. The method suggested here will give an indication of the modal dependence as it measures the difference in branching efficiency with fully filled and equilibrium mode distribution, corresponding to short and long line length systems respectively.

Test for dependence on modal distribution

Purpose
To determine the difference in branching efficiency for fully filled and equilibrium mode distribution.

Test arrangement
The following equipment is needed:
- Equipment needed for measurement of optical branching efficiency according to 13.2.1.
- Means for launching light with the specified mode distributions into the fibre optic wavelength multiplexer/demultiplexer.

Test sample
A fibre optic wavelength multiplexer/demultiplexer representative of the application or as specified.

Test procedure
- Launch light into the fibre in such a way that fully filled mode distribution is achieved.
- Measure the branching efficiency for that particular mode distribution at the specified wavelength(s) according to one of the methods described in 13.2.1.
- Repeat the procedure for the equilibrium mode distribution.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of arrangement for launching light into the wavelength multiplexer/demultiplexer.
- The branching efficiency at each mode distribution.

13.2.3 Polarisation sensitivity

The IEC generic specification includes a method to measure polarisation sensitivity of a wavelength multiplexer/demultiplexer (IEC 875-1, clause 17.6). The proposed test method is basically the same, but with a few modifications.

Polarisation sensitivity test

Purpose
The purpose of the test is to establish the dependence of branching efficiency on state of polarisation of incoming light.

Test arrangement
The following equipment is needed:
- Means for measuring change in transmittance as described for Test 13.2.7.
- Means for generating a linearly polarised beam whose direction of polarisation can be rotated 360°.

Test sample
An fibre optic wavelength multiplexer/demultiplexer representative for the application or as specified.

Test procedure
The change in transmittance is measured as the direction of polarisation in the incoming light is rotated 360°. The reference signal is measured simultaneously such that it would reflect any change in input signal as the direction of polarisation is rotated (this requires a polarisation independent coupler).

The procedure is repeated at each wavelength of interest.

Results
The following shall be recorded:
- Light source (peak wavelength, linewidth)
- Description of means for achieving a rotatable linearly polarised beam.
- Change in transmittance as a function of direction of polarisation and return loss (if required)

13.2.4 Optical power handling capability

The referenced test is applicable with a few modifications. The light source should operate at the same wavelength and have the same spectral character as in the intended application. The power level shall be increased in steps to the specified level.

13.2.5 Change in transmittance

The referenced test method is used when the parameter of interest is the change in optical branching efficiency under varying operating conditions, for example during mechanical and environmental loads.

13.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
13.3.1	Vibration	IEC 875-1 clause 18.2	
13.3.2	Shock	IEC 875-1 clause 18.4	
13.3.3	Acceleration	clause 4.4.13	
13.3.4	Crush resistance	clause 4.4.10	
13.3.5	Impact	clause 4.4.12	
13.3.6	Drop	clause 4.4.14	
13.3.7	Bump	IEC 875-1 clause 18.3	
13.3.8	Strength of attachment of fibre/cable - pulling - axial compression - torsion - bend/flex/nutation	 clause 4.4.4 clause 4.4.11 clause 4.4.5 clause 4.4.35	See 13.3.2

Table 13.3 Test methods for mechanical characteristics of a fibre optic wavelength multiplexer/demultiplexer.

13.3.1 Test severities

The mechanical test methods referenced include preferred combinations of test parameters (level of vibration, shock, acceleration, impact etc.). In those cases where these levels do not fulfil the requirements in the detail specification, the test severities should be adjusted accordingly. This will not, however, change the test procedures.

13.3.2 Strength of fibre/cable attachment

The referenced tests include methods to measure the strength of attachment of fibre. If the input and output port of the fibre optic wavelength multiplexer/demultiplexer are connectors, these tests should be replaced by tests for strength of coupling mechanisms, and strength of fibre/cable attachment found for fibre optic connectors, see Chapter 7.

13.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
13.4.1	Climatic sequence	IEC 875-1 clause 19.2	
13.4.2	Temperature extremes	clause 4.4.17 clause 4.4.18 clause 4.4.19	Cold Dry heat Damp heat
13.4.3	Rapid change in temperature	IEC 875-1 clause 19.4	See 13.4.1
13.4.4	Vacuum test (including temperature cycling)	See 13.4.2	
13.4.5	Condensation	IEC 875-1 clause 19.3	
13.4.6	Corrosive atmosphere	IEC 875-1 clause 19.6	not considered applicable
13.4.7	Dust	IEC 875-1 clause 19.7	not considered applicable
13.4.8	Flammability	IEC 875-1 clause 19.9	
13.4.9	Sealing	clause 4.4.23 clause 4.4.25	Panel/barrier sealed Hermetic sealed
13.4.10	UV radiation	See 13.4.3	
13.4.11	Ionizing radiation	See 13.4.4	
13.4.12	Solar radiation	See 13.4.5	
13.4.13	Resistance to solvents and contaminating fluids (as required)	IEC 875-1 clause 21	See 13.4.6
13.4.14	Ageing	IEC 875-1 clause 20	
13.4.15	Rapid depressurisation	See 13.4.7	

Table 13.4 Test methods for environmental characteristics of a fibre optic wavelength multiplexer/demultiplexer.

13.4.1 Rapid change in temperature

The recommended test procedure is applicable with the following modifications:

- The change in transmittance at the specified wavelength(s) and in the specified optical paths shall be monitored during the whole test procedure, including during the transfer between the two chambers of high and low temperatures.
- High and low temperature, temperature change rate and number of cycles should be given in the detail specification.

13.4.2 Vacuum test (including temperature cycling)

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the fibre optic wavelength multiplexer/demultiplexer.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic wavelength multiplexer/demultiplexer to 125°C or as specified.
- Measurement equipment for determining the optical branching efficiency at the specified wavelength(s) and in the specified optical paths (stabilised optical source, optical detector, launching optics, spectrometer (if required)).

Test sample
A fibre optic wavelength multiplexer/demultiplexer representative for the application or as specified.

Procedure
The dimensions of the wavelength multiplexer/demultiplexer and the dimensions of any strain relief mechanism etc. shall be measured prior to evacuation. The branching efficiency in the specified optical paths shall be measured before the test at the specified wavelength(s) to verify the performance of the wavelength multiplexer/demultiplexer.

The sample is placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. After the test is completed the optical branching efficiency shall be measured at the specified wavelength(s). The dimensions shall also be measured and a visual inspection shall also be made to look for any damage or change in appearance.

The set temperature(s), duration of test at each temperature and number of cycles shall be as specified in the detail specification.

Results
The following data shall be given
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Branching efficiency before and after test cycle.
- Result of visual inspection/geometrical control.

13.4.3 UV radiation test

Purpose
To determine that the fibre optic wavelength multiplexer/demultiplexer can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the fibre optic wavelength multiplexer/demultiplexer to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard

to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber

- Measurement equipment for determining the change in transmittance in the specified optical paths and at the specified wavelength(s) (stabilised optical source, optical detector, launching optics, spectrometer, (if required)).

Test sample

A fibre optic wavelength multiplexer/demultiplexer representative for the application or as specified.

Procedure

The optical branching efficiency shall be measured at the specified wavelength(s) prior to irradiation. The sample is then placed in the chamber and the fibre ends connected to the transmittance measurement equipment. The sample is then subjected to the specified irradiance level for the specified time. The change in transmittance at the specified wavelength(s) is monitored continuously during the exposure. After completion of exposure the sample shall be removed from the chamber. Further a visual inspection shall be made to look for any damage or changes in appearance.

Results

The following data shall be given:

- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Branching efficiency before test.
- Change in transmittance during the test at the specified wavelength(s).
- Result of visual inspection.

13.4.4 Ionizing radiation

No test method exists for testing with respect to ionizing radiation. The test recommended for optical fibres (IEC 793-1-D3) could be used with a few modification. These modifications are:

Dose rate/total dose level

Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Test sample
A fibre optic wavelength multiplexer/demultiplexer representative for the application or as specified. The fibre attached to the wavelength multiplexer/demultiplexer should be characterised with respect to ionizing radiation in advance to be able to separate the effects of ionizing radiation related to wavelength multiplexer/demultiplexer from the effects related to the fibre.

Measurements
The branching efficiency in the specified optical paths shall be measured at the specified wavelength(s) before the sample is irradiated. During irradiation the change in transmittance shall be monitored at the specified wavelength(s) in the specified optical paths. The wavelength multiplexer/demultiplexer shall be visually inspected before and after irradiation to look for damage or changes in structure or appearance.

13.4.5 Solar radiation

A test with respect to solar radiation is described by IEC (IEC 875-1, clause 19.12). We have, however, not found this test quite suitable to cover all aspects of testing with respect to solar radiation. We therefore propose the following test procedure.

Solar radiation test

Purpose
The purpose of the test is to determine that the wavelength multiplexer/demultiplexer can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the wavelength multiplexer-/demultiplexer to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength(s) (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A fibre optic wavelength multiplexer/demultiplexer representative for the application or as specified.

Procedure
The optical branching efficiency in the specified optical path is measured prior to irradiation at the specified wavelength(s). The sample is placed in the test chamber and the pigtails connected to the measurement equipment which is located outside the chamber.

The wavelength multiplexer/demultiplexer is then subjected to the specified irradiance level for the specified time. The change in transmittance in the specified optical paths is recorded continuously during the exposure at the specified wavelength(s). After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or changes in appearance.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Optical branching efficiency before test.
- Change in transmittance during the test at the specified wavelength(s).
- Result of visual inspection.

13.4.6 Resistance to solvents and contaminating fluids

The proposed test method is applicable with the following modification:
- The type of fluids, temperature and duration of immersion shall be as specified in the detail specification.

13.4.7 Test for rapid depressurisation

Purpose
To determine the performance of the fibre optic wavelength multiplexer/demultiplexer when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow fibre pigtails to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED). Optical power meter to monitor the change in transmittance and launching optics.

Test sample
A fibre optic wavelength multiplexer/demultiplexer representative of the application or as specified.

Procedure
The fibre optic wavelength multiplexer/demultiplexer is visually inspected and the geometrical dimensions are measured before depressurisation. The optical branching efficiency is measured

at the specified wavelength(s). The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The change in transmittance in the specified optical paths shall be monitored at the specified wavelength(s) during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the sample is removed from the chamber, the geometrical dimensions of the wavelength multiplexer/demultiplexer are measured, and a visual inspection made to look for any damage or change in appearance or structure.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Optical branching efficiency prior to depressurisation.
- Change in transmittance during the test at the specified wavelength.
- Geometrical dimensions before and after test.
- Result of visual inspection.

13.4.8 Test severities

In the referenced test methods preferred combinations of parameter severities and duration of load are usually given. These combinations may not be adequate for space application and the values given in the detail specifications should be used.

14.0 FIBRE OPTIC ISOLATORS

IEC has issued a draft document called "Generic Specifications for Fibre Optic Isolators", document reference no. 86B (Secretariat), 226. It was discussed in a meeting in September 1991, and it is expected it will be issued as an official document within about one year.

Most of the required tests are described in this document. Those tests which have been found applicable are referenced with respect to the appropriate clause in this document. Only the clause number is given in the tables since the IEC document has as of yet not received a number.

14.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
14.1.1	Outline dimensions	Clause 4.4.2	Measured according to detail specifications or as appropriate
14.1.2	Mass	Clause 4.4.2	Measured as appropriate

Table 14.1 Test methods for geometrical characteristics of a fibre optic isolator.

14.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
14.2.1	Insertion loss	Clause 4.5.3	see 14.2.1
14.2.2	Polarisation dependence	Clause 4.5.11	
14.2.3	Backward loss	Clause 4.5.4	
14.2.4	Return loss	Clause 4.5.6	
14.2.5	Spectral loss	Clause 4.5.7	see 14.2.2
14.2.6	Susceptibility to ambient light coupling	Clause 4.5.5	
14.2.7	Optical power handling capability	Clause 4.5.12	
14.2.8	Change in insertion loss and backward loss	Clause 4.5.9	see 14.2.3

Table 14.2 Test methods for optical characteristics of a fibre optic isolator.

14.2.1 Insertion loss

Four test methods are given by the IEC. Which method is applicable depends on the input/output ports of the component. The isolator may have fibre or cable pigtails with or without connectors or the connectors may be an integral part of the housing.

14.2.2 Spectral loss

The purpose of this test is to determine wavelength dependence of the insertion loss, backward loss and return loss. The separate tests listed for the same properties are normally done at one discrete wavelength.

14.2.3 Change in insertion loss and backward loss

During many of the mechanical and environmental tests it may be required to monitor the change in insertion loss and/or backward loss during the test. The referenced clause describes a method which shall be used when measurement of change in insertion loss and/or backward loss is required.

It should be noted that it may be difficult to measure insertion loss and backward loss truly simultaneously due to interference problems. By use of couplers and/or switches one can, however, measure both parameters quasicontinuously by alternating between the two measurements. Another possibility is to use two or more samples and measure insertion loss and backward loss on separate samples. The detailed specifications should state how the measurement should be performed in this respect.

14.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
14.3.1	Vibration	Clause 4.6.3	
14.3.2	Shock	Clause 4.6.11	
14.3.3	Acceleration	Clause 4.6.15	
14.3.4	Crush resistance	Clause 4.6.12	
14.3.5	Impact	Clause 4.6.14	
14.3.6	Drop	Clause 4.6.16	
14.3.7	Bump	Clause 4.6.10	
14.3.8	Strength of attachment of fibre	Clause 4.6.6 Clause 4.6.13 Clause 4.6.18 Clause 4.6.7	Pulling Axial compression Flex, nutation Torsion

Table 14.3 Test methods for mechanical characteristics of a fibre optic isolator.

14.3.1 Strength of attachment of fibre

The recommended test methods are specified for cables, but are considered applicable for fibres also. Clause 4.6.4 of the IEC draft document gives a test for fibres. But the description is considered incomplete, and the test methods referenced in Table 14.3 are preferred.

14.3.2 Test severities

In the listed test methods there are in most cases indicated preferred severities. However, the test severities should be as specified in the detail specifications.

14.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
14.4.1	Climatic sequence	Clause 4.7.7	
14.4.2	Temperature extremes	Clause 4.7.5 Clause 4.7.6	Dry heat Damp heat
14.4.3	Rapid change in temperature	See 14.4.1	
14.4.4	Vacuum test (including temperature cycling)	See 14.4.2	
14.4.5	Condensation	Clause 4.7.8	
14.4.6	Corrosive atmosphere	Clause 4.7.13	Usually not applicable
14.4.7	Dust	Clause 4.7.14	Usually not applicable
14.4.8	Flammability	Clause 4.7.16	
14.4.9	UV radiation	See 14.4.3	
14.4.10	Ionizing radiation	See 14.4.4	
14.4.11	Solar radiation	See 14.4.5	
14.4.12	Resistance to solvents and contaminating fluids (as required)	Clause 4.7.22	See 14.4.6
14.4.13	Susceptibility to external magnetic fields	Clause 4.5.8	
14.4.14	Ageing	Clause 4.7.21	
14.4.15	Rapid depressurisation	See 14.4.7	

Table 14.4 Test methods for environmental characteristics of a fibre optic isolator.

14.4.1 Rapid change in temperature

The recommended test method is found in Clause 4.7.9, but with the following modifications:
- Measurement should be made of change in insertion loss and/or backward loss as specified (see

14.2.3) during the whole test sequence including during the transfer between the two chambers of high and low temperatures.
- High and low temperatures, temperature change rate, and number of cycles should be as given in the detail specifications.

14.4.2 Vacuum test

Purpose
To determine how the exposure to vacuum and temperature cycling affects the performance of the fibre optic isolator.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the fibre optic isolator to 125°C or as specified.
- Measurement equipment for determining the insertion loss and backward loss of the isolator.

Test sample
One or more representative sample of the fibre optic isolator.

Procedure
The insertion loss and backward loss of the isolator shall be measured before the start of the test at the specified wavelength(s). The sample is then placed in the chamber, the chamber evacuated and the sample subjected to the specified temperature cycles. The set temperature(s), duration at each temperature and number of cycles shall be as specified in the detail specification.

After completion of the test cycles the sample shall be removed from the chamber and the measurement of insertion loss and backward loss repeated. A visual inspection shall be made to look for any damage or change in the appearance or structure of the isolator.

Results
The following data shall be given.
- Pressure in vacuum chamber.
- Temperature cycle diagram including number of cycles.
- Insertion loss and backward loss before and after test at the specified wavelength.
- Result of visual inspection.

14.4.3 UV radiation test

Purpose
To determine that the fibre optic isolator can withstand exposure to the specified UV radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the UV radiation and capable of emitting sufficient power in the specified spectral range to expose the isolator to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre/cable ends to be connected to the

measuring equipment outside the chamber.
- Measurement equipment for determining the insertion loss and backward loss of the isolator.
- Measurement equipment for determining the change in insertion loss and backward loss.

Test sample
One or more representative sample of the isolator.

Procedure
The insertion loss and backward loss at the specified wavelength(s) shall be measured before the test. The sample is placed in the chamber and the fibre/cable ends connected to the measurement equipment. Any fibre lengths used to connect the isolator to the measurement equipment should be protected from the UV radiation to ensure that no losses are induced in these lengths. The fibre is then subjected to the specified irradiance level for the specified time. The change in insertion loss and/or backward loss (as specified) shall be measured during the test at the specified wavelength. Reference is made to 14.2.3. After completion of the exposure the sample shall be removed from the chamber and a visual inspection shall be made to look for any damage or change in the appearance or structure of the isolator.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Insertion loss and backward loss before test.
- Change in insertion loss and backward loss during the test at the specified wavelength.
- Result of visual inspection.

14.4.4 Test for ionizing radiation

It is recommended that test arrangement described in IEC 793-1-D3 be used, but with a few modifications. Two somewhat different test procedures are described in the IEC test, one for low level of radiation, (background radiation) and one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed but with a different total dose/dose rate combination. It is recommended that one of the following total dose/dose rate combinations be used [4] unless otherwise specified.

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

The test may be carried out at room temperatures unless otherwise specified.

The insertion loss and backward loss at the specified wavelength shall be measured before the test. The change in insertion loss and/or backward loss (as specified) shall be measured during the test at the specified wavelength. Reference is made to 14.2.3. A visual inspection should also be made after the test.

One should be aware that the ionizing radiation will induce losses in the fibre(s) connecting the isolator(s) to the outside measurement equipment. A correction might have to be made to the measured changes in loss to determine the changes in the isolator itself.

The following data shall be given:
- Radiation dose/dose rate.
- Duration of exposure.
- Temperature of isolator during exposure.
- Insertion loss and backward loss before the test.
- Changes in insertion loss and backward loss as a function of dose.
- Any corrections made for losses induced in the fibres.
- Result of visual inspection.

14.4.5 Solar radiation test

Purpose
To determine that the fibre optic isolator can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating the solar radiation and capable of emitting sufficient power in the specified spectral range to expose the isolator to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the fibre/cable ends to be connected to the measuring equipment outside the chamber.
- Measurement equipment for determining the insertion loss and backward loss of the isolator.
- Measurement equipment for determining the change in insertion loss and backward loss.

Test sample
One or more representative sample of the isolator.

Procedure
The insertion loss and backward loss shall be measured before the test at the specified wavelength(s). The sample is placed in the chamber and the fibre/cable ends connected to the measurement equipment. Any fibre lengths used to connect the isolator to the measurement equipment should be protected from the solar radiation to ensure that no losses are induced in these lengths. The fibre is then subjected to the specified irradiance level for the specified time. The change in insertion loss and/or backward loss (as specified) shall be measured during the test at the specified wavelength. Reference is made to 14.2.3. After completion of the exposure the sample shall be removed from the chamber and a visual inspection shall be made to look for any damage or change in the appearance or structure of the isolator.

Results
The following data shall be given:
- Irradiance level and spectral character of radiation.

- Duration of exposure.
- Insertion loss and backward loss before test.
- Change in insertion loss and backward loss during the test at the specified wavelength.
- Result of visual inspection.

14.4.6 Resistance to solvents and contaminating fluids

The recommended test method lists a number of fluids which might not all be relevant for space applications. Reference is instead made to ESA/SCC Generic Specification No. 3901, para. 9.21. The type of fluids, temperature and duration of immersion shall be as given in the detailed specification.

14.4.7 Rapid depressurisation test

Purpose
To determine the performance of the fibre optic isolator when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow the isolator to be connected to the measuring equipment outside the chamber.
- Measurement equipment for determining the insertion loss and backward loss of the isolator.
- Measurement equipment for determining the change in insertion loss and backward loss.

Test sample
One or more representative isolator.

Procedure
The insertion loss and backward loss at the specified wavelength shall be measured before the test. The outer dimensions of the sample shall also be measured. The sample is then placed in the test chamber and connected to the measurement equipment located outside the chamber. The chamber pressure is then reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The change in insertion loss and/or backward loss (as specified) at the specified wavelength shall be recorded continuously during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the sample is removed from the chamber, the outer dimensions of the sample measured, and a visual inspection made to look for any damage or change in the cable structure.

Results
The following data shall be given:
- Rate of pressure fall and minimum pressure.
- Insertion loss and backward loss before test.
- Change in insertion loss and backward loss (if specified) during the test at the specified wavelength.
- Sample dimensions before and after the test.
- Result of visual inspection.

14.4.8 Test severities
In the listed test methods there are in some cases indicated preferred severities. However, the test severities should be as specified in the detail specifications.

15.0 COMBINED ELECTRIC/FIBRE OPTIC CABLE

For the combined cable a complete set of test methods will have to be established for both the electrical and optical part. Only the optical part will be considered here, but the tests shall all be done on the combined cable. It is assumed that appropriate test methods exist for the various types of electrical cables that might be used in a combined cable, and the electrical part of the combined cable will not be considered further. Account will, however, be taken of the heating effect of the electrical cable on the optical fibre cable. There is no electromagnetic interference on the optical cable from the electrical cable nor the other way around.

It may well be that in some cases one can do a combined test for the electrical and optical part, and this is specifically mentioned for some of the tests.

The various test methods for the combined cable are essentially the same as for the optical fibre cable, see Ch. 6. The main difference is that in some of the tests, the electrical cable shall be energised to test out the possible effects of the resistive heating on the optical part of the cable.

15.1 Test methods for geometrical characteristics

Test	Characteristics	Test method	Remarks
15.1.1	Length of cable	See 15.1.17	
15.1.2	Thickness of sheath	IEC publication 189, 540	Mechanical test method
15.1.3	Overall dimensions	IEC publication 189, 540	Mechanical test method
15.1.4	Fibre geometrises for cabled fibres are measured using the same methods as for the uncabled fibres, see 5.1		
15.1.5	Mass		Measured as appropriate

Table 15.1 Test methods for geometrical characteristics of a combined electric/fibre optic cable

15.1.1 Measuring of cable length

The cable length can be measured by various mechanical means. The fibre length in the cable can be measured by Test 5.1.7. The fibre length can, however, be longer than the cable length, depending on the cable design. This is in particular the case for cables where the fibres are stranded and for cables where the fibres have purposely been given a so-called excess length. For such cables the measured fibre length has to be adjusted to arrive at the correct cable length.

15.2 Test methods for optical characteristics

Test	Characteristics	Test method	Remarks
15.2.1 15.2.2 15.2.3	Attenuation	IEC 793-1-C1A IEC 793-1-C1B IEC-1-C1C	Cut back Insertion loss Backscattering (OTDR)
15.2.4	Cut-off wavelength	IEC 793-1-C7	
15.2.5	Continuity	IEC 793-1-C4	
15.2.6 15.2.7	Change in optical transmission	IEC 793-1-C10A IEC 793-1-C10B	Transmission Backscattering

Table 15.2 Test methods for optical characteristics of a combined electric/fibre optic able

Of the optical characteristics only the attenuation and cut-off wavelength will be significantly affected by the cabling process. Methods for determining the other optical characteristics of the fibres are given in Ch. 5. These methods are of course also applicable to cabled fibres.

15.2.1 Attenuation

Test method IEC 793-1-C1A (cut back) and IEC 793-1-C1B (insertion loss) are suitable for both spectral loss measurements and measurements at one or more discrete wavelengths. Method IEC 793-1-C1C (backscattering) is for practical purposes limited to determining the attenuation in the wavelength regions of 850 nm, 1300 nm and 1550 nm due to availability of equipment.

The attenuation shall be measured with no load and with maximum load on the electrical cable or with load as specified.

15.2.2 Continuity/change in optical transmission

These test methods are to be used when it is required to measure change in transmission including possible fibre break, in the various mechanical and environmental tests.

15.3 Test methods for mechanical characteristics

Test	Characteristics	Test method	Remarks
15.3.1	Tensile strength	IEC 794-1-E1	
15.3.2	Abrasion	IEC 794-1-E2 (Draft)	see 15.3.2
15.3.3	Crush	IEC 794-1-E3	
15.3.4	Impact	IEC 794-1-E4	
15.3.5	Repeated bending	IEC 794-1-E6	
15.3.6	Torsion	IEC 794-1-E7	
15.3.7	Flexing	IEC 794-1-E8	
15.3.8	Snatch	IEC 794-1-E9	
15.3.9	Kink	IEC 794-1-E10	
15.3.10	Bend under tension	IEC 794-1-E11	
15.3.11	Vibration	EIA-455-11A	
15.3.12	Cold bend	IEC 794-1-E11 Clause 20.7	

Table 15.3 Test methods for mechanical characteristics of a combined electric/fibre optic cable

15.3.1 Test severities

In the listed test methods recommended severity classes are sometimes given. These might not always be applicable to space applications, and the test severities shall be as stated in the detail specifications.

15.3.2 Abrasion

The test listed is quite similar to the one being used for electrical cables, see ESA SCC Generic Specification 3901, Para. 9.23. The cable surface is abraded by a steel needle. Another test which more simulate a rubbing action can be found in MIL-SPEC DOD-C-00850458 (EC), para. 4.7.33. The IEC-test has been chosen so that the fibre optic cables are subjected to a similar test as electrical cables. The abrasion test for the electrical and optical parts might thus be combined.

15.4 Test methods for environmental characteristics

Test	Characteristics	Test method	Remarks
15.4.1	Temperature cycling	See 15.4.1	
15.4.2	Rapid change of temperature	See 15.4.2	
15.4.3	Vacuum test (including temperature cycling)	See 15.4.3	
15.4.4	Solar radiation	See 15.4.4	
15.4.5	UV radiation	See 15.4.5	
15.4.6	Ionizing radiation	See 15.4.6	
15.4.7	Flammability	MIL-STD DOD-STD-1678 Test method 5010	see 15.4.7
15.4.8	Ageing	See 15.4.8	
15.4.9	Rapid depressurisation	See 15.4.9	
15.4.10	Resistance to fluids	MIL-STD DOD-STD 1678 Test method 8030	

Table 6.4 Test methods for environmental characteristics of a combined electric/fibre cable.

15.4.1 Temperature cycling

The recommended test method is IEC 794-1-F1 with the following modification:

- The temperature cycling test should be run with no load and with maximum rated load or load as specified on the electrical cable.

15.4.2 Rapid change of temperature

The recommended test method is EIA/TIA-455-71 with the following modifications:
- The temperatures of the two chambers, one at high and one at low temperature, shall be as specified.
- The transfer time between the two chambers at high and low temperature shall be as specified.
- The transmitted power at the specified wavelength shall be recorded continuously throughout the test including during the transfer between chambers.
- Test cycles shall be done both with no load and maximum rated load or load as specified on the electrical cable.

15.4.3 Thermal vacuum test

Purpose
To determine the ability of the combined electric/fibre optic cable to operate in vacuum under varying temperatures.

Test arrangement
The following equipment is needed:
- A thermal vacuum chamber having a pressure of 10^{-5} Torr or less and a capability of heating the cable to 125°C or as specified. The test chamber must have appropriate ports (feed-throughs) to allow the fibre ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength f.inst. a stabilised LED, optical power meter to monitor the transmitted power and launching optics.
- Means for measuring cable diameter and sheath thickness.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The outer diameter and cable sheath thickness shall be measured before the test. The cable sample is then placed in the chamber and the fibre ends connected to the measurement equipment located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable ends shall be located inside the chamber, unless otherwise specified, and connected to the outside via short fibre lengths. It must be ensured that no losses are induced in the feedthroughs or in any splices located inside the chamber during the test. The electric cable shall not be loaded unless specified.

The chamber is evacuated and the sample subjected to the specified temperature cycles. The transmission through the fibre loop(s) shall be measured continuously during the test. The set temperature(s), stay time at each temperature and number of cycles shall be as specified in the detailed specification.

After the completion of the test cycles, the sample shall be removed from the chamber. The cable diameter and cable sheath thickness shall be measured, and a visual inspection made to look for any damage or change in cable structure and cable materials.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Pressure in vacuum chamber.
- Load on electrical cable (if specified).
- Temperature cycle diagram including number of cycles.
- Change in attenuation during the test at the specified wavelength.
- Cable diameter and cable sheath thickness before and after the test.
- Result of visual inspection.

15.4.4 Solar radiation test

Purpose
To determine that the combined electric/fibre optic cable can withstand exposure to the specified solar radiation level.

Test arrangement
The following equipment is needed:
- A test chamber equipped with suitable lamps for simulating solar radiation and capable of emitting sufficient power in the specified spectral range to expose the cable to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The cable sample is placed in the test chamber and the fibre ends connected to the measurement equipment which is located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable must be spread out so that the whole length is exposed to uniform radiation. Splices and uncabled fibre(s) should be shielded from the sun radiation to avoid any risk of radiation induced losses. The electric cable shall not be loaded unless specified.

The cable is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or change in the outer cable jacket.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Load on electric cable, if applicable.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

15.4.5 UV radiation test

Purpose
To determine that the combined electric/fibre optic cable can withstand exposure to the specified UV radiation level.

Test arrangement

The following equipment is needed:

- A test chamber equipped with suitable lamps for simulating UV radiation and capable of emitting sufficient power in the specified spectral range to expose the cable to the specified level of irradiance. Reference is made to ESA PSS-01-706, "The particle and ultraviolet (UV) radiation testing of space materials" with regard to typical levels and spectral content. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power, and launching optics.

Test sample

A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure

The cable sample is placed in the test chamber and the fibre ends connected to the measurement equipment which is located outside the chamber. For multifibre cables several fibres may be looped, and when applicable, at least four fibres shall be subjected to the test. The cable must be spread out so that the whole length is exposed to uniform radiation. Splices and uncabled fibre(s) should be shielded from the UV radiation to avoid any UV induced losses. The electric cable shall not be loaded unless specified.

The cable is then subjected to the specified irradiance level for the specified time. The transmitted power is recorded continuously during the exposure. After completion of the exposure the sample shall be removed from the chamber and a visual inspection made to look for any damage or change in the outer cable jacket.

Results

The following data shall be given:

- Cable length.
- Number of fibres in the loop and loop length.
- Load on electrical cable, if applicable.
- Irradiance level and spectral character of radiation.
- Duration of exposure.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

15.4.6 Test for ionizing radiation

It is recommended that test IEC 793-1-D3 be used, but with a few modifications. Two somewhat different test procedures are described in the IEC test, one for low level of radiation (background radiation) one for high level of radiation (adverse nuclear environments). It is recommended that the procedure for adverse nuclear environment be followed, but with a different total dose/dose rate combination. Unless otherwise specified one of the following total dose/dose rate combinations are recommended [4]:

rad(Si)	Suggested dose rate rad(Si)/s
3k	0.03
10k	0.1
20k	0.15
50k	0.3
100k	0.5
1000k or higher	5.0

Several fibres in the cable may be looped for the transmission loss environment. The total fibre length should be at least 200 m. The cable length should not be less than 50 m. The electric cable shall not be loaded during the test unless specified.

The cable dimension (outer diameter, sheath thickness etc.) shall be measured before and after the exposure. In addition a visual inspection shall be made of the cable after the test.

It should be noted that the ionizing radiation can be expected to induce losses in the fibres. If the purpose of the test is to determine losses caused by radiation induced changes in the cable materials or structure, the losses induced directly in the fibre must be subtracted.

15.4.7 Flammability test

The recommended test method is quite similar to the one specified for electrical cables, see ESA SCC Generic Specification No., 3901, Para. 9.20. The test of the electrical and optical cable parts might thus be combined. The test has been used in a recent NASA study of fibre optic cables for space use [6]. The purpose of the test is to determine the flammability of the cable, and if the cable when subjected to a flame, will cause sparking, sputtering or dripping of flaming particles.

Should there also be a requirement for measuring the optical transmission properties of the cable during the test, a somewhat longer cable specimen (specified length is 600 mm) may be needed or some type of tubing may be required at the sample ends to protect the fibres from the flame.

15.4.8 Ageing test [7]

Purpose
To simulate long term (life time) degradation processes by subjecting the combined electric/fibre optic cable to an extended exposure at a high temperature.

Test arrangement
The following equipment is needed:
- A temperature test chamber capable of maintaining a stable temperature over a long period. Max. temperature at least as specified for the test. The chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.

- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), power meter to monitor the transmitted power and launching optics.
- Means for measuring cable diameter and sheath thickness.

Test sample
A cable length of at least 50 m, but sufficient to give a looped length of at least 200 m, or as specified.

Procedure
The cable diameter and sheath thickness shall be measured at both ends before the test. The sample is then placed in the chamber, and the fibre ends connected to the measurement equipment outside the chamber. For multifibre cables several fibres can be looped, and when applicable, at least four fibres shall be included in the test. The electrical cable should be loaded to its maximum rated level during the whole test or to the level specified.

The cable is then heated to a temperature 10°C above maximum specified operating temperature if not otherwise specified and maintained at that temperature for 240 hours or as specified. (The results from the evaluation test of the particular component in question should be taken into account when determining test temperature and duration of test). The test is performed in dry air if not otherwise specified. The transmitted power at the specified wavelength is monitored continuously during the test. After the test is completed, the outer cable diameter and sheath thickness is again measured, and the cable is visually inspected for damage or change in the cable structure.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Load on electrical cable.
- Temperature and duration of test.
- Cable diameter and sheath thickness before and after test.
- Change in attenuation during the test at the specified wavelength.
- Result of visual inspection.

15.4.9 Rapid depressurisation test

Purpose
To determine the performance of the combined electric/fibre optic cable when subjected to a rapid pressure fall from 1 atm to 10 Torr or less.

Test arrangement
The following equipment is needed:
- A vacuum chamber where the pressure can be reduced from 1 atm to 10 Torr or less in 5 seconds or as specified. The test chamber must have appropriate ports to allow the cable ends to be connected to the measuring equipment outside the chamber.
- A suitable optical power source operating at the specified wavelength (f.inst. a stabilised LED), optical power meter to monitor the transmitted power and launching optics.

Test sample
A cable length of at least 50 m, but sufficient to give a looped fibre length of at least 200 m, or as specified.

Procedure
The outer dimensions shall be measured at both ends of the cable samples before the test starts. The sample is then placed in the test chamber and the fibre ends connected to the measurement equipment located outside the chamber. For multifibre cables several fibres can be looped, and when applicable, at least four fibres shall be subjected to the test. The cable ends shall be located inside the chamber, unless otherwise specified, and connected to the outside via short fibre lengths spliced to the fibre(s) under test. The electric cable shall not be loaded during the test unless specified.

The chamber pressure is reduced at the specified rate until a stable pressure of not more than 10 Torr (or as specified) is reached. The transmitted power at the specified wavelength shall be recorded continuously during the test until a stable output is reached and the pressure has stabilised below 10 Torr, or as specified. The chamber is then brought back to 1 atm, the cable is removed from the chamber, the outer dimensions of the cable measured, and a visual inspection made to look for any damage or change in the cable structure.

Results
The following data shall be given:
- Cable length.
- Number of fibres in the loop and loop length.
- Load on electrical cable, if applicable.
- Rate of pressure fall and minimum pressure.
- Change in attenuation during the test at the specified wavelength.
- Outer cable dimensions before and after the test.
- Result of visual inspection.

15.4.10 Resistance to fluids

The proposed test method is quite similar to the one used for electrical cables, see ESA SCC Generic Specification No. 3901, para. 9.21. The test of the electrical and optical parts of the cable might thus be carried out at the same time. The type of fluids, temperature and duration of immersion shall be as given in the detail specification. A representative list can be found in the just referenced para. 9.21.

16. REFERENCES

[1] J. Feth, H. Blake, "Characterization of high birefringence fibre for sensor applications", Tech. Digest Symp. on Optical Fiber Measurem., 1990, NIST, pp. 109-114 (1990)

[2] Data Sheet, York V.S.O.P. Inc.

[3] I.P. Karminov, "Polarization in optical fibers", IEEE J. Quantum Eletron. 17, pp. 15-22, (1981)

[4] ESA/SCC Specification No. 22900, "Total dose steady - state irradiation test method"

[5] MIL-SPEC DOD-F-49291, Para. 3.5.10 and 4.7.2.10

[6] A.K. Sharma, G. Jacobs, "NASA/GSFC reliability evaluation of high temperature fiber optic cables", SPIE Vol. 1580, Fiber Optic Components and Reliability, pp. 54-63 (1991)

[7] MIL-SPEC DOD-C-00850458, Para. 3.6.2 and 4.7.16

1.0 INTRODUCTION

This is the report on Task 4, ESTEC Contract No 8906/90/NL/PM (SC), "Quality Standards for Optoelectronics". The purpose of the work has been to:

- Investigate development trends and availability of the following optical fibre types suitable for space usage:
  - Large core fibres (100 - 500µm core diameter) generally used for optical power transmission purposes
  - Single mode fibres
  - Polarization maintaining fibres.

The work has been done through studies of the literature and contacts with leading manufacturers.

In Ch. 2 a brief discussion is given of the fibre properties of special concern when considering space usage. Then in Chs. 3, 4 and 5 the trends and availability of large core fibres, single mode fibers and polarization maintaining fibres are described, respectively. The findings are summarized in Ch. 6. The names and addresses of the companies contacted are listed in Appendix A. Some selected data sheets are found in Appendix B.

2.0 FIBRE PROPERTIES OF CONCERN IN SPACE USAGE

In the report for Task 1 of the project an extensive discussion has been given of the problems expected to be met in the application of passive fibre optic components in space. For optical fibres the properties of particular concern as compared to normal terrestrial applications, are the abilities to withstand:

- exposure to high levels of ionizing radiation
- operation in vacuum
- operation at high and low temperatures

These topics were all discussed in the Task 1 report, but a brief discussion will be given here with emphasis on the problems met when attempting to find available fibres for space applications.

2.1 Effects of ionizing radiation

When an optical fibre is subjected to ionizing radiation, the attenuation will increase due to formation of colour centers. The ionizing radiation my also affect the fibre coating. The induced attenuation depends on several factors [1]. Fibre parameters such as core and cladding composition, fibre structure, type and concentration of dopants, the conditions and methods for preform fabrication, fibre drawing conditions and type of coating are all important for the resulting induced attenuation. The loss is also dependent on signal power level (photobleaching), signal wavelength and operating temperature. Finally, the induced attenuation will depend on the characteristics of the radiation source, the most important parameters are total dose, dose rate, time after exposure, energy spectrum of the radiation, type of radiation, and radiation history.

The level of ionizing radiation encountered in space will depend heavily on the orbit and also on the shielding of the fibre. In the Task 1 report levels as high as 5×10^5 rad/year have been indicated. While for the US Space Station levels of about 400 rad/year are expected [2].

The effects of ionizing radiation on optical fibres have been studied extensively. It is clear that fibres with pure silica core show highest radiation resistance, see Table 1 where a qualitative comparison has been given between fibres with pure silica core and cores doped with Ge and with Ge and P [1].

	Core material		
	SiO_2	$Ge–SiO_2$	$Ge–P–SiO_2$
Intrinsic loss	Low	Low	Low
Bandwidth	?	High	Highest
Steady state response (dB/km·rad)	Low	Low	High
Transient response	Low	High	Low
Recovery at 23°C	Good	Good	Poor
Low temperature behavior	Good	Very poor	Fair
Long wavelength (1.5 μm) radiation response	Good	Good	Moderate–poor
Radiation hardening	Yes?	No	No
Photobleaching	Yes	Slight	Slight
Dose rate dependence	Moderate	High	Low–none
Steady state growth	Saturating with decrease at high dose	Saturating	Linear

Table 1 Comparison of the radiation response and intrinsic properties of optical fibres [1]

Fibres doped with phosphorous are particularly sensitive to ionizing radiation and should probably be avoided in space applications.

Fibres with a pure silica core will of necessity be a step index fibre. For multimode fibres this will result in a limited bandwidth. But for our purpose where we are looking for fibres for power transmission, this will generally not be a problem of concern. Single mode fibres with a step index profile have a large bandwidth, and when one also considers the rather short transmission lengths met in space applications, such fibres should be quite satisfactory with regard to transmission capacity. Polarization maintaining fibres have Ge-doped cores and can therefore be expected to exhibit higher induced losses than the other two fibre types.

Optical fibres are always given a protective coating (primary coating) of a suitable plastic. For most fibre types the coating is applied outside the optical cladding and does not directly affect the optical guiding properties. The role of the coating is here to protect the glass surface. For so-called plastic clad silica (PCS) fibres the plastic coating actually forms the optical cladding. Large core fibres are often PCS-fibres.

Ionizing radiation can affect the primary coating. If the coating is damaged, it may loose its protective properties and mechanically degrade the fibre. For PCS-fibres it may also affect the optical properties. Studies of the mechanical degradation have been made by Norris et al [3] and also by Boisde et al [4]. Norris and co-workers found that fluorine containing polymer can become brittle at doses above ca. 1 Mrad. Further, it seeems fluorine containing gases are formed which chemically attacks the glass surface and weakens the fibre. In Fig. 1 are summarized some of the results of this study. The breaking tensile stress has been measured as a function of exposure. Shown is stress giving failure for 50% of the tested samples. Although the doses applied are quite high, it seems advisable to avoid fluorine containing coating for accumulated levels of the order of 1 Mrad or higher.

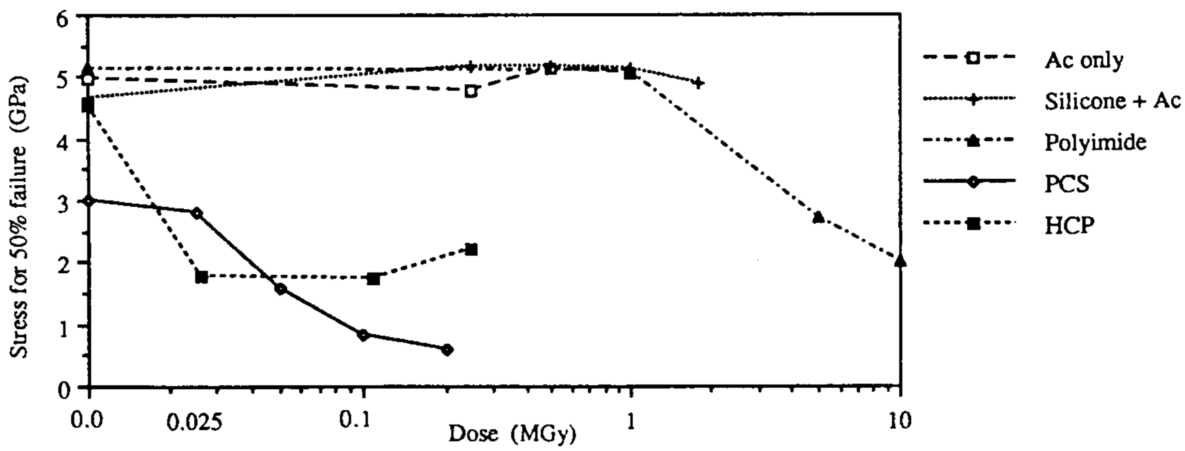

Figure 1 Tensile stress for 50% failure against dose received. 1 MGy = 10^8 rad. Ac = acrylate, HCP is fibre with proprietary coating (Ensign Bickford) [3]

It can also be mentioned that the coating type can indirectly affect the radiation induced losses since the coating application process may influence the glass properties [5].

2.2 Vacuum operation

Operation in vacuum will not affect the glass fibre itself. The coating may, however, be affected for example due to outgassing. Not much information is available on the performance in vacuum of various coatings since this is an application not normally encountered in terrestrial applications. A few studies have, however, been made in connection with planned space applications.

In a study by Alcatel Standard Electrica for ESTEC [6 ,7] it was found that fibres with coatings of polyamide (primary) and fluorin resin (secondary) and fibres with UV-curved acrylate (primary) and polyamide (secondary) showed good stability under temperature and vacuum testing in the range of -50°C to 100°C.

Studies in the US [8, 9] have shown good results for fibres with silicone and polyimid coatings. However, since the tests have included both thermal cycling and vacuum operation and in some cases also cabled fibres, it can be difficult to separate out the losses caused by the fibre coatings due to vacuum operation. It seems, however, that coatings of silicon, polyamide, polyimide and UV-curved acrylated are applicable in vacuum. It should, however, be noted that the acrylate coatings normally used on optical fibres have a maximum operating temperature of 85°C.

2.3 Operation at high and low temperatures

Silica glass is a very stable material which maintains its properties over a large temperature range both above and below normal room temperature. Some of the typical coatings have, however, a limited operational range. There are two main problems.

The coating might change its properties to such a degree at high/low temperatures that the coating no longer can do its job. It might for example melt or evaporate (high temperature) or become brittle (low temperature). For some PCS-fibres the change in index of refraction with temperature can also cause a problem since the guiding ability is dependent on the difference in index of refraction between the core and cladding.

The material in the coating will generally have a thermal expansion coefficient which is two orders of magnitude larger than that of silica. Operation at high and low temperature may therefore put strain on the fibre and cause microbend losses. For polarization maintaining fibres the strain can cause depolarization. This is due to the fact the the birefringent property of the fibre is caused by built-in anisotropic stresses.

In the Task 1 report possible operating temperatures was indicated to be - 55°C to +125°C. Expected temperature extremes for the US Space Station is -65°C to +85°C for external components and -15°C to + 65°C for inside components. These latter numbers are based on measurements on the so-called Long Duration Exposure Facility which was launched and recovered in 1990 [2].

Most standard telecommunication fibres in use today have a UV-cured acrylat coating. They are typically specified to operate in the temperature range of -65°C to +85°C. For higher temperatures polyimide and also certain silicone type coatings can be used.

3.0 LARGE CORE FIBRES FOR POWER TRANSMISSION

As discussed in Ch. 2, pure silica core fibres are the most radiation resistant fibres, and for core diameters over 100 μm the available fibres are generally of this type. The discussion will thus mainly be related to pure silica core fibres.

There are two main types of pure silica core fibres. The so-called plastic clad fibres (PCS-fibres) and fibres with a glass optical cladding. For the latter type the cladding is made from fluorine-doped silica to achieve a cladding with a lower refractive index than that of pure silica.

Assuming the fibres are to be used for high power transmission, the effects of photobleaching may result in a substantial reduction of the radiation induced losses. In Fig. 2 is shown an example of the effects of a photobleaching on different fibre types [10]. The experimental conditions are given in the figure. The Corning fibre is a single mode fibre with a Ge-doped core. The other two are both pure silica core fibres. The abbreviation DIB stands for "drawing induced band" and refers to an absorption band at 630 nm which has been found to be related to the radiation resistance of the fibre.

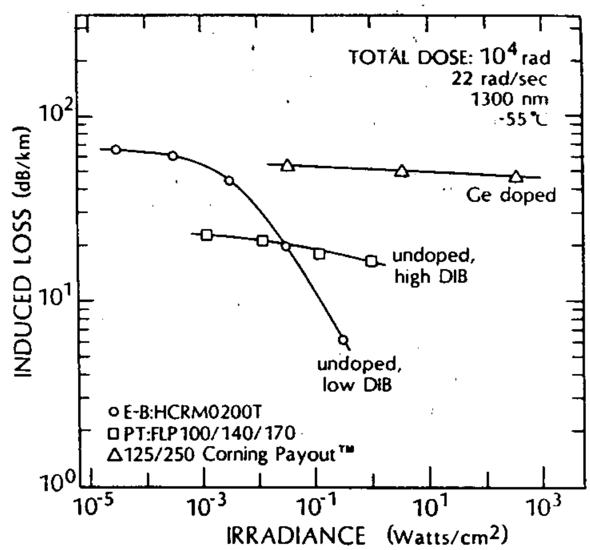

Figure 2 Induced losses versus irradiance at 1300 nm for different fibre types (see text for further details) [10]

For the fibre showing the largest photobleaching effect the highest power level is 100 μW. If the curve can be extrapolated to higher power, it seems the impact on the radiation induced loss can be substantial for high power transmission. Experimental data on photobleaching at high power levels for this fibre type does, however, not seem available. [11].

The pure silica core fibres are usually offered with both low OH (a few ppm) and high OH (several hundred to one thousand ppm) content. The high OH fibres are generally regarded as being more radiation resistant than the low OH fibres. It has, however, been found that by using a proper manufacturing process fibres with a low OH content can be made with a radiation sensitivity as low as that of high OH fibres [12]. It can also be noted that to remove the OH-ions chlorine is used as a drying agent. The concentration of the remaining chlorine will also affect the radiation induced losses [13].

Fibres with high OH content will have high absorption peaks around 940 nm, 1240 nm and 1390 nm with absorption "tails" extending in both directions from each peak. This means that these fibres are most suitable for operation at wavelengths below 850 nm.

For very high power transmission the fibre might get damaged. Typical specified maximum allowable power levels are a few GW/cm^2 for short pulses (nanoseconds) and around 100 kW/cm^2 for continous power. One must be aware that proper preparation of the fibre entrance face and cleanliness is of great importance for achieving a high threshold.

In the following fibres from several manufactures will be described in more detail. The order in which they are discussed is random.

3.1 Ensign-Bickford Optics Co

Ensign Bickford has available both PCS and all silica fibres with core diameters in the range of 100 μm to 1000 μm. The PCS-fibre has a patented HCS (hard clad silica) optical cladding which again is surrounded by a Tefzel buffer layer. The all silica fibre has a silica optical cladding. Outside the cladding there is a hard coating similar to the one used in the PCS-fibre and then a Tefzel buffer layer.

The PCS-fibre and the all silica fibre have a specified operational temperature range of -65°C to +125°C and -65°C to +135°C, respectively.

The polymer coating used in these fibres contains fluorine as does Tefzel [3]. As discussed before, degradation in strength has been observed for fibres with such coatings for dose levels above ca. 1Mrad, see Fig. 1.

The PCS-fibre is offered in a radiation resistant type fibre called HCR. This fibre has been used in many studies of radiation induced losses [10, 13, 14]. In Fig. 3 is shown examples of the induced loss measured at -55°C and +22°C, and the recovery rate.

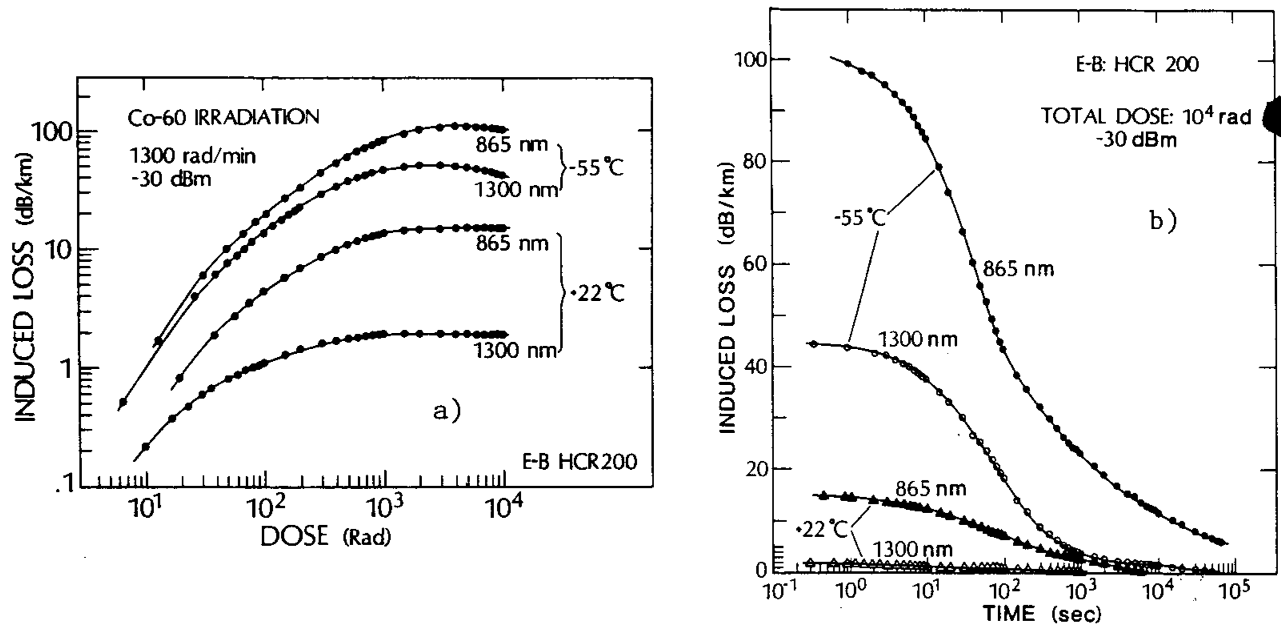

Figure 3 a) Radiation induced loss in HCR fibre, 200 μm core. b) Decay of loss after exposure to 10 krad [14]

The loss appears to saturate at dose level above ca. 1 Krad. As expected the induced loss is strongly dependent on temperature and wavelength. The dose rate is quite high (1300 rad/min) meaning that the fibre was exposed for only ca. 8 minutes. The strong decay rate show that exposure to the same dose, but at a lower decay rate would give a lower loss due to the thermal deexcitation. Additional data on the temperature dependence and photobleaching effects in the HCR fibre can be found in Ref. 13.Data on radiation induced losses in the all silica fibre are not available, but the core material is similar to that of the HCR fibre [11].

The HCR fibre is said to be applicable to laser power delivery, but no maximum allowable power is specified. For the all silica fibre the limits for power transmission is given as 100 kW/cm^2 for CW lasers and 1.5 GW/cm^2 for pulsed lasers.

Finally, it can be mentioned that Ensign-Bickford just has introduced a new high temperature fibre specified to operate from -65°C to +350°C. It is similar to the all silica fibre described earlier, but has a more temperature resistant coating.

3.2 3M Specialty Optical Fibres

3M will provide two types of PCS-fibres with a temperature range of -25°C to +150°C and -65°C to +125°C, respectively. The latter type designated TECS hard clad fibre appears in many ways similar to the hard clad silica fibre from Ensign-Bickford. Fibres are available with core diameters in the range of 200 - 1000 µm. Both fibre types come in a high-OH and low-OH version and have an outer buffer coating of Tefzel.

An example of the radiation induced losses in these fibres is shown in Fig. 4 [15].

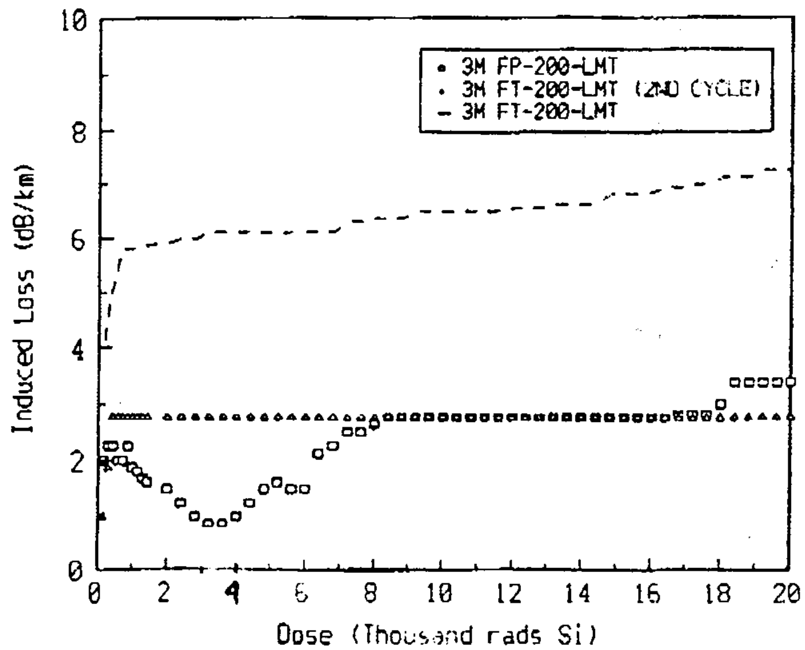

Figure 4 Radiation induced loss for two PCS-fibres from 3M [15]

For the TECS-fibres (FT-200-LMT) the tested type is the so-called premium performance fibre which is the most radiation resistant. The wavelength is 820 nm and the dose rate 420 rads/min. Considering the lower dose rate used here the induced loss is quite similar to that observed for the Ensign-Bickford fibre, see Fig. 3.

The peak optical power capability is given as 5 GW/cm^2 at 1064 nm with a 10 nsec pulselength.

3.3 Heraeus Quarzglas

Heraeus produces preforms (Brand name FLUOSIL) which are used in the fabrication of pure silica, large core diameter fibres. Companies that supply fibres drawn from these preforms are:

Ceram Optec, Bonn, Germany
Polymicro Technologies Inc., Phoenix, AZ
Fibreguide Industries, Stirling, NJ
SpecTran Corp, Sturbridge, MA

Detailed studies have been made of the radiation induced losses in fibres made from the Heraeus preforms [6, 16, 17, 18, 19]. The most recent results will be summarized in the following. According to Heraeus the F100 core material is the most radiation resistant [20]. Details of available fibres will be described in the subchapter for the various companies and in Appendix B.

In a recent paper Fabian et al have described radiation induced losses in fibres made with high purity stoichiometric core materials [19]. The OH-content is 600 ppm which means the fibre is most suitable for wavelengths below ca. 850 nm.

In the study the fibre dimensions are 104 µm core / 125 µm outer diameter. The fibres have been exposed to a dose rate of 20 rad/s up to a total dose of 10^5 rad, and the induced loss measured at 865 nm. The results are shown in Fig. 5 where also the decay after exposure is shown.

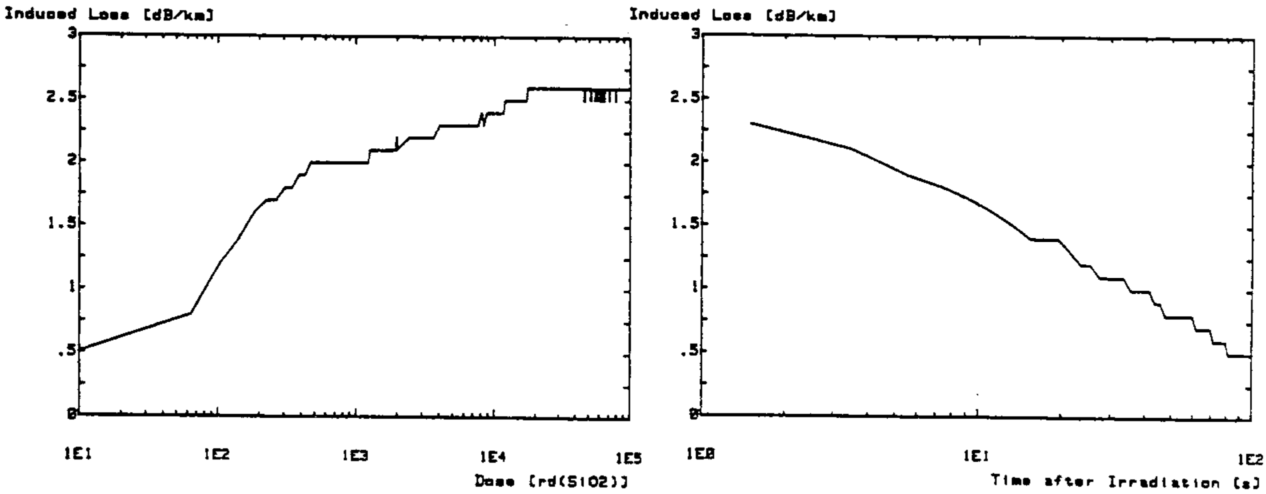

Figure 5 Radiation induced loss and decay for new high purity, pure silica core fibre from Hereaus. Wavelength 865 nm. Room temperature[19]

As can be seen from Fig. 5 the loss is only about 2.4 dB/km even after 10^5 rad exposure, and considering the rapid decay which the fibre exhibits, a substantial lower loss would be expected for exposure with a lower dose rate. This appears to be one of the most radiation resistant fibres reported so far. Studies at other temperatures are not yet available.

3.4 Polymicro Technologies

Polymicro Technologies offers a variety of silica core/silica clad fibres with core diameters from 100 μm and upwards. The fibres can be delivered with acrylate or silicone or polyimide buffers. For the latter an operating temperature up to 400°C is specified. The fibre is said to have a high laser damage threshold, but no value is specified.

3.5 SpecTran Corp.

SpecTran offers radiation hard step index fibres with 105 μm and 200 μm core diameters. As noted before these fibres are drawn from preforms made by Heraeus [22]. The fibres can be supplied with Pyrocoat heat resistant coating (polyimide). It is said that the coating will not outgass, and it can withstand extreme temperatures. It is being considered for the US Space Station [21].

A 100/140 μm Ge-doped graded index fibre from SpecTran (Type SR-328H) has been thoroughly tested with respect to ionizing radiation [2, 21] as a candidate for the US Space Station. As mentioned before the expected radiation level is here in the order of 1 rad/day. The fibre is to be used in a communication system, and a graded index fibre is needed due to the required bandwidth. Spectran says the fibre is qualified for space flight [22].

3.6 Ceram Optec

Ceram Optec will provide PCS-fibres, hard polymer clad fibres and silica core /silica clad fibres from 100 μm and upwards. A variety of coatings can be provided including polyimide. The specified operation range for the polyimide silica clad/silica core fibres is -190°C to +385°C.

3.7 Past suppliers

Several companies have in the past supplied large core fibres which have been studied with a view towards space applications [1, 23]. Some of these companies are, however, no longer offering this fibre type. Raychem (USA) now only offers cables. Mitsubishi Cable (Japan) (previously Dainichi Nippon Fibre) is now concentrating on plastic fibres. Quartz et Silice (France) is no longer making fibres.

4.0 SINGLE MODE FIBRES

Most available single mode fibres have a Ge-doped core. Single mode fibres with pure silica core do, however, exist, and they show superior radiation resistance. As an example of the difference between the two fibre types, Fig. 6 shows the radiation induced losses in a standard fibre and a pure silica core fibre both produced by the same method (PCVD - plasma chemical vapor deposition) by Philips, [24]. The pure silica core shows clearly a lower induced loss.

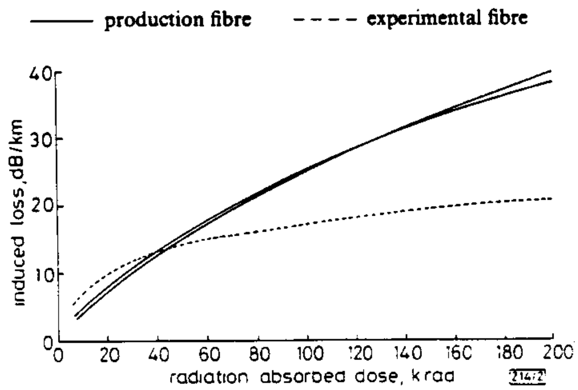

Figure 6 Radiation induced loss in standard single mode fibre (-) and a pure silica core fibre (...).Wavelength: 1300 nm [24]

Even better performance has been achieved by Sumitomo Electric Industries as shown in Fig. 7, and the discussion will concentrate on the Sumitomo fibre since this fibre is well tested. It has until recently been the only pure silica core fibre on the market. Ensign-Bickford has said they plan to market a single mode fibre of this type, but no data are yet available on radiation resistance [11].

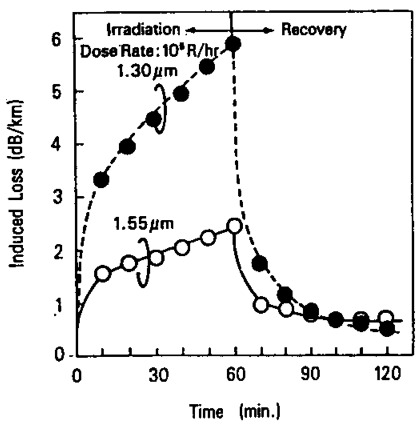

Figure 7 Radiation induced loss and decay for Sumitomo pure silica core single mode fibre. Total dose 10^5 rad [25]

4.1 Sumitomo Electric Industries Ltd.

The Sumitomo fibre has been tested for a period of 3 years at a rate of 2.12. rad/hour, see Fig. 8 [25].

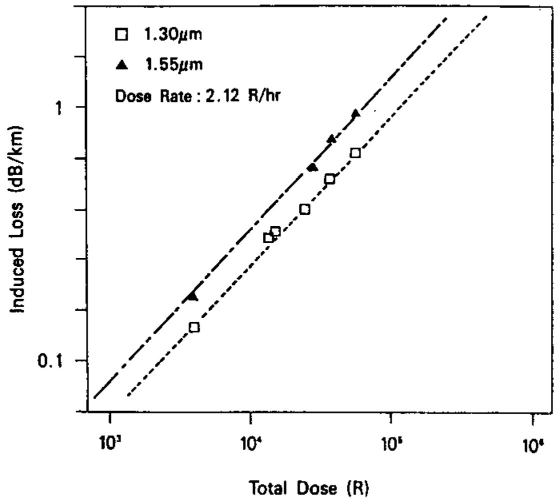

Figure 8 Radiation induced loss versus dose at 1300 and 1550 nm for Sumitomo pure silica core single mode fibre [25]

The losses can be separated into dose dependent and dose rate dependent terms. At the applied dose rate only the dose dependent losses give contribution. For dose rates of the order of 10^{-3} to 10^2 rad/h the induced loss ($\Delta\alpha$) at 1300 nm can be calculated from:

$$\log(\Delta\alpha(t)) = 0.54x\log(\O t) - 2.73 \quad (1)$$

Here t is time and Ø dose rate. Loss is in dB/km, and dose in rad. For 1550 nm the loss is a bit higher.

It is important to be aware that for the dose dependent losses the losses will increase with increasing temperature. The dose rate dependent losses will decrease with increasing temperature, and it is these latter losses which dominate for short term exposure.

The fibre has previously been available with cut-off wavelengths in the 1100 - 1280 nm and 1350-1580 nm range. But Sumitomo will now only deliver fibres with the long cut-off wavelengths apparently due to low market demand for the other type.

The fibre can be delivered with a primary coating of silicon and secondary coating of PFA. The specified maximum operating temperature with such a coating is 150°C. (This coating is not included in data sheet in Appendix B).

4.2 Ensign Bickford Optics Co.

As mentioned previously this fibre has not yet come on the market. According to the preliminary data sheet it will be available with a variety of cut-off wavelengths. The specified operating temperature with the standard primary coating is -40°C to 80°C, but a polyimide coating can be provided. No data is yet available on radiation resistance.

5.0 POLARIZATION MAINTANING FIBRES

Polarization maintaning (PM) (or preserving) fibres are used in for example coherent fibre optic sensors such as the fibre optic gyroscope and may also be used in coherent fibre optic transmission systems. There are essentially two ways to produce a PM fibre [26]. One method is to make the core noncircular so that the refraction index distribution in the two principal directions are different. To achieve a high birefringence the refraction index difference between core and cladding must be relatively large which results in a small core diameter, and the fibres are difficult to fabricate and join.

The most common method to make PM fibres is to somehow introduce asymmetric stresses over the fibre core. The asymmetric stresses give birefringence due to the elasto-optic effect. There are several ways to produce the asymmetric stress. One can employ an elliptical cladding, or one can introduce two highly doped regions on opposite sides of the core resulting in thermal stresses due to difference in thermal expansion. There are several techniques for including the two doped regions, and when photomicrographs are taken of the fibre cross section, the doped regions form characteristic shapes resulting in names like "bow-tie fibre" and "PANDA-fibre".

It is known that built-in mechanical stresses in the fibre affect the radiation sensitivity, and the available PM fibres all seem to have Ge-doped cores. The PM fibres may therefore be expected to be more sensitive to ionizing radiation than pure silica core fibres.

An example of this is shown in Table 2 which shows the measured loss for two Corning PM fibres (for 850 nm and 1300 nm respectively) and a standard Corning single mode fibre (1521 SM) [27]. The measurements were made with a dose rate of 0.5 rads/hours, and the total dose varied from 600 to 2100 rads. In this range the loss increased linearly with dose.

Fibre	Induced loss (dB/km - krad)
Corning PM fibre (0.85 μm)	5.78
Corning PM fibre (1.3 μm)	0.47
Corning 1521 SM (1.3 μm)	0.11

Table 2 Induced loss for PM fibre and standard single mode (SM) fibre [27]

Due to the asymmetric stress distribution the induced loss may also be different for the two axes But this effect does not appear to be large [27].

For the PM fibre it is important that the degree of cross-coupling of power from the axis into which the linearly polarized beam is launched, to the perpendicular axis is small. The cross-coupling is usually defined by the so-called h-parameter:

$$h = (1/L)\tanh^{-1}(P_y/P_x) \qquad (2)$$

Here L is the fibre length, P_x the power exiting in the axis to which it was launched and P_y the power exiting in the other axis. (x and y are the two axes of the birefringent fibre)

Alternatively one can give

$$\text{Extinction ratio} = P_{min} / (P_{min} + P_{max})$$

Here P_{min} and P_{max} are minimum and maximum output power when the transmitted light is detected through an polarization analyzer being rotated 360°.

When the temperature varies, the fibre coating may induce thermal stresses in the PM fibre affecting the cross coupling. A requirement on the coating is that the h-paramer should stay within the specified value over the operating temperature range.

5.1 3M Specialty Optical Fibers

3M has recently started to offer a radiation hardened PM fibre. An elliptical region surrounds the core and applies an asymmetric stress on the core. Fibres are available for various operating wavelengths. The fibre can be supplied with a coating giving stable polarization performance (small variation in the h-parameter) over a -55°C to +85°C temperature range. Coatings which can operate up to +125°C will be offered shortly [15]. The presently available coating is a dual component soft primary/hard acrylate coating. The performance under vacuum operation has not been tested [15].

Curves for the radiation induced losses of the PM fibre is shown in Fig. 9 and 10.

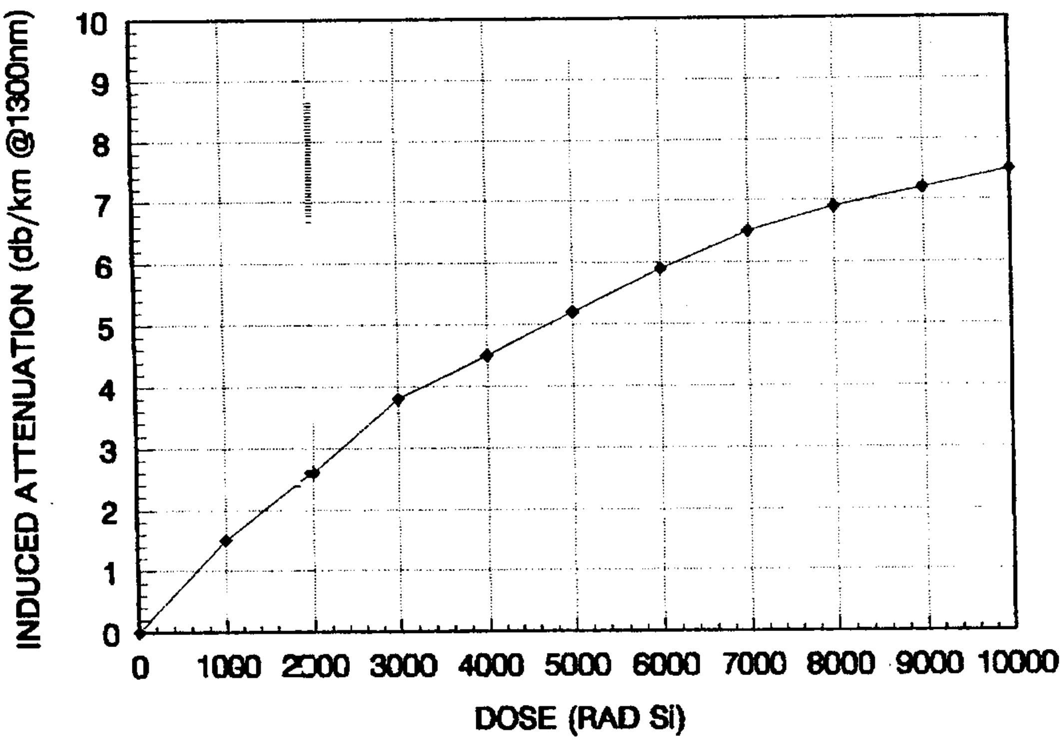

Figure 9 Radiation induced losses versus dose at 1300 nm for 3M radiation hardened PM fibre. Dose rate 1300 rad/min. Temperature 28°C. 1 μW power. [15]

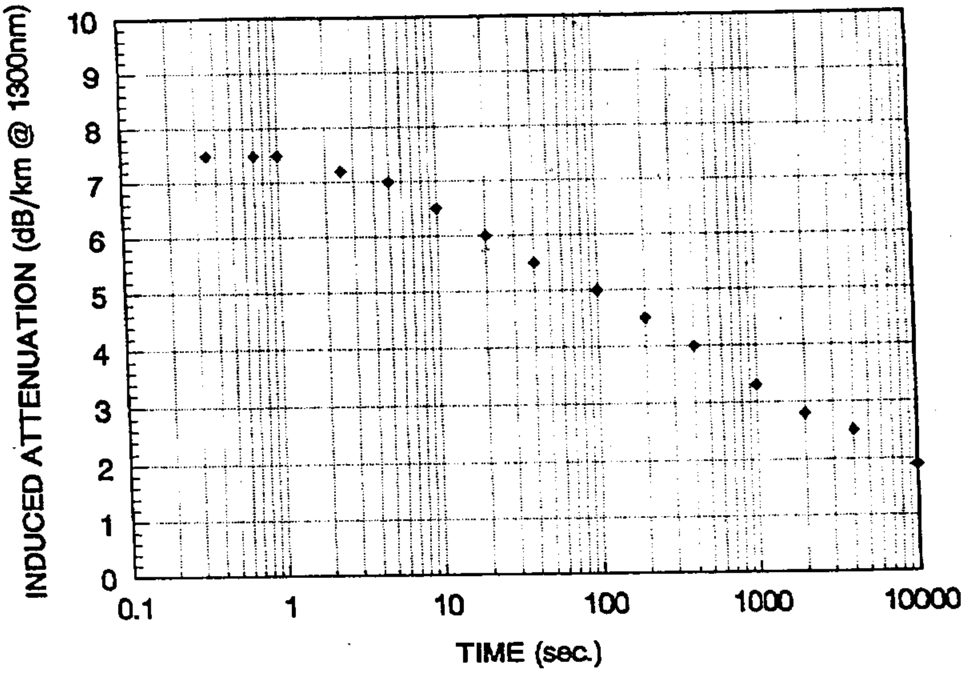

Figure 10 Recovery after 10 kRad exposure for 3M radiation hardened PM fibre. Wavelength 1300 nm. Temperature 28°C. 1μW power [15].

One sees that the fibre exhibits a good recovery indicating that with a low dose rate exposure the induced loss after 10 kRad exposure would probably be less than 2 dB/km.

5.2 York Fibres Ltd.

York offers a PM fibre called HiBi fibre. The fibre includes two stress applying sectors which look like a bow-tie. Fibres with various operating wavelengths are available.

In Fig. 11 is shown extinction ratio versus temperature for a 100 m fibre length [28]. The performance is quite stable from ca. -50°C to +80°C.

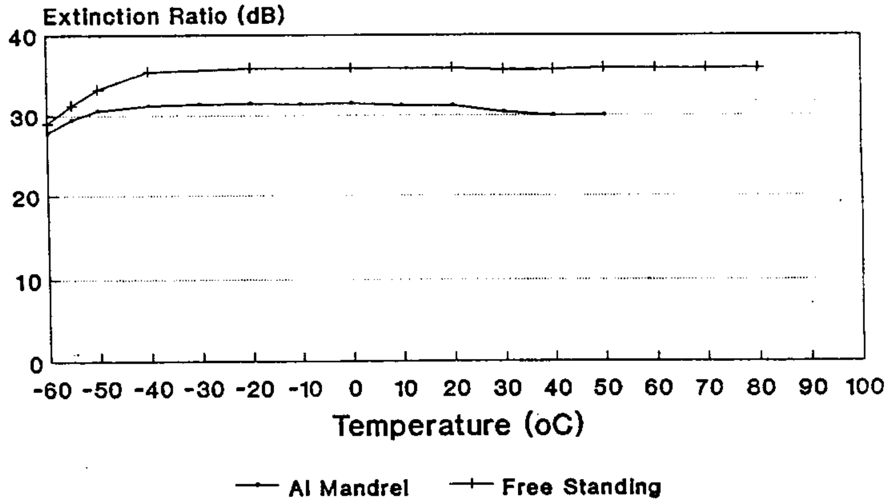

Figure 11 Extinction ratio versus temperature for York PM fibre. Fibre length 100 m. Coil diameter 60 mm.

The coating material shows about 3% weigth loss after heating to 88°C for 8 weeks. Data on peformance in vacuum is not available. York suggests polyimide as a possible candidate for vacuum and high temperature operation.

In Figs. 12 and 13 are shown the radiation induced losses at 1309 nm for 10 kRad dose at high dose rate and the decay after exposure. Induced losses at 837 nm are about 4 times higher. No decay is evident at least for the first 10 000 seconds indicating poor performance even at long term low dose rate exposure.

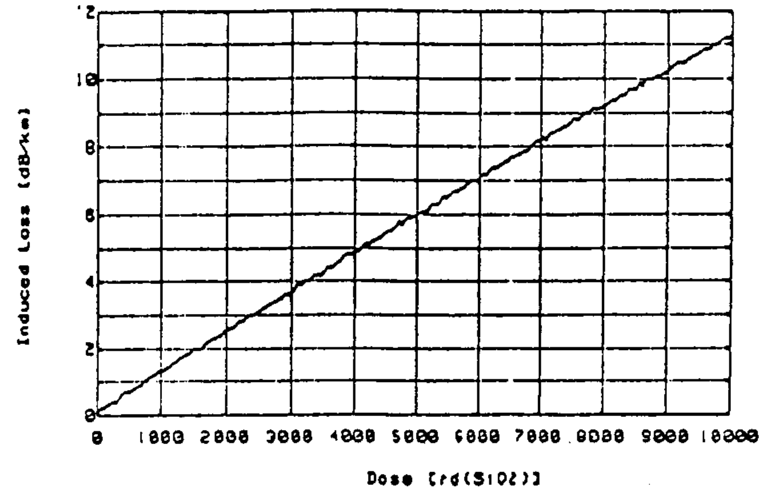

Figure 12 Radiation induced loss York PM fibre. Wavelength 1309 nm. Dose rate 1272 rad/min. Power 10 μW. Temperature 22°C.

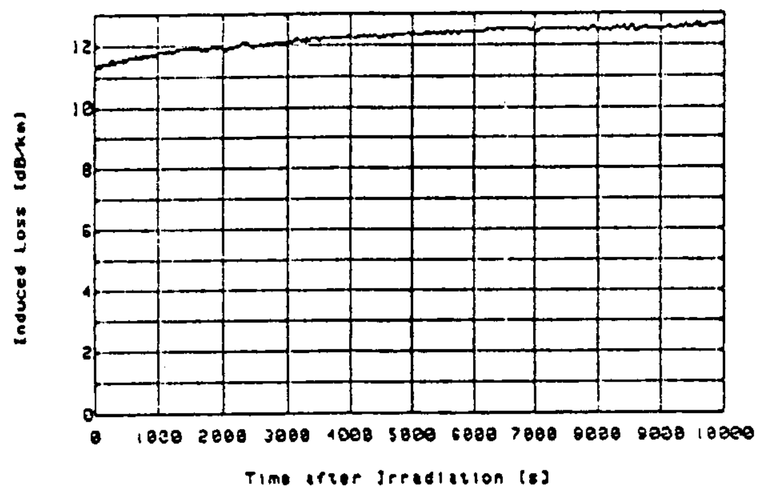

Figure 13 Decay after exposure to 10 kRad dose. Other parameters as in Fig. 12.

5.3 Corning

Corning offers PM fibres for various wavelengths. An example of the radiation induced losses in the Corning fibres was given in Table 2. In a separate study [29] the temperature dependence of the induced losses has been investigated. It was found that at 850 nm the losses were lower at -20°C than at room temperature. But at 1300 nm the losses were lowest at room temperature. Operating temperature is -55°C to +85°C. The stated specifications including those for cross-coupling are said to be met in this temperature range.

5.4 Ensign Bickford Optical Co.

Ensign-Bickford has recently introduced a PM fibre. Fibres at various operating wavelengths are available. The standard operating tempearture is -40°C to 80°C, but a polyimide coating can be provided. No data are available on radiation resistance [11].

6.0 CONCLUSION

Pure silica core fibres exhibit the lowest radiation induced losses. Large core fibres and single mode fibres of this type and with low sensitivity to ionizing radiation now appears available. Polarization maintaining fibres show larger losses, but radiation hardened PM fibres have recently become available.

One problem with respect to determining radiation resistance is that most available data are for high dose rates and short exposure times. In space the fibres will experience low to moderate dose rates for long exposure times. To extrapolate from short term exposure data to long term exposure one must know which losses are permanent and which will decay with time.

Among the fibre coatings polyimide appears the most promising for space application. Fibres with polyimide coating have been tested in the US space program with good results [21], and several companies will deliver fibres with such a coating. The study done by Standard Electrica [6, 7] for ESTEC indicates that also other coating materials can be used.

Among the large core fibres a new fibre recently developed by Heraeus appears to have the lowest radiation induced losses. But the temperature dependence of the losses and photobleaching effects still need to be studied. Photobleaching at high power levels is of particular interest for the intended application, and this is a topic which does not appear to have been much studied for any fibre.

The pure silica core, single mode fibre from Sumitomo appears to be the most promising of the single mode fibres. The performance under vacuum operation of the available coating must, however, be evaluated.

The most promising PM fibre is the new radiation resistant fibre from 3M. Again the available coating need to be evaluated with respect to operation in vacuum.

In conclusion, fibres with high radiation sensitivity, and coatings which can operate at high and low temperatures and in vacuum seem available. However, in some cases companies having the best fibre with respect to radiation resistance do not have the best coatings, and vice versa. This may cause some problems in procuring the most suitable fibre. Finally, it must be emphasized that none of the most promising fibres have undergone complete tests with respect to application in space. Investigations have to be performed of radiation induced losses including dose dependence under long term exposure, temperature dependence and photobleaching effects. Further, the effects on the coating(s) of operation at high and low temperature and in vacuum must be studied.

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5. APPENDICES

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High Temperature All Silica Fiber - Ensign-Bickford
Power-Core Fiber - 3M
Silica/Silica Fiber Series - Polymicro Technologies Inc.
Radiation Hard Optical Fiber - SpecTran
Pyrocoat Heat-resistance Coating - SpecTran
Polyimide Coated, Quartz/Quartz-Fiber - CeramOptec
Sumitomo Electric Indistries
Radiation-Resistant Singlemode Fiber - Ensign-Bickford
Polarization-Maintaining Single-Mode Fiber -3M
York, HiBi Fibers, Information Note 01; The Basics
PRSM Polarization-Retaining Single-Mode Fiber - Corning Optical Fiber
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APPENDIX A

Names and addresses of companies contacted

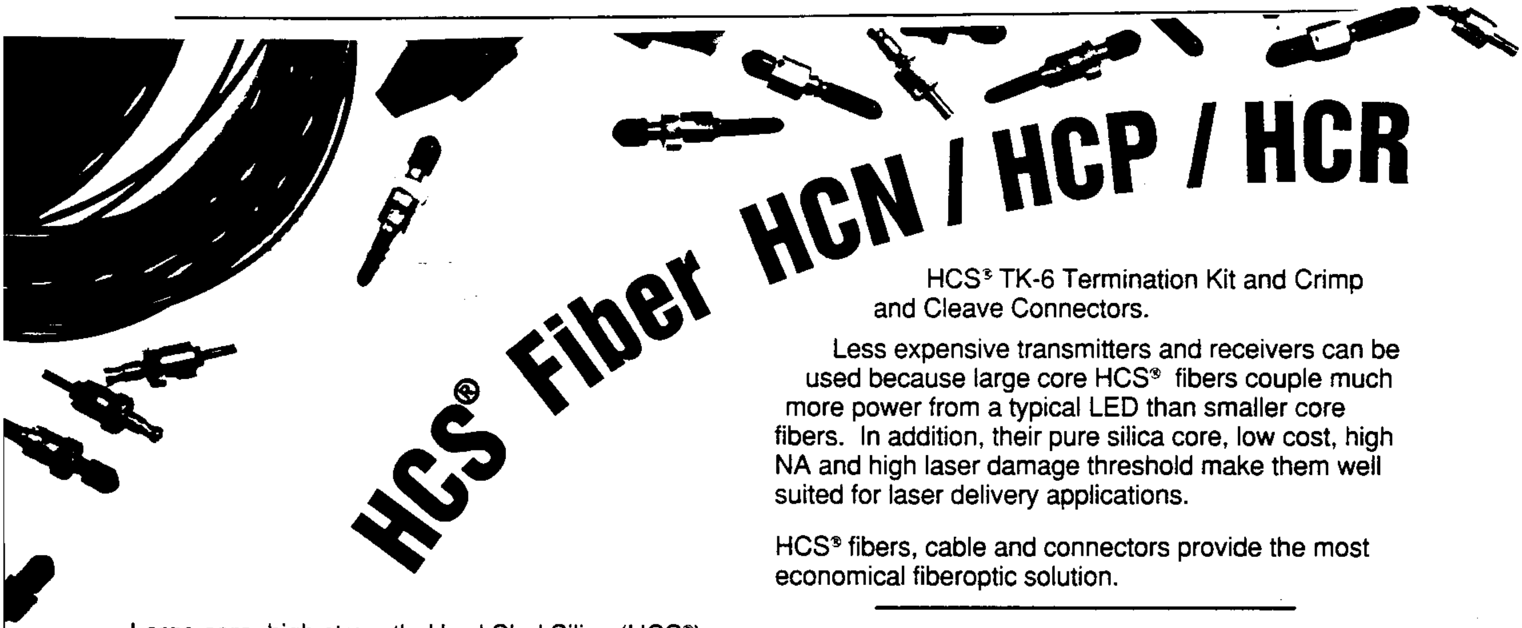
Company	Fibre types	Remarks
3M Specialty Optical Fibers 420 Frontage Road West Haven CT 06516-4190, USA	Large core Polariz. maint.	
Alcatel Fibers Optiques 35 rue Jean-Jaures BP 20, 95871 Bezons Cedex, FRANCE	Single mode	No reply
Ceram Optec GmbH Siemensstrasse 12 Bonn 5300, GERMANY	Large core	
Corning Inc. Telecom Products Div. Corning, NY 14831, USA	Single mode Polariz. maint.	
Ensign-Bickford Optics Co. 150 Fisher Dr. Avon, CT 06001, USA	Large Core Single mode Polariz. maint.	
Fiberguide Industries Inc. 1 Bay Street Stirling, NJ 07980, USAa	Large core Single mode	No reply
Heraeus Quarzglas GmbH Postfach 1554, D6450 Hanau, GERMANY	Large core	Preforms only
ISPRA Israel Product Research Co. Ltd 16 Galgal Haplada St. Industrial Zone Herzlya, ISRAEL	Large core Single mode	
Lightwave Technolgies Inc. 1161 San Antonio Rd. Mountain View, CA 94043, USA		Now part of Ensign-Bickford
Lycom NKT Alle 75 Brøndby 2605, DENMARK	Single mode	No reply
Mitsubishi Corporation Biblioteksgt. 12 S-11146, Stockholm, SWEDEN		Plastic fibres only
Northern Fibercom 189 Durfee St. Southbridge, MA 01550, USA		Cables only

Company	Fibre types	Remarks
Philips Optical Fiber BV P.O. Box 218 56000 MD, Eindhoven, THE NETHERLANDS	Single mode	
Polymicro Technologies Inc. 3035 N. 33 rd Drive Phoenix, AZ 85017-5204, USA	Large core	
Raychem AS Postboks 31 1414 Trollåsen, NORWAY		Cables only
SpecTran Corp. 50 Hall Rd. Sturbridge, MA 01566, USA	Large core Single mode	
Sumitomo Electric Europe S.A. 30 Dorset Square London NW1 6QJ, ENGLAND	Single mode	
York Fibers Limited School Lane, Chandlers Ford Hants S05 3DG, ENGLAND	Polariz. maint.	

APPENDIX B

Selected data sheets from companies

having products of possible interest



HCS® Fiber HCN / HCP / HCR

Large core, high strength, Hard Clad Silica (HCS®) fibers arer easy to use and allow you to realize substantial cost savings.

Field termination of HCS® fibers, in 3 minutes or less, with minimal training and no consumables, is possible with our HCS® TK-6 Termination Kit and Crimp and Cleave Connectors.

Less expensive transmitters and receivers can be used because large core HCS® fibers couple much more power from a typical LED than smaller core fibers. In addition, their pure silica core, low cost, high NA and high laser damage threshold make them well suited for laser delivery applications.

HCS® fibers, cable and connectors provide the most economical fiberoptic solution.

Features and Benefits

Reliable, Easy Field Installation of Connectors. Patented HCS® polymer technology permits direct crimping onto the cladding, utilizing the HCS® TK-6 Termination Kit and crimp and cleave SMA or ST® connectors.

Enhanced Optical Budget. HCS® fibers offer large core and a high numerical aperture (NA) of .37 which allow greater coupling efficiency. *A typical surface emitting LED will couple approximately 10 times more power into a typical HCS® 200 µm fiber than into 62.5 µm fiber (about 5 times more than 100 µm fiber).*

Real Cost Savings. The coupling efficiency of large core HCS® fibers allows for the use of less expensive transmitters and receivers. Field terminations are performed in 3 minutes or less, with minimal training and require no consumables. HCS® is available in three grades to allow you to make the most economical fiber selection.

Tight Bend Radius. Proof testing HCS® fiber to levels far exceeding industry standards (up to 600 kpsi, depending on core size) ensures the survivability of HCS® fibers in extreme conditions.

Wide Selection of Cable Styles. Fully dedicated cable department produces a variety of custom and standard cable designs.

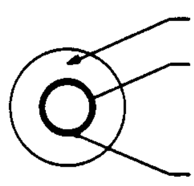
Applications

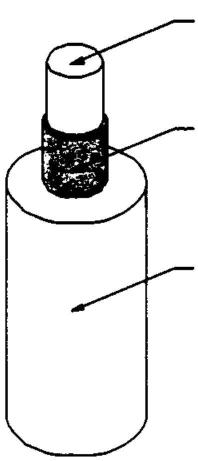
Disposable Medical Assemblies
Laser Power Delivery
Medical Sensors

Factory Automation Links
Industrial Sensors
High Voltage Environments
Illumination

Laser Ordnance
Avionics
Space Based Systems
Weaponry
Nuclear Reactor Systems

Point-to-Point Data Communication Links
Tapped Bus Networks





Ensign-Bickford Optics Company

Ensign-Bickford Optics Company, 150 Fisher Drive, Avon, Connecticut 06001 USA
TEL 203-678-0371 FAX 203-674-8818

HCR, the Radiation Resistant HCS® Fiber

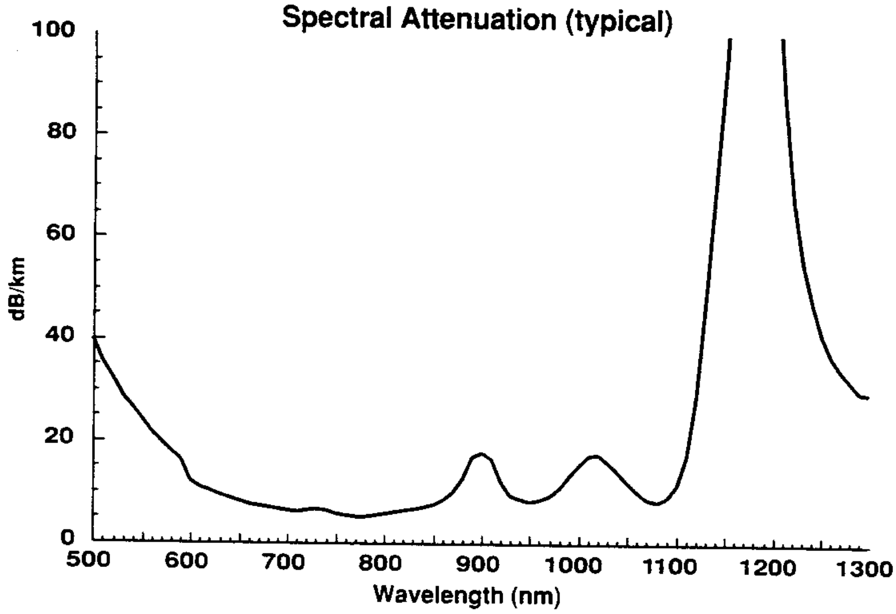
For use in radiation environments, both high dose and high dose rate

Specifications

Product Code	Core Ø (μm)	Cladding Ø (μm)	Buffer Ø (μm)	Maximum Core-to-Clad Offset (μm)	Nominal Bandwidth (MHz-km)	Proof Test (kpsi) [100% tensile proof tested]	Short-Term (60 mins.) Minimum Bend Radius (mm @ 23° C) ††	Long-Term (20 yrs.) Minimum Bend Radius (mm @ 23° C) ††	Typical Stock Lengths (m) ±5%
HCR-M0110T-08	110±5	125+1/-5	250-0/+50	5	17	200	4	7	1100
HCR-M0125T-08	125±5	140+2/-5	250-0/+50	5	17	200	5	8	1100
HCR-M0200T-05	200±5	230+0/-10	500±50	5	17	200	8	12	2200
HCR-M0300T-06	300±6	330+5/-10	650±50	8	15	150	15	24	1100
HCR-M0400T-06	400±10	430+5/-10	730±50	9	13	100	29	47	1100
HCR-M0600T-06	600±10	630±10	1040±40	9	9	50	87	142	500
HCR-M1000T-06	1000±15	1035±15	1400±50	10	--	--	*121	*200	200
Temperature Range -65° C to +12[illegible]									

NOTE: Additional radiation information available upon request

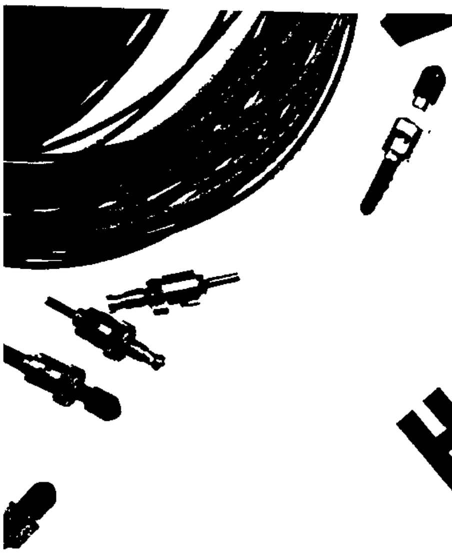
Spectral Attenuation (typical)



Fiber Transmission

λ (nm)		dB/km
633	Helium Neon	8
660	LED	7
820	LED	6
1064	Nd:YAG	12
1300	Diode Laser	30

†† Conditions are ambient: 50% relative humidity, 23 C.
Static fatigue parameter: 24.
* Statistically determined



HCS® All-Silica Fiber

The combination of our patented hard coating and large core, step-index, all-silica fiber construction offers you the benefits of high power transmission and high tensile strength.

The all-silica fiber, available in high OH^- and low OH^- grades, enables you to efficiently handle power transmissions from the UV to the near IR. The hard coat allows for tight bend radius and ensures fiber survivability in rugged environments.

Applications

Laser Delivery Systems
Spectroscopy
Sensors, Industrial and Medical
Radiation Analysis

Laser Welding
Laser Ordnance Initiation
Illumination

Aircraft/Industrial Cabling

Features and Benefits

High Power Laser Delivery. Peak power levels approaching 1 GWatt/cm^2 are possible with proper endface preparation.

Excellent UV, Visible and Near IR Transmission. Available in both high and low OH to allow transmission over a broad spectral range.

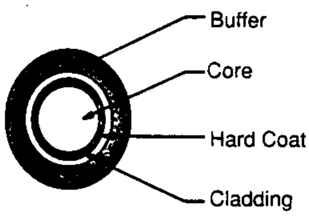
High Tensile Strength. Chemically bonded hard coating unique to Hard Clad Silica (HCS®) fibers ensures high strength. Average tensile strength of 720 kpsi.

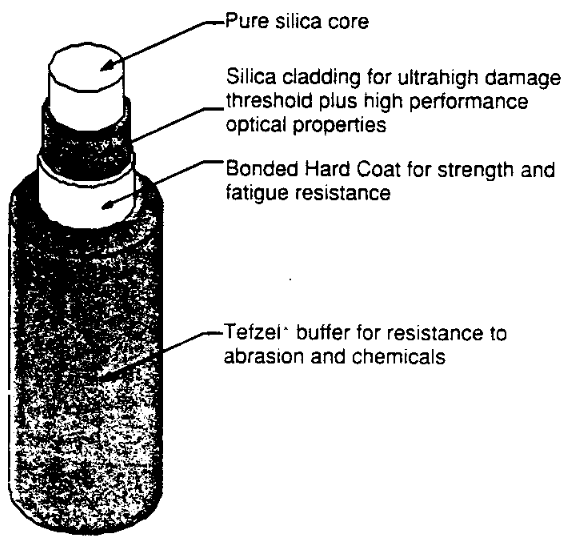
Tight Bend Radius. Proof testing fiber to levels far exceeding industry standards (up to 600 kpsi) ensures the survivability of all-silica fibers in extreme conditions.

Radiation Resistance. Step-index core and cladding materials enhance performance in high dose and high dose rate environments.

Sterilizible. Steam, ETO, e-beam or gamma radiation methods.

Biocompatible Materials. All materials certified Class VI non-toxic and biocompatible





Ensign-Bickford Optics Company

Ensign-Bickford Optics Company, 150 Fisher Drive, Avon, Connecticut 06001 USA
TEL 203-678-0371 FAX 203-674-8818

HCL, Low OH⁻ Fiber

Specifications:

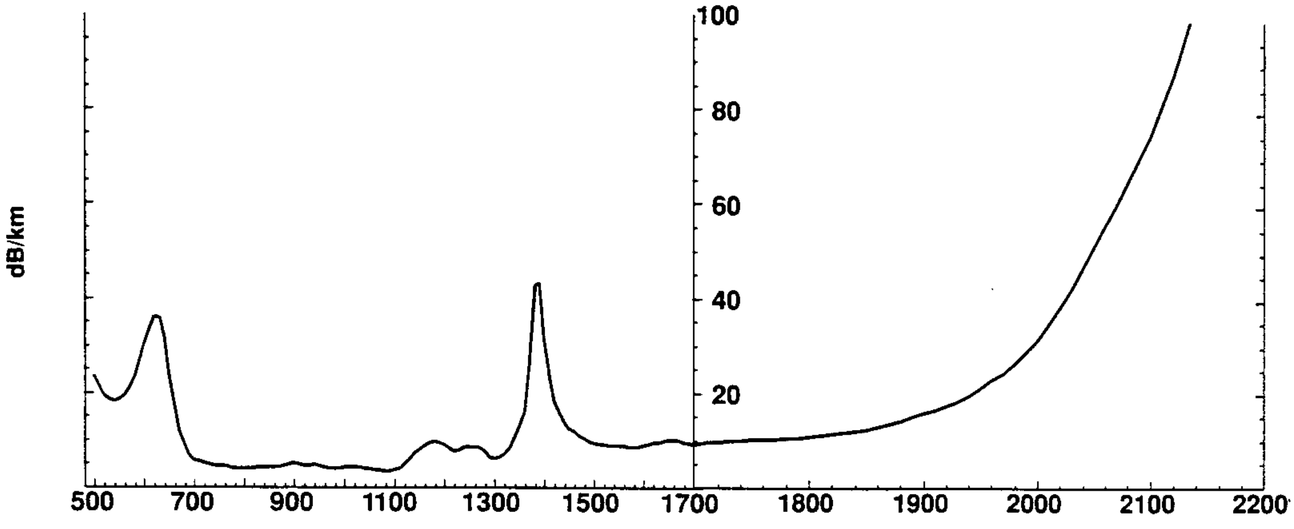
Product Code	Core Ø (μm)	Cladding Ø (μm)	Hard Coat Ø (μm)	Buffer Ø (μm)	Maximum Core-to-Hard Coat Offset (μm)	Nominal Bandwidth (MHz-km)	Proof Test (kpsi) Fiber is 100% tensile proof tested	Short-Term (60 mins.) Minimum Bend Radius [mm @ 23° C] ††	Long-Term (20 yrs.) Minimum Bend Radius [mm @ 23° C] ††	Typical Stock Lengths (m) ±5%
HCL-M0100T-12	100±5	130±5	140±5	250-0/+50	6	25	200	5	8	1100
HCL-M0200T-08	200±5	240±5	260±6	375±50	7	25	200	9	14	1100
HCL-M0365T-08	365±10	400±10	430+5/-10	730±50	9	--	100	29	47	1100
HCL-M0400T-08	400±10	480±10	515±10	830±50	9	--	50	70	113	500
HCL-M0550T-08	550±12	600±10	630±10	750±50	9	--	50	87	142	500
HCL-M0940T-10	940±15	1000±15	1035±15	1400±50	11	--	--	*121	*200	200

Temperature Range for Continuous Usage: -65° C to +135° C
Suitable for Temperature Excursions up to 200° C

Spectral Attenuation (typical)

Fiber Transmission

λ (nm)		dB/meter
532	KTP	.018
755	Alexandrite	.004
850	LED	.004
1093	Cr:MgF	.003
1300	Diode Laser	.006
1550	Diode Laser	.008
2010	Thulium	.034
2100	Ho:YAG	.075



†† Long-term conditions are ambient: 50% relative humidity, 23° C.
Static fatigue parameter: 24.
* Statistically determined

Ensign-Bickford Optics Company

01/92

HIGH TEMPERATURE ALL SILICA FIBER

TCL - Low OH⁻ TCG - High OH⁻

Preliminary Data Sheet*

APPLICATIONS

Scientific
Spectroscopy
Sensing/Diagnostics
Radiation Analysis
Vacuum Deposition

Industrial
Local Area Networks
Laser Welding
Sensors
Illumination
Optical Wiring Harnesses
Engine Controls
Down Hole Well-Logging

Laser Surgery
Arthroscopy
Lithotripsy
Angioplasty
Coagulation
Dentistry
Diskectomy

FEATURES AND BENEFITS

The Ensign-Bickford Optics Company (EBOC) High Temperature, All Silica fiber provides premium performance in adverse environments due to the rugged, chemically resistant, proprietary high temperature polymer coating. The pure Silica Core and Doped Silica Cladding ensure ultrahigh damage threshold with peak power levels approaching 1 GWatt/cm². Excellent chemical, abrasion and high temperature resistance is achieved with the proprietary coating. EBOC's TCG and TCL fiber have an average tensile strength of 720 kpsi, withstand temperature ranges from -65° to +350°C, and are radiation resistant.

SPECIFICATIONS*

	Core Ø (µm)	Cladding Ø (µm)	High Temperature Coat Ø (µm)	Maximum Core-to-Coat Offset (µm)	Maximum Attenuation (dB/km @ 820 nm)	Numerical Aperture (1 km 5% Intensity)	Nominal Bandwidth (MHz-km)	Proof Test (kpsi)	Short-Term (60 mins.) Minimum Bend Radius (mm @ 23°C)††	Long-Term (20 yrs..) Minimum Bend Radius (mm @ 23°C)††
TCG-M0200H	200±5	240±6	260±6	7	10	.22	25	100	18	30
TCL-M0200H	200±5	240±6	260±6	7	8	.22	25	100	18	30

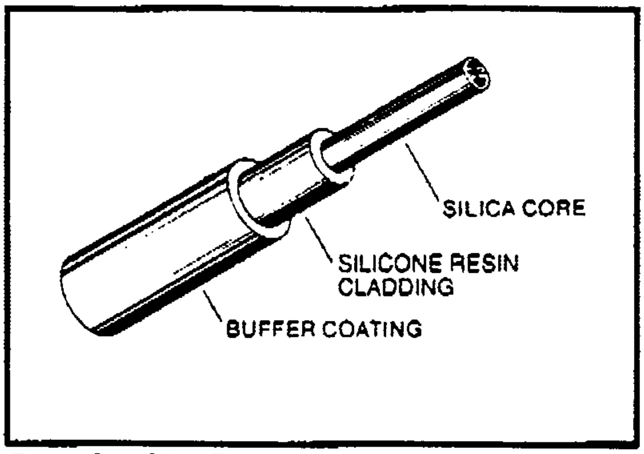
For more information call (203-678-0371), FAX (203-674-8818), or write (150 Fisher Drive, Avon, CT 06001) our Technical Sales Department.

†† Conditions are ambient: 50% relative humidty, 23°C
Static fatigue parameter: 24.

* Subject to change without notice

Power-Core Fiber

PCS -- Plastic-Clad Silica



Plastic-Clad Silica Fiber Construction

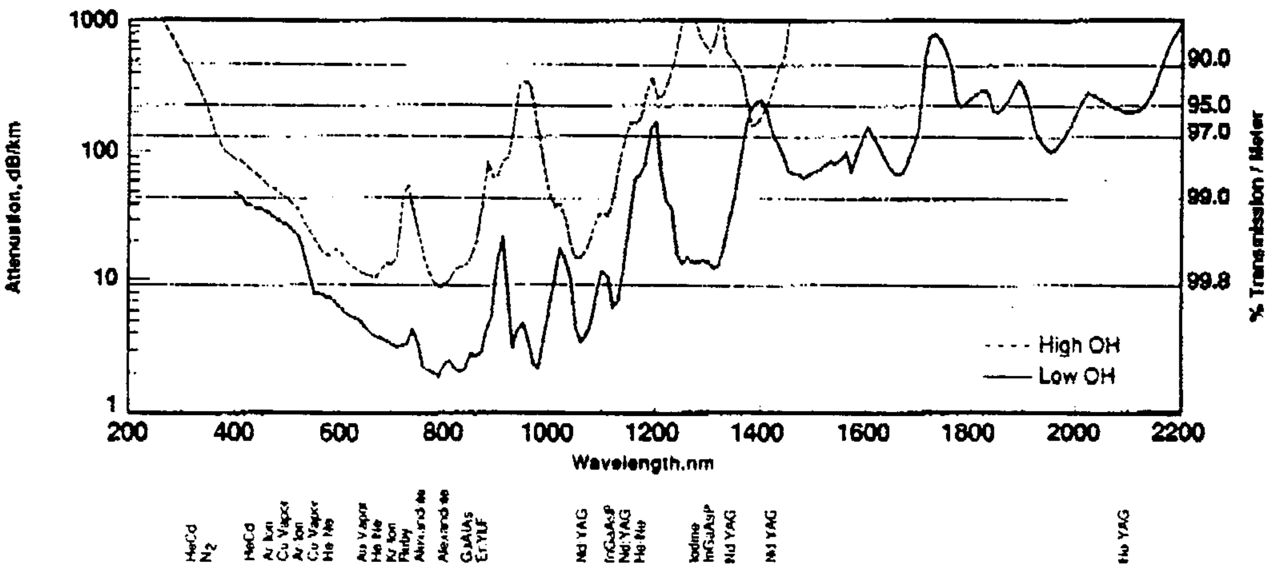
Applications

- Laser Delivery Systems
  - Medical
  - Industrial
  - Ordnance Initiation
- Short-Haul Data and Video Communications
- Illumination Systems
- Sensing Systems
  - Medical
  - Industrial
  - Spectroscopy

Advantages

- Two cladding types available:
  - Non-mechanically strippable clad fiber has a -35°C temperature capability and provides a stable termination with less pistoning. Recommended for crimp-and-cleave termination systems.
  - Mechanically strippable clad fiber has a -25°C temperature capability and provides easy cladding removal.
- Easy light coupling and low microbend loss due to high numerical aperture.
- Silicone-clad design provides low-cost UV performance superior to hard-clad polymer fibers.
- Both Low- and High-OH fiber designs available, providing a broad spectral transmission range from 220nm to 2400nm.
  - High-OH version provides superior radiation resistance in Co_{60} environments.
- Core, cladding and buffer are USP Class VI approved for non-toxicity and biocompatibility.
- Sterilizable (Radiation, EtO, Steam)
- Custom fiber sizes and coatings are available for specific applications.

Typical Spectral Response



Manufactured in the USA

3M

PCS -- Plastic-Clad Silica

LOW-OH FIBER — Designed for Visible to Near-IR Transmission

Part Number	Unit	FP-200-LMT	FP-400-LHT	FP-600-LHT	FP-1.0-LHT
Core Diameter	µm	200 ± 5	400 ± 8	600 ± 10	1000 ± 20
Clad Diameter	µm	380 ± 20	600 ± 30	830 ± 30	1400 ± 50
Buffer Diameter[1]	µm	600 ± 30	750 ± 30	1050 ± 30	1600 ± 50
Maximum Attenuation @ 820nm	dB/km	6	8	8	8
Bandwidth	MHz-km	20	13	9	—
Nominal Concentricity	%	95	95	85	80
Numerical Aperture[2]		0.40 ± 0.02	0.40 ± 0.02	0.40 ± 0.02	0.40 ± 0.02
Acceptance Angle (Full)		47°	47°	47°	47°
Peak Optical Power Capability[3]	MW	1.6	6.3	14.0	64.3
Operating Temperature Range	°C	-35 to +150	-25 to +150	-25 to +150	-25 to +150
Proof Test Level	kpsi	50	40	25	—
Minimum Bend Radius					
— Recommended Short Term	mm	26	75	100†	150†
— Recommended Long Term	mm	40	100	140†	180
— Absolute Short Term†	mm	10	15	25	35
— Absolute Long Term†	mm	20	30	45	85
Standard Lengths	m	1100, 2200	500	300	50

HIGH-OH FIBER — Designed for UV to Visible Transmission

Part Number	Unit	FP-200-UHT	FP-400-UHT	FP-600-UHT	FP-1.0-UHT
Core Diameter	µm	200 ± 5	400 ± 8	600 ± 10	1000 ± 20
Clad Diameter	µm	380 ± 20	600 ± 30	830 ± 30	1400 ± 50
Buffer Diameter[1]	µm	600 ± 30	750 ± 30	1050 ± 30	1600 ± 50
Maximum Attenuation @ 820nm	dB/km	12	12	12	12
Typical Attenuation @ 400nm	dB/km	40	40	40	40
Nominal Concentricity	%	95	95	85	80
Numerical Aperture[2]		0.40 ± 0.02	0.40 ± 0.02	0.40 ± 0.02	0.40 ± 0.02
Acceptance Angle (Full)		47°	47°	47°	47°
Peak Optical Power Capability[3]	MW	1.6	6.3	14.0	64.3
Operating Temperature Range	°C	-25 to +150	-25 to +150	-25 to +150	-25 to +150
Proof Test Level	kpsi	50	40	25	—
Minimum Bend Radius					
— Recommended Short Term	mm	26	75	100†	150†
— Recommended Long Term	mm	40	100	140†	180
— Absolute Short Term†	mm	10	15	25	35
— Absolute Long Term†	mm	20	30	45	85
Standard Lengths	m	1100, 2200	500	300	50

[1] Standard buffer coating is Tefzel® 210
[2] 2 meters, 50% intensity
[3] Based on 5 GW/cm² for 1064nm Nd:YAG laser with 10 nsec. pulse length.
† Determined statistically for short gauge length.

#78-6900-1903-5 Rev. B

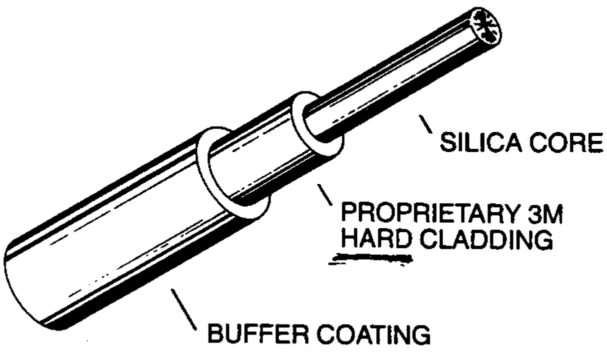
3M Specialty Optical Fibers

420 Frontage Road
West Haven, CT 06516-4190 USA
(203) 934-7961

3M

Power-Core Fiber

TECS™ Fiber -- Technology-Enhanced Clad Silica



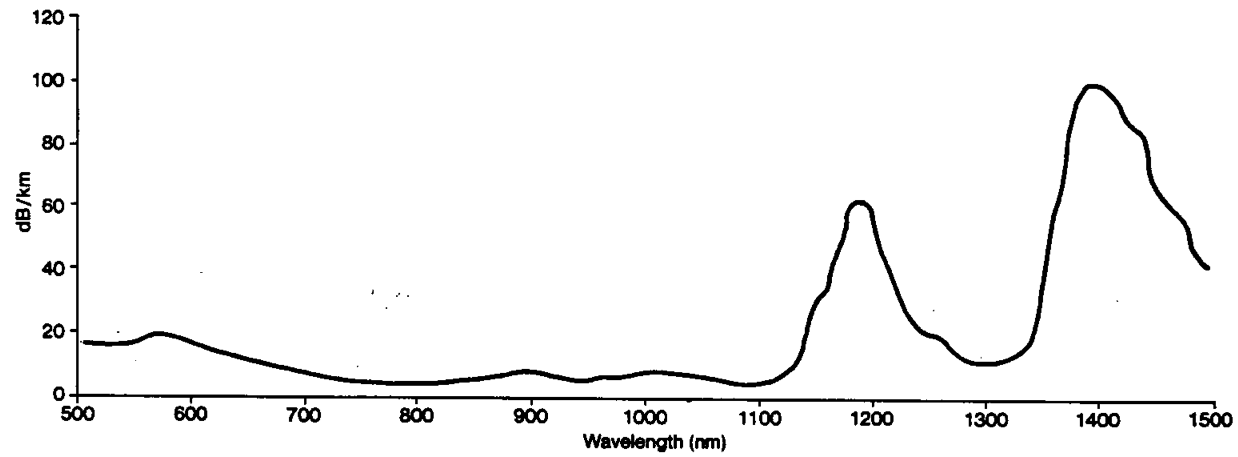
Applications

- Laser Delivery Systems
- Data Communications
- Video Communications
- Illumination
- Sensing Systems

Advantages

- Hard cladding provides increased fiber strength and reduced static fatigue in humid environments.
- High numerical aperture for easy light coupling and low microbend loss.
- Small overall fiber size for small size constraints.
- High core to clad bonding prevents pistoning and provides more stable terminations.
- Revolutionary crimp and cleave connector system is user friendly and offers easy, high quality, repeatable results.
- Optimum transmission range from 500 to 2400nm.
- Temperature range of -65° to +125°C provides system stability at very low temperatures.
- High core to clad ratio for excellent connection alignment, fiber core positioning, and high transmission bundles.
- Standard and Advanced Radiation Resistant versions available for superior performance in CO_{60} environments.

Typical Spectral Response



3M

TECS™ HARD CLAD FIBER SPECIFICATIONS

LOW-OH FIBER — Designed for Visible to Near-IR Transmission

Standard Performance Fiber[1] Attenuation @ 630nm ≤ 50 dB/km Part Number →	Unit	FT-200-DMT	FT-300-DMT	FT-400-DMT	FT-600-DMT	FT-800-DMT	FT-1.0-DMT
Premium Performance Fiber Attenuation @ 630nm ≤ 10 dB/km Part Number →		FT-200-LMT	FT-300-LMT	FT-400-LMT	FT-600-LMT	FT-800-LMT	FT-1.0-LMT
Core Diameter	μm	200 ± 5	300 ± 6	400 ± 8	600 ± 10	800 ± 10	1000 ± 15
Clad Diameter	μm	230 +0,-10	330 +5,-15	430 +5,-15	630 ± 10	830 ± 10	1035 ± 15
Buffer Diameter[2]	μm	500 ± 30	650 ± 30	730 ± 30	1040 ± 30	1040 ± 30	1400 ± 50
Maximum Attenuation @ 820nm	dB/km	6	6	8	8	8	8
Bandwidth	MHz-km	20	15	13	9	—	—
Maximum Core Offset	μm	5	5	7	9	9	10
Numerical Aperture[3]		0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02
Acceptance Angle (Full)		46°	46°	46°	46°	46°	46°
Peak Optical Power Capability[4]	MW	1.6	2.8	6.3	14.0	25.0	64.3
Operating Temperature Range	°C	-65 to +125	-65 to +125	-65 to +125	-65 to +125	-65 to +125	-65 to +125
Proof Test Level	kpsi	100	100	50	50	—	—
Minimum Bend Radius							
— Recommended Short Term	mm	13	20	53	80	106†	133†
— Recommended Long Term	mm	20	30	80	120	160†	180
— Absolute Short Term†	mm	5	8	12	18	20	30
— Absolute Long Term†	mm	10	15	20	30	40	60
Standard Lengths	m	1100, 2200	500	500	300	100	50

HIGH-OH FIBER — Designed for UV to Visible Transmission

Part Number	Unit	FT-200-UMT	FT-300-UMT	FT-400-UMT	FT-600-UMT	FT-800-UMT	FT-1.0-UMT
Core Diameter	μm	200 ± 5	300 ± 6	400 ± 8	600 ± 10	800 ± 10	1000 ± 15
Clad Diameter	μm	230 +0,-10	330 +5,-15	430 +5,-15	630 ± 10	830 ± 10	1035 ± 15
Buffer Diameter[2]	μm	500 ± 30	650 ± 30	730 ± 30	1040 ± 30	1040 ± 30	1400 ± 50
Maximum Attenuation @ 820nm	dB/km	12	12	12	12	12	12
Typical Attenuation @ 400nm	dB/km	75	75	75	75	75	75
Bandwidth	MHz-km	20	15	13	9	—	—
Maximum Core Offset	μm	5	5	7	9	9	10
Numerical Aperture[3]		0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02	0.39 ± 0.02
Acceptance Angle (Full)		46°	46°	46°	46°	46°	46°
Peak Optical Power Capability[4]	MW	1.6	2.8	6.3	14.0	25.0	64.3
Operating Temperature Range	°C	-65 to +125	-65 to +125	-65 to +125	-65 to +125	-65 to +125	-65 to +125
Proof Test Level	kpsi	100	100	50	50	—	—
Minimum Bend Radius							
— Recommended Short Term	mm	13	20	53	80	106†	133†
— Recommended Long Term	mm	20	30	80	120	160†	180
— Absolute Short Term†	mm	5	8	12	18	20	30
— Absolute Long Term†	mm	10	15	20	30	40	60
Standard Lengths	m	1100, 2200	500	500	300	100	50

[1] Not recommended for radiation environments.
[2] Standard buffer coating is Tefzel® 210
[3] 2 meters, 50% intensity
[4] Based on 5 GW/cm² for 1064nm Nd:YAG laser with 10 nsec. pulse length.
† Determined statistically for short gauge length.

PRODUCT LIST

SILICA/SILICA FIBER SERIES

FI Ultra-Low OH⁻

FIP - POLYIMIDE BUFFER

PRODUCT NUMBER*	CORE/CLAD RATIO	CORE (μm)		CLAD (μm)		BUFFER (μm)	
		OD	±	OD	±	OD	±
100110125**	1.1	100	7	110	5	125	5
150165180	1.1	150	7	165	5	195	5
200220240	1.1	200	8	220	5	240	5
300330360	1.1	300	14	330	10	360	10
400440470	1.1	400	17	440	10	470	10
500550580	1.1	500	20	550	12	580	12
600660690	1.1	600	25	660	15	690	15
800880910	1.1	800	28	880	15	910	15
100120140	1.2	100	7	120	5	140	5
200240270	1.2	200	8	240	5	270	5
320385415	1.2	320	14	385	10	415	10
400480510	1.2	400	17	480	10	510	10
500600630	1.2	500	20	600	12	630	12
600720750	1.2	600	25	720	15	750	15
100140170	1.4	100	7	140	5	170	5

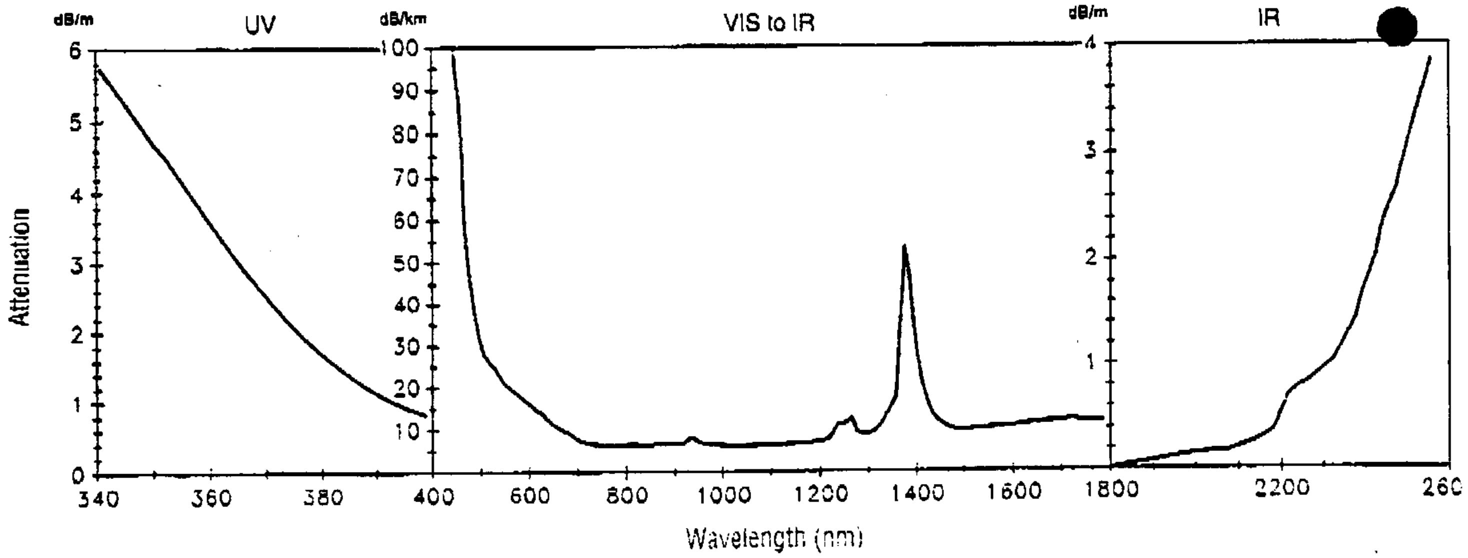
*Add appropriate 3-letter prefix to complete product number.

** Not recommended for operation beyond 1,000 nm.

CHARACTERISTICS:

- Step Index
- Doped Silica Clad/Pure Silica Core
- Numerical Aperture: 0.22±.02
- UV-VIS-IR Transmission, 380 — 2500 nm
- Low OH⁻ Core
- Proof Test Level: 100 kpsi
- Operating Temperature to 400°C
- Radiation Resistant
- High Laser Damage Threshold
- Sterilizable (γ, Eto, Steam)
- Sizes for Bundling
- Tighter Tolerances Available
- Polyimide Concentricity to ±1 μm
- Dual Buffers are Available
- Biocompatible Materials - USP Class \

FI SPECTRAL ATTENUATION



POLYMICRO TECHNOLOGIES INCORPORATED
3035 N. 33rd Drive, Phoenix, AZ 85017-5204
(602) 272-7437 FAX (602) 278-1776

To Order:
CALL (602) 272-7437
FAX (602) 278-1776

PRODUCT LIST

SILICA/SILICA FIBER SERIES

FH High OH⁻

FV UV Enhanced High OH⁻

FHP, FVP - POLYIMIDE BUFFER

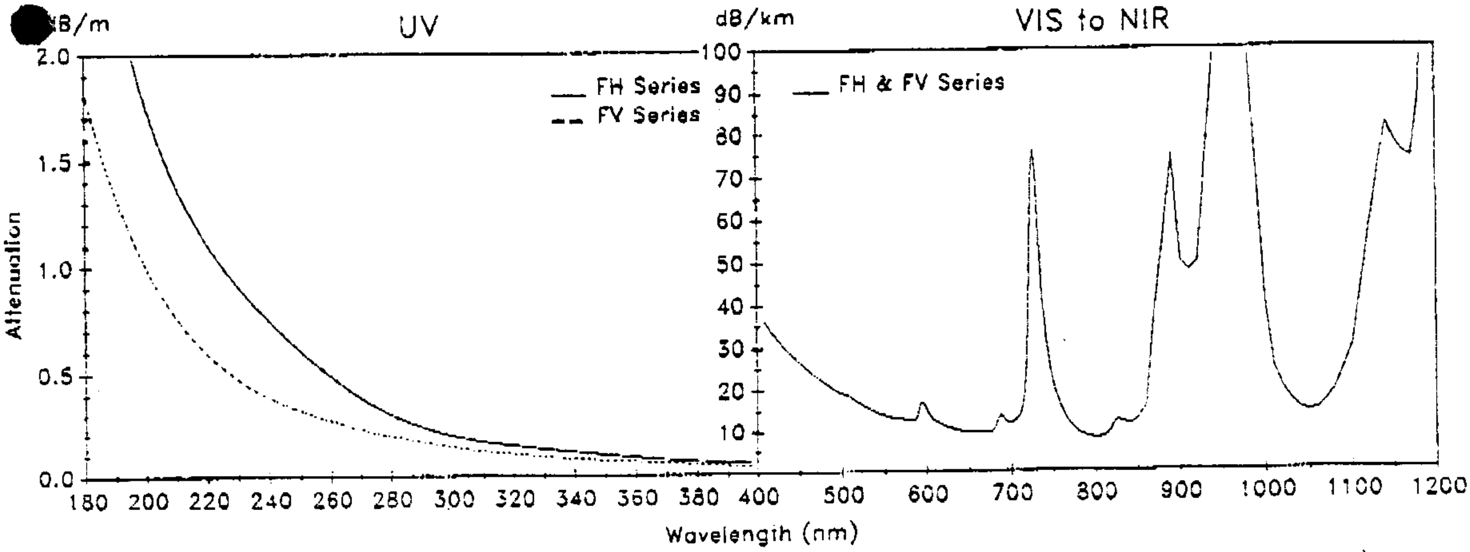
PRODUCT NUMBER*	CORE/CLAD RATIO	CORE (μm)		CLAD (μm)		BUFFER (μm)	
		OD	±	OD	±	OD	±
050055065	1.1	50	5	55	5	65	5
100110125	1.1	100	7	110	5	125	5
150165180	1.1	150	7	165	5	195	5
200220240	1.1	200	8	220	5	240	5
300330360	1.1	300	14	330	10	360	10
400440470	1.1	400	17	440	10	470	10
500550580	1.1	500	20	550	12	580	12
600660690	1.1	600	25	660	15	690	15
800880910	1.1	800	28	880	15	910	15
100120140	1.2	100	7	120	5	140	5
200240270	1.2	200	8	240	5	270	5
320385415	1.2	320	14	385	10	415	10
400480510	1.2	400	17	480	10	510	10
500600630	1.2	500	20	600	12	630	12
600720750	1.2	600	25	720	15	750	15
100140170	1.4	100	7	140	5	170	5

*Add appropriate 3-letter prefix to complete product number.

CHARACTERISTICS:

- Step Index
- Doped Silica Clad/Pure Silica Core
- Numerical Aperture: 0.22±.02
- UV-VIS-NIR Transmission, 180—1100 nm
- High OH⁻ Core
- Proof Test Level: 100 kpsi
- Operating Temperature to 400°C
- Superior Radiation Resistance
- High Laser Damage Threshold
- Sterilizable (γ, Eto, Steam)
- Sizes for Bundling
- Tighter Tolerances Available
- Polyimide Concentricity to ±1 μm
- Dual Buffers are Available
- Biocompatible Materials - USP Class VI

SPECTRAL ATTENUATION



POLYMICRO TECHNOLOGIES INCORPORATED
3035 N. 33rd Drive, Phoenix, AZ 85017-5204
(602) 272-7437 FAX (602) 278-1776

To Order:
CALL (602) 272-7437
FAX (602) 278-1776

SpecTran™

SpecTraguide™
Radiation Hard Optical Fiber

Radiation can penetrate the core of optical fiber, causing an increase in attenuation which may interrupt communications. SpecTraguide Radiation Hard optical fiber is specially designed to resist radiation, ensuring accurate, uninterrupted communications in the vicinity of a controlled radiation source or nuclear event.

SpecTraguide Radiation Hard fiber is the product of an exhaustive research and testing program. In evaluations conducted by U.S. government agencies, including the Naval Research Laboratory and the Harry Diamond National Laboratory, SpecTraguide's loss resistance and recovery rates were proven exceptional.

- ☐ Available in both single-mode and multimode constructions
- ☐ Qualified for advanced defense applications including AEGIS, FEMA and the Ground Launch Cruise Missile program
- ☐ Recommended for use in and around all radiation sources

		Graded Index		Step Index			Single-mode
Product Number		200R	320R	420R	820R[1]	840R[1]	102[3]
Core Diameter	um	50	100	100	105	200	—
Clad Diameter	um	125	140	140	125	240	125
Buffer Diameter	um	500	500	500	500	500	250
Numerical Aperture	um	.20	.27	.24[2]	.20[2]	.20[2]	—
Mode Diameter 1300 nm	um						10.0
Attenuation (Max) @850 nm	dB/km	4.0	5.0	5.0	15.0	15.0	—
@1300 nm	dB/km						.50
@1550 nm	dB/km						.35
Bandwidth (Min) @850 nm	MHz-km	200	100	20	20	20	
Length	km	———— 1.1–2.2 ————					2.2 12.6
Strength (Min)	kpsi	100	100	100	50	50	50

[1] Pure silica core [2] Measured using long NA technique [3] Standard single-mode products

SpecTran™

SpecTraguide™
PYROCOAT™ Heat-Resistant Coating

Conventional, acrylate-coated optical fiber withstands ambient temperatures up to 80°C. PYRO COAT, a unique polyimide coating, significantly extends that operating range. In temperatures as high as 375°C, PYROCOAT preserves the outstanding optical performance and rugged mechanical characteristics of SpecTraguide fiber.

PYROCOAT is available only from SpecTran, an innovator in optical fiber for demanding applications.

Extended thermal protection
- ☐ Up to 375°C

Ideal for military and medical applications
- ☐ Maintains fiber performance in harsh environments
- ☐ Withstands sterilization heat

Maintains dielectric properties of fiber
- ☐ Eliminates ground loop potential

Chemically stable coating
- ☐ Organic, thermally applied
- ☐ Resists organic solvents

Chemically bonded to fiber
- ☐ Applied in line with fiber draw
- ☐ Thermally cured
- ☐ Does *not* strip when buffer coating is removed
- ☐ Meets *all* SpecTraguide quality and performance standards

PYROCOAT Heat-Resistant Coating Characteristics

Coating Thickness	(minimum)	um	10
Tensile Strength	(minimum)	kpsi	50
Young's Modulus		kpsi	300–350
Maximum Temperature		°C	375

PYROCOAT will not dissolve in most organic solvents. To strip the coating, use one of the following methods:
1. Burn off with flame from a butane source
2. Apply voltage to nichrome wire until red; wipe PYROCOAT fiber against wire 3. Molten caustic soda 4. Hydrozene 5. Ethylene diamine heated to near boiling 6. 30% sodium hydroxide heated to near boiling. 7. Hot sulphuric acid

100% quality tested

We test every spool of SpecTraguide fiber for quality and performance. As a member of the Electronic Industries Association, we use standard industry test procedures to characterize our fiber for more than 25 individual performance parameters. Spool labels detail exact performance data.

Our commitment

We deliver on time, as promised and we back our products with responsive service and technical support. For both standard and special-use fiber, a growing list of customers depends on the SpecTran™ commitment.

Special applications

SpecTran is one of the world's leading producers of optical fiber. In addition to PYROCOAT-protected fiber, we offer.
Single-mode, Step Index Multimode (single/dual window), Graded Index Multimode (single/dual window), Radiation Hard, UV Transmitting, Infrared Transmitting and Hermetically Coated fiber. We can also develop special-use fiber to meet unique and demanding applications. Contact our Applications Engineering Department for further information.

To order:

Refer to SpecTraguide conventional fiber data sheets to determine the product(s) best suited to your application. Order that product number followed by the letter P, to specify PYROCOAT coating.

Specify the attenuation (first, FW; second, SW; or dual, DW), bandwidth and length required. Please contact the Sales Order Department.
508 347-2261
FAX 508 347-2747
for minimum order requirements and further details.

SpecTran Corporation
50 Hall Road
Sturbridge, MA 01566
(508) 347-2261
Fax: (508) 347-1211

CeramOptec

Polyimide Coated

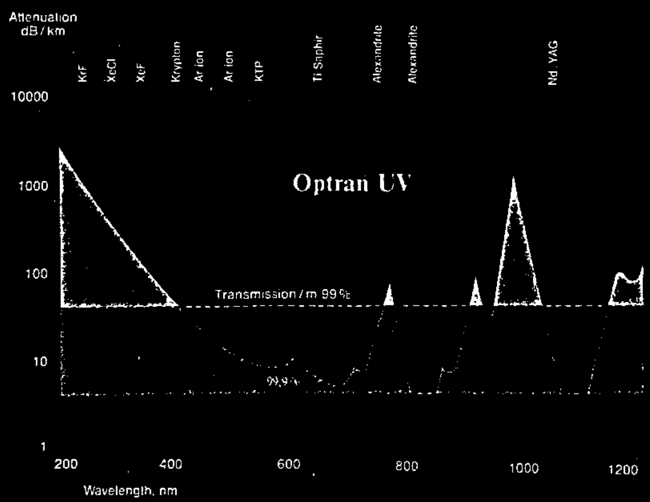
Quartz / Quartz-Fiber

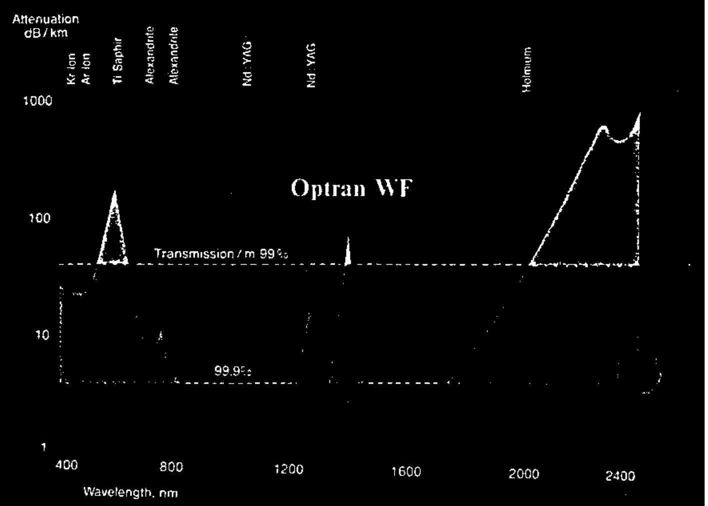
Features

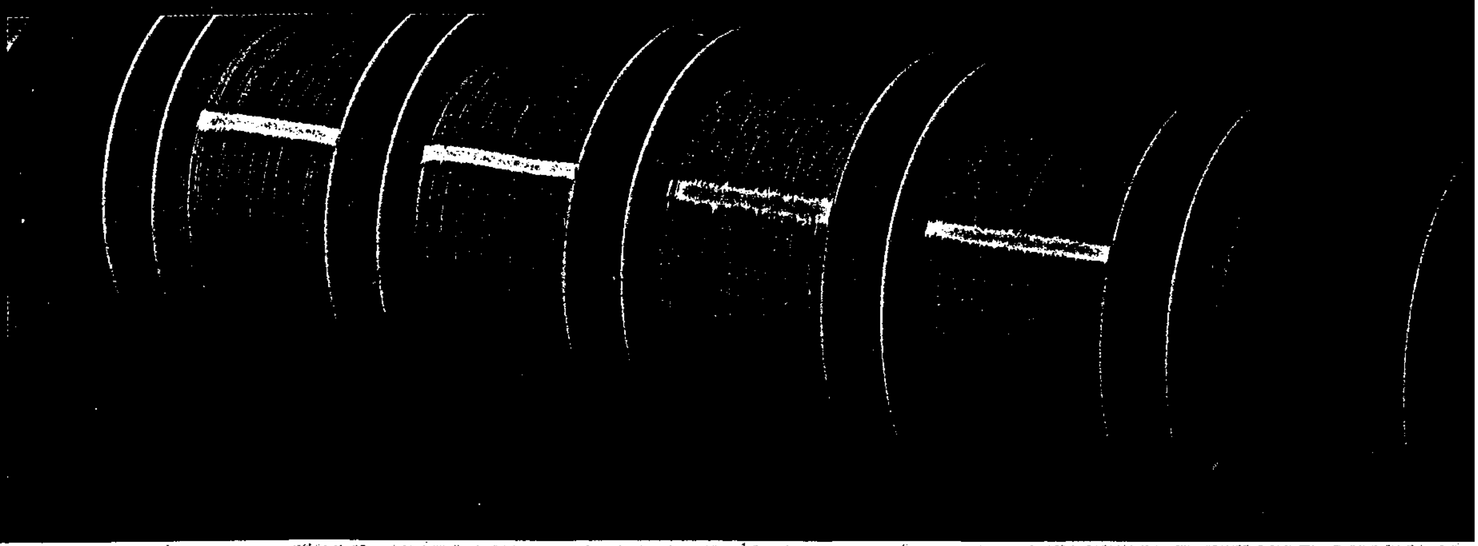
- Broad temperature range (−190° to +385° C)
- Thin jacket diameter
- Laser damage resistant
- High core to clad ratio
- Biocompatible materials
- Sterilizable by ETO, gamma and steam
- Manufactured at GMP compliant facility
- Radiation resistant
- High transmission in NIR

Applications

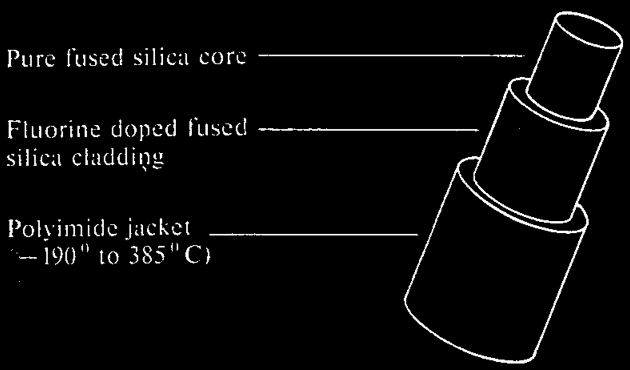
- High vacuum environment
- High efficiency bundles and arrays
- High temperature bundles
- High temperature sensors
- Databus
- Spectroscopy
- Laser welding/soldering
- Smart skin
- Medical laser delivery systems







Fiber design



Properties

- Step index profile
- Pure silica core
- Numerical aperture: 0.22 ± 0.02
- Laser damage resistant core transmits 1.3 kW/mm^2 CW at 1060 nm, up to 10 J, pulsed
- Bend radius: momentary 100 x clad radius; long term 600 x clad radius
- Useful spectral transmission range: from 180 to 2400 nm
- Polyimide's high refractive index (1.78) strips cladding modes
- Standard prooftest: 70 kpsi

Product Code	Ø Core (μm) ± 2%	Ø Clad (μm) ± 2%	Ø Jacket (μm) ± 5%	Operating Wavelength (nm)
UV 50 / 125 P	50	125	150	180 to 1100
UV 100 / 110 P	100	110	135	180 to 1100
UV 100 / 120 P	100	120	145	180 to 1100
UV 100 / 140 P	100	140	165	180 to 1100
UV 105 / 125 P	105	125	150	180 to 1100
UV 200 / 220 P	200	220	245	180 to 1100
UV 200 / 240 P	200	240	265	180 to 1100
UV 320 / 385 P	320	385	410	180 to 1100
UV 400 / 424 P	400	424	450	180 to 1100
UV 400 / 480 P	400	480	505	180 to 1100
UV 600 / 636 P	600	636	660	180 to 1100

Product Code	Ø Core (μm) ± 2%	Ø Clad (μm) ± 2%	Ø Jacket (μm) ± 5%	Operating Wavelength (nm)
WF 50 / 125 P	50	125	150	350 to 2400
WF 100 / 110 P	100	110	135	350 to 2400
WF 100 / 120 P	100	120	145	350 to 2400
WF 100 / 140 P	100	140	165	350 to 2400
WF 105 / 125 P	105	125	150	350 to 2400
WF 200 / 220 P	200	220	245	350 to 2400
WF 200 / 240 P	200	240	265	350 to 2400
WF 320 / 385 P	320	385	410	350 to 2400
WF 400 / 480 P	400	480	505	350 to 2400
WF 600 / 660 P	600	660	685	350 to 2400

Notes:

Additional protective jackets can be extruded over the polyimide coated fibers (nylon, Tefzel®, polyetherketones or liquid crystal polymers).

Other core / clad ratios and numerical apertures available upon request.

Information given is believed to be reliable. CeramOptec offers no warranties as to its accuracy and disclaims any liability in connection with its use.

Tefzel® is a DuPont registered product

Please contact our sales engineering departments:

CeramOptec Inc.
188 Moody Road, Enfield, CT 06082, USA
Tel.: 203 / 763 - 4855, Fax: 203 / 763 - 2942

CeramOptec GmbH
Siemensstraße 8, 5300 Bonn 1, Germany
Tel.: 228 / 611051, Fax: 228 / 611053

or our local representative.

FIBER IDENTIFICATION

ES1-36/22-UV1

- ES1-36/22-**UV1** → Coating type { NY1, UV1, SI } { NY1 : Nylon; UV1 : UV curable acrylate; SI1 : Silicone }
- ES1-**36/22**-UV1 → Fiber grade AA'/CC' { AA' : Attenuation at 1300nm = AA'/100(dB/km); CC' : Attenuation at 1550nm = CC'/100(dB/km) }
- **ES1**-36/22-UV1 → Fiber type { ES1 : Germanium doped core fiber; PS1 : Pure Silica Core Fiber; DS1 : Dispersion Shifted Fiber }

GERMANIUM-DOPED-CORE-SINGLEMODE FIBER

GRADE	ATTENUATION (dB/km)		DISPERSION (ps/km·nm)		CUT-OFF WAVELENGTH (nm)	MODE FIELD DIAMETER (μm)	CORE CONCENTRICITY ERROR (μm)	CLADDING DIAMETER (μm)
	1300nm	1550nm	1285–1330nm	1550nm				
ES1-45/30	0.45	0.30	3.5	20	1200–1330 1100- 1280	9.5±0.5(1300nm) 10.0±1.0(1300nm)	0.8	125±2
ES1-40/25	0.40	0.25	3.5	20				
ES1-36/22	0.36	0.22	3.5	20				

PURE-SILICA-CORE-SINGLEMODE FIBER

GRADE	ATTENUATION (dB/km)		DISPERSION (ps/km·nm)		CUT-OFF WAVELENGTH (nm)	MODE FIELD DIAMETER (μm)	CORE CONCENTRICITY ERROR (μm)	CLADDING DIAMETER (μm)
	1300nm	1550nm	1285–1330nm	1550nm				
PS1-34/20	0.34	0.20	3.5	20	1100–1280 1350–1580	8.9±0.8(1300nm) 10.8±0.8(1550nm)	0.8	125±2
PS1-33/19	0.33	0.19	3.5	20				
PS1-32/18	0.32	0.18	3.5	20				

DISPERSION-SHIFTED-SINGLEMODE FIBER

GRADE	ATTENUATION (dB/km)	DISPERSION (ps/km·nm)	CUT-OFF WAVELENGTH (nm)	MODE FIELD DIAMETER (μm)	CORE CONCENTRICITY ERROR (μm)	CLADDING DIAMETER (μm)
	1550nm	1525–1575nm				
DS1-25	0.25	3.5	1050–1300	8.0±0.8(1550nm)	0.8	125±2
DS1-23	0.23	3.5				

COATING MATERIAL

COATING TYPE		PRIMARY MATERIAL	PRIMARY DIAMETER (μm)	SECONDARY MATERIAL	SECONDARY DIAMETER (μm)
NY	1	SILICONE (DOUBLE COATING)	400	NYLON	900
NY	2	UV CURABLE ACRYLATE (DOUBLE COATING) SILICONE	250 400	NYLON	900
UV	1	UV CURABLE ACRYLATE (DOUBLE COATING)	250	—	—
UV	2	UV CURABLE ACRYLATE (DOUBLE COATING)	400	—	—
SI	1	SILICONE (DOUBLE COATING)	400	—	—

SUMITOMO ELECTRIC INDUSTRIES, LTD.

Tokyo — **Sumitomo Electric Industries, Ltd. (International Business Division)**
3-12, Moto-Akasaka 1-chome, Minato-ku, Tokyo 107 Japan
Tel: (03) 423-5771 Telex: 28202 SEITOK J

New York — **Sumitomo Electric U.S.A., Inc.**
551 Madison Avenue, New York, NY 10022 U.S.A.
Tel: (212) 308-6444 Telex: 0640739 SUMOELEC NYK

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23440 Hawthorne Blvd., Building 2, Suite 210, Torrance, CA 90505 U.S.A.
Tel: (213) 373-8493 Telex: (TWX) 9103446368 SEUSA TRNC

London — **Sumitomo Electric Europe S.A.**
30 Dorset Square, London NW1 6QJ, England, U.K.
Tel: (01) 723-4003 Telex: 291709 SEELON G

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Ensign-Bickford Optics Company

6/92

RADIATION-RESISTANT SINGLEMODE FIBER

General Product Information

- Fibers have pure fused silica core for operation in high-radiation environments.
- Pure silica core allows high optical energy to be transmitted.
- Fluorine doped cladding.
- Nominal numerical aperture (NA) is
- Core index tolerance 0.0042 - 0.0048.

Optical Specifications

Fiber Numbers

Radiation-Resistant	F0500E	F1506E	F0808E	F1060E	F2300E
Operating Wavelength (nm)	515	630	820	1060	1300
Cutoff Wavelength (nm)	380 ±60	580 ±30	750 ±50	970 ±60	1180 ±70
Attenuation (dB/km)	20-30	8-12	2-4	1-2	0.4-1
Mode Field Diameter (µm)	3.7	4.6	6.0	7.7	9.5

* Equivalent to Telecommunications Fibers. For details consult F2300B-4 data sheets.

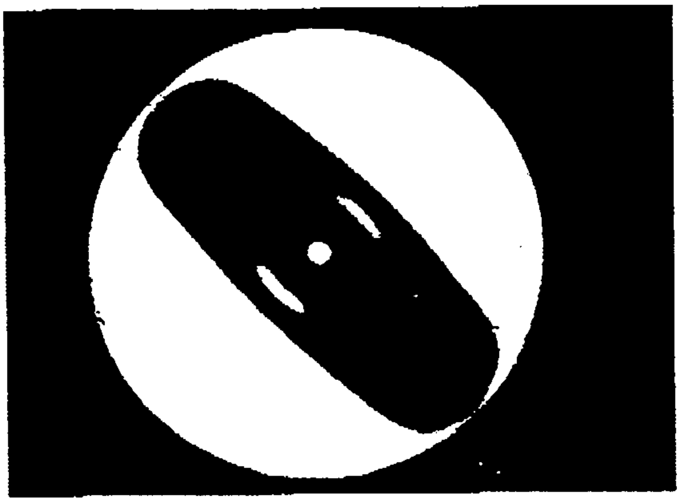
Physical Specifications

Cladding Diameter[1]	125 ±2 µm
Core/Cladding Eccentricity	1 µm max.
Cladding Non-Circularity	2 % max.
Coating Diameter	250 ±15 µm (135[1], 500 & 900 µm available)
Coating Concentricity	70 % min.
Standard Proof Test[2], Entire Length (Proof Test for at least 1 second)	50 kpsi (0.35 GN/m^2)
Operating Temperature[3]	-40° to +80° C
Available Length	100 m to 20.5 km

[1] Fibers are available with 80 ±2 µm cladding diameter.
[2] Higher proof-tests can be provided.
[3] For high-temperature Polyimide coatings, please consult the factory for details.

150 Fisher Drive, P. O. Box 1620, Avon, Connecticut 06001 USA
Phone: 203-678-0371 Fax: 203-674-8818

Polarization-Maintaining Single-Mode Fiber
(DWS Series)



The elliptical element applies an asymmetric stress on the fiber core resulting in stress-induced birefringence.

Applications
- Interferometric Sensors
- Fiber Optic Gyroscopes
- Advanced Communication Systems
- Polarization-Maintaining Fiber Cable

Advantages
- High numerical aperture design prevents signal loss under tight bends and preserves optical performance in miniature packaging applications and standard cable designs.
- Stress-induced birefringence allows low-loss transmission of polarized light with little crosstalk between the fiber polarization modes.
- Now available for 630, 820, 1060, 1320 and 1550nm wavelengths.
- New extended temperature fiber coating system offers stable polarization performance over a -55° to +85°C operating range.

Part Number	Unit	FS-HB-3611	FS-HB-4611	FS-HB-5651	FS-HB-6621	FS-HB-7621
Operating Wavelength	nm	630	820	1060	1320	1550
Mode Field Diameter	µm	3.7 ± 0.5	5.1 ± 0.5	6.3 ± 0.5	8.0 ± 0.5	9.5 ± 0.5
Fiber Diameter	µm	80 ± 2	80 ± 2	100 ± 2	125 ± 2	125 ± 2
Coating Diameter	µm	200 ± 15	200 ± 15	200 ± 15	250 ± 15	250 ± 15
Core/OD Offset[1]	µm	<1.5	<1.0	<1.0	<1.0	<1.0
Maximum Attenuation	dB/km	15.0	5.0	3.0	2.0	2.0
Cut-off Wavelength	nm	<620	800[2]	<1020	<1280	<1500
Numerical Aperture		0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.01	0.13 ± 0.01
Birefringence		4×10^{-4}	4×10^{-4}	4×10^{-4}	4×10^{-4}	4×10^{-4}
h Parameter	/m	$<10^{-5}$	$<10^{-5}$	$<10^{-5}$	$<10^{-5}$	$<10^{-5}$
Proof Test Level	kpsi	50	50	50	50	50
Coating Type		Soft Primary/ Acrylate	Soft Primary/ Acrylate	Soft Primary/ Acrylate	Soft Primary/ Acrylate	Soft Primary/ Acrylate
Standard Lengths	m	110, 1100	110, 1100	110, 1100	110, 1100	110, 1100

[1] Typical offset of <0.5µm can be supplied on request. Consult product manager.
[2] Shorter wavelength version for 780nm diodes can be supplied. Consult product manager.

Special Note:
Each fiber spool will specify the actual Mode Field Diameter and calculated ESI values for that spool.

Important Notice to Purchaser:
All statements, technical information and recommendations related to the Seller's products are based on information believed to be reliable, but the accuracy or completeness thereof is not guaranteed. Before utilizing the product, the user should determine the suitability of the product for its intended use. The user assumes all risks and liability whatsoever in connection with such use.

Any statements or recommendations of the Seller which are not contained in the Seller's current publications shall have no force or effect unless contained in an agreement signed by an authorized officer of the Seller. The statements contained herein are made in lieu of all warranties, express or implied, including but not limited to the implied warranties of merchantability and fitness for a particular purpose which warranties are hereby expressly disclaimed.

Seller shall not be liable to the user or any other person under any legal theory, including but not limited to negligence or strict liability, for any injury or for any direct or consequential damages sustained or incurred by reason of the use of any of the Seller's products that were defective.

#78-6900-1925 8 Rev. B

3M Specialty Optical Fibers
420 Frontage Road
West Haven, CT 06516-4190 USA
(203) 934-7961

3M

INFORMATION NOTE 01:

YORK HIBI; THE BASICS:-

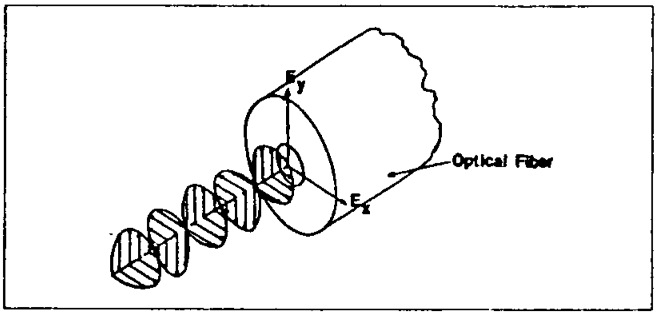
WHAT IT IS....WHAT IT DOES....HOW IT WORKS

What Is York HiBi?

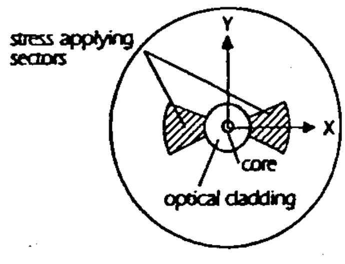
York HiBi is a singlemode, polarisation-preserving optical fiber designed for high-performance interferometric and polarimetric sensors, integrated optics and coherent communications.

Why Does It Preserve Polarisation?

The fundamental mode which propagates in a singlemode fiber is actually a degenerate combination of two orthogonally-polarised components - a situation represented graphically below.



In a conventional singlemode fiber, these components travel with the same velocity and so environmental disturbances can cause energy to couple from one component to the other, with the result that the polarisation-state of the light may vary unpredictably. In York HiBi, the bows of the 'bow-tie' make the core birefringent by placing it in tension. This birefringence causes the two components to travel at different velocities and so prevents the inadvertent transfer of optical power from one to the other. The higher the birefringence, the greater is this velocity difference and the more strongly will the fiber preserve polarisation - the 'slow' and 'fast' axes of HiBi are shown below as axes 'X' and 'Y' respectively.



Principal polarization states of HiBi fiber.

IF YOU NEED TO KNOW MORE, JUST CALL US ON +44 (0) 703 260411 (UK) OR 609 924 4040 (USA).

SPECIFICATIONS FOR HiBi FIBERS

York HiBi fibers are designed for operation at selected wavelengths between 488nm and 1550nm. Other wavelengths in this range are available on request.

			NEW		NEW	NEW
Fiber type:	HB 450	HB 600	HB 750	HB 800	HB 1250	HB 1500
Operating wavelengths λ_{op} * (nm):	488, 514	633	780	830	1300	1550
Cut-off wavelengths (nm):	<488	<600	<750	<800	<1250	<1500
Attenuation at λ_{op} (dB/km):	<100	<12	<8	<5	<2	<2

Other specifications:

Polarization cross-coupling** (or extinction ratio):	-20dB over 1km (typical)
Beatlength at 633 nm:	typical 1.3mm, max. 2mm
Fiber diameter — all types:	125 μm ± 3 μm (r.m.s. variation < 1 μm)
Fiber diameter — HB 800 also available with:	80 μm ± 3 μm
Coating diameter:	220 μm (nominal)
Coating type:	mode stripping acrylate
Core diameter:	2-8 μm depending on wavelength
Core refractive index difference:	0.01 nominal

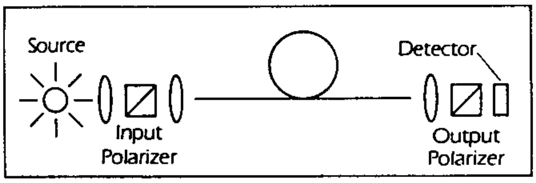
* Typical operating wavelength shown. As with any singlemode fiber, a broad operating window of about 200nm is available provided care is taken to avoid dual mode effects near the cut-off wavelength and bend losses at long wavelengths.

** POLARIZATION CROSS-COUPLING MEASUREMENT.

The measurement is peformed after manufacture under the following conditions:-

i). the fiber is measured on a standard 32cm diameter drum taking only reasonable care to avoid conditions likely to result in small-scale bends, eg. uneven surfaces or winding several layers on top of one another. The results provide a realistic estimate of performance except under severe microbending conditions.

ii). the measurement system is as shown in the schematic diagram. The source is either a filtered white light source or a low coherence semiconductor device: narrow linewidth laser sources can lead to over optimistic results. Input and output polarizers are rotated to determine the fiber's principal axes and to measure the direct and cross-coupled optical power. The cross-coupling or extinction ratio is then given by Pmin/(Pmax + Pmin).



It is to be emphasised that while the cross-coupling measured as described above is an important indication of basic fiber quality, the performance may be affected by installation in situations producing uneven stresses on the fiber. In particular the construction of coils consisting of many layers should be undertaken with great care. York's short beatlength fiber is designed to provide the highest possible resistance to polarization cross-coupling in these circumstances. Please consult York for advice.

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Developmental Product

PRSM™ Polarization-Retaining Single-Mode Fiber

Issued: 1/91

Supersedes: 1/90

Introduction

Corning is currently offering polarization-retaining single-mode fiber that utilizes stress-induced birefringence to produce its polarization maintaining properties. This developmental fiber may be used for a variety of applications, including interferometric sensors and coherent detection communication systems. Available fibers include designs optimized for 850 nm, 1300 nm, and 1550 nm operation.

Corning also has the ability to design and produce custom fibers with a variety of geometries, operating wavelengths, and coatings to meet customer requirements for specific applications.

Contact Corning to discuss the fiber design best suited for your applications.

Product Characteristics:	PRSM™ 850	PRSM™ 1300	PRSM™ 1550
Structure	---------- Stress Induced Birefringent ----------		
Operating Wavelength (nm)	780-850	1270-1330	1530-1570
Attenuation Rate (dB/km)[1]	3.0 to 6.0	1.5 to 4.0	1.0 to 3.0
h-parameter (x 10^{-5} m^{-1})[1]	0.3 to 10	0.3 to 10	0.3 to 10
Beat Length @ λ_{op} (mm)	2	3	4
Mode-Field Diameter (µm)	5	7-8	6-7
Cladding Diameter (µm)	80	125	80
Core to Clad Offset (µm)	1.0	1.0	1.0
Coating Diameter (µm)	185	250	≤185
Proof Test Level (kpsi)	50	50	50
Operating Temperature[2] (°C)	−55 to +85	−55 to +85	−55 to +85
Standard Length (meters)	1100	1100	1100
Minimum Order (meters)	100	100	100

[1] Attenuation and h-parameter measurements made on standard Corning Incorporated shipping reel.

[2] Operating temperature range implies that the fiber will have the above characteristics when greater than 200 meters of fiber, wound in a loose coil configuration, is temperature cycled through the range 55°C to +85°C.

Ensign-Bickford Optics Company

6/92

POLARIZATION-MAINTAINING SINGLEMODE FIBER

General

- Optimized for use in coil assemblies such as needed for fiber optic gyros and interferometric sensors.
- UV-curable acrylate coating is easily removed with commercially available stripping tools.
- Composed of three regions: a GeO_2-doped elliptical core, a fluorine-doped elliptical cladding perpendicular to the core, and a circular silica support surrounding the core/cladding system.
- Functions as **polarizer** when wound on a mandrel.

Optical Specifications

	Fiber Numbers				
Polarization-Maintaining	**PMF 500**	**PMF 630**	**PMF 820**	**PMF 1060**	**PMF 2300**
Operating Wavelength (nm)	515	630	820	1060	1300
Cutoff Wavelength (nm)	380 ±60	580 ±30	750 ±50	970 ±60	1180 ±70
Attenuation (dB/km)	20-30	8-12	2-4	2-3	1-2
Cross Talk (dB)	NA	NA	NA	NA	- 30 in 5 m - 10 in 500 m
Beat Length (mm)	9	NA	NA	NA	NA

Physical Specifications

Cladding Diameter[1]	125 ±2 µm
Core/Cladding Eccentricity	1 µm max.
Cladding Non-Circularity	2 % max.
Coating Diameter	250 ±15 µm (135, 500 & 900 µm available)
Coating Concentricity	70 % min.
Standard Proof Test[2], Entire Length (Proof Test for at least 1 second)	50 kpsi (0.35 GN/m^2)
Coating Operating Temperature[3]	-40° to +80° C
Available Length	100 m to 20.5 km

[1] Fibers are available with 80 ±2 µm cladding diameter.
[2] Higher proof-tests can be provided.
[3] For high-temperature Polyimide coatings, please consult the factory for details.

150 Fisher Drive, P. O. Box 1260, Avon, Connecticut 06001 USA
Phone: 203-678-0371 Fax: 203-674-8818

C. List of active chemical substances

List of fluids from [A20]:

a) ethyl alcohol, ACS grade, 99.5% pure,
b) isopropyl alcohol, best commercial grade, 99.8,
c) trichorotrifluorethane, clear, 99.8 pure,
d) trichlorethylene, 99.9% pure,
e) acetone, electronic grade,
f) xylene, electronic grade,
g) azeotropic mixture of ethyl achohol (4% by weight) and trichlorotrifluoroethane,
h) propellant, hydrazine, Military specification MIL-P-26536,
i) propellant, nitrogen tetroxide, Military spesification MIL-26539,
j) propellant, dimethylhydrazine, (UDHH), ARIANE grade.

D. Contacts with manufacturers of fibre optic components

Letters have been sent to a number of manufacturers of fibre optic components. The letters included a brief description of the project and request for test programmes and test results with particular emphasis on the areas of ionizing radiation, operation in vacuum, broad temperature ranges, large temporal and spatial temperature gradients, and high vibrational and shock levels.

A list of manufacturers and addresses is enclosed. The manufacturers are also listed in Table D.1 which give a brief summary of the received responses. The main impression from these answers is that most of the work is concentrated on the environment met in ordinary terrestrial applications. However, since development of fibre optic technology for harsh environments such as aircrafts, ships, offshore and even spacecrafts requires further emphasis on ruggedness, some companies have performed tests which exceeds the ordinary requirements. The areas which have been paid most attention are extended temperature range and high levels of vibration and shock. None of the companies reported on radiation testing or testing for operation in vacuum.

The intention is to follow up these contacts with a clarification of our interest and a more detailed description of the environment. Some of the manufacturers with a very broad product ranges included test programmes and test results for a limited part of this range. These companies will be addressed once more to find out whether corresponding test data is available for the other components as well.

Manufacturer	Response	Components included in answer	Remarks
3M Speciality Optical Fibers 420 Frontage Road West Haven CT 06516, USA	Test reports	Connectors, FDDI Connectors, couplings and cable assemblies	Used FOTP specifications. Temperature range -40 to 80°C.
Fiberguide Industries 1 Bay st. Stirling NJ 07980, USA			
AT&T Network Systems 111 Madison Avenue Morristown NJ 07962, USA			
Corning France Division des Produits pour les Telecommunications 44 Avenue de Valvins 77211 Avon Cedex, FRANCE			
Corning Inc., Att: Grant Watkins Telecom Products Div. HP RO 03, Corning NY 14831, USA	Test report	Couplers	Used FOTP and IEC specifications High vibration level (20g), temperature range -40 to 85 °C
Societa Cavi Pirelli SpA Viale Sarca 202 Milan 20126, ITALY			
York Tech. Ltd.,Att:C.Emslie York House, Scool Lane Chandlers Ford, Hampshire S05 3DG United Kingdom			
Norland Products Incorp. P.O.Box 145 North Brunswick NJ 08902, USA			
OFTI, Dept BG 5 Fortune Drive Billerica MA 01821, USA			
DIAMOND SA CH 6616 Losone Via dei Patrizi 5, ITALY	Test program	Connectors	Cooperates with companies in space/avionic industry. Will test for adverse environments.
SEIKO Instruments USA Inc. Electronic Components Division 2990 West Lomita Blvd Torrance, California 90505,USA			
Amphenol Corp. 1925 A Ohio Street Lisle IL 60532, USA Amphenol Corp. Bendix Connector Operations 40-60 Delaware Ave Sidney NY 13838,USA	Test reports	Connectors WDM	Used FOTP and Bellcore specifications. Temperature range -40 to 80°C.
AMP Inc. P.O.Box 3608 Harrisburg PA 17105, USA			

Manufacturer	Response	Components included in answer	Remarks
Souriau, Fiber Optics Div. 3, ave du Marechal Devaux Paray Vieille Poste, 91550 FRANCE			
JDS Optics PObox 6706, Station J Ottawa Ont, CANADA	Letter		No data for harsh environments
Mitsubishi Gas Chemical, America Ltd., 9th floor 520 Madison Avenue New York NY 10022, USA			
SIFAM, Fibre Optics Div Woodland Rd Torquay Devon TQ 2 7 AY, UK	Letter		Have performed environmental test, results not yet available
Canstar 5 Walkup Drive Westborough MA 01581, USA			
GOULD Inc. Fib Optics Div, Att: John Hussar 6730 Baymeadow Drive,Suite D Glen Burnie MD 21060, USA	Test report	Couplers	High shock levels, (300-1000g), temperature range from -40 to 85°C
OZ Optics Ltd Unit # 2-244 Westbrook Road West Carleton Industry Park Carp, Ontario KOA 1 LO, CANADA	Data-sheets		
Fibersense and Signals Inc. 2144 Danforth Ave Toronto, Ontario M4C 1 J9 CANADA			
NSG, America Inc. 28 Worlds Fair Drive Sommerset, NJ 08870, USA			
Ensign-Bickford Optics Company 150 Fishe Drive, P.O.box 1260 Avon CT 06001, USA			
BT&D Technologies Whitehouse Road Ipswich, Suffolk IP1 5PB , UK	Letter		Need further specification of requirements
NEC Electronics Inc. 401 Ellis St. Mountain View CA 94043, USA			
Siemens AG Infoservice EC/7084 Postfach 2348, 08510 Furth 2 DEUTSCHLAND			

Table D.1

E. Definitions

Acceptance: Determination that equipment or material is acceptable to the user regarding built standard and demonstration of its capability or performing satisfactorily to its requirements. The acceptance tests, therefore, intend to demonstrate flight worthiness of the item under simulated conditions expected from ground handling, launch and orbital operations. The purpose of the test is to locate latent material and workmanship defects in a proven design.

Attenuation: The quantitative expression of power decrease which may be expressed by the ratio of the values at two points of a quantity related to power in a well defined manner. Attenuation is generally expressed in logarithmic units, such as decibels.

Backscattering: The scattering of a light beam into directions generally reverse to the original one.

Bandwidth (of an optical fibre): That value numerical equal to the lowest modulation frequency at which the magnitude of the baseband transfer function of an optical fibre decreases to a specified fraction, generally to one half, of the zero frequency value.

Beat length: The repetition length of the polarization pattern in a bifringent fibre.

Birefringent fibre: An optical fibre which exhibits linear or circular bifringence.

Bounce time: The elapsed time for the insertion loss between two specified ports of a switch to reach and remain within 0.5 dB of its steady state value from when it initially reaches within 0.5 dB of the steady state value.

Cold-start: Is the minimum temperature specified for which the equipment shall be designed to be activated, when in a non-operating state, on a frequent basis. The equipment shall ensure that upon such activation, with the temperature moving into the operating range, the equipment performance quickly reaches specification requirements. During warm-up period the equipment is not required to give its nominal performance.

Critical hardware: Critical hardware is an equipment performing a safety or reliability critical function (see further ESA PSS-01-40).

Cross talk (optical): An undesired conversion of information between different independent optical signals.

Cut off wavelength (of a mode): That free space wavelength above which a given bound mode cannot exist in a waveguide.

Cut off wavelength (of an optical fibre): In a single-mode fibre, it is that wavelength greater than which the second order LP_{11} mode ceases to propagate.

Note: The measured value in general depends upon the measurement conditions and in particular the sample length and radius of the single loop of fibre under test.

Dispersion: The dependence of a propagation parameter on wavelength.

Equipment temperature: Is the temperature of its case (supposed nearly isothermal) measured close to its mounting surface.

Failure: Occur when equipment or system does not meet its specification requirements for any reason, including environmental testing.

Fibre optic attenuator: A fibre optic attenuator is a device intended to decrease the optical power in an optical waveguide transmission line.

Fibre optic branching device (coupler): A passive fibre optic branching device is a component possessing three or more optical ports and which acts to share light among its ports in a predetermined fashion.

Fibre optic connector:	A fibre optic connector is a component normally attached to an optical cable or piece of apparatus, for the purpose of providing frequent optical interconnection/disconnection of optical fibres or cables.
Fibre optic isolator:	A fibre optic isolator is a two port non-reciprocal optical device intended to suppress backward reflections, while having minimum insertion loss in the forward direction. The device is based on the Faraday effect.
Fibre optic splice:	A fibre optic splice is a permanent or separable (meant to be permanent, but it can be separated) joint between two optical fibres that generally provides protection from damage which might result from normal handling.
Fibre optic switch:	A fibre optic switch is a device that upon demand couples optical radiation from one port to one or more other ports.
Fibre optic wavelength multiplexer/ demultiplexer:	A wavelength division multiplexer is a branching device with two or more input ports and one output where the light in each input port is restricted to a preselected wavelength range. The output port is a combination of the light from these preselected wavelength ranges.
Insertion loss:	The increase in the total optical attenuation caused by the insertion of an optical component into an transmission path.
Launch phase:	Time period commencing at launch vehicle lift-off and ending with the injection into the transfer orbit.
Macrobending:	In an optical fibre, all macroscopic deviations of the fibre axis from a straight line.
Microbending:	Randomly distributed curvatures of an optical fibre involving local axial displacement of the order of a few micrometers and changing over distances of the orders of a few millimetres.
Modal noise:	Noise generated in an optical fibre system by the combination of the effect of differential modal attenuation and of fluctuations in the distribution of optical energy among the bound modes or in the relative phases of the bound modes.
Numerical aperture:	The term numerical aperture is often abbreviated NA. It is defined as the sine of the vertex half-angle of the largest cone of meridional rays that can enter or leave the core of an optical fibre, multiplied by the refractive index of the medium in which the vertex of the cone is located.
Operating temperature:	The operating temperature limits specify the temperature extremes at and between which the equipment shall be designed to operate, with performance and reliability meeting specification requirements (derating requirements apply).
Optical fibre:	An optical fibre is a filament shaped optical waveguide made of dielectric materials.
Optical fibre cable:	An optical fibre cable is a cable structure containing one or more optical fibres or optical fibre bundles, fabricated to meet optical, mechanical and environmental specifications.
Orbit phase:	Time period commencing after injection into the transfer orbit and continuing throughout the life of the satellite.
Polarization:	The orientation of the electric field vector of the electromagnetic radiation.
Polarization beat length:	See 'Beat length'.
Pre-launch phase:	Time period commencing after the satellite is delivered to the launch base and ending at the time of lift-off.

Qualification:	This is the demonstration, by analysis or test or combination of both, that an item is built to a defined standard, can meet its performance requirements for its specified lifetime under simulated conditions more severe than those expected from ground handling, launch and orbital operations. The purpose of qualification test is to uncover deficiencies in design and method of manufacture. It is not intended to exceed design safety margin or to introduce unrealistic modes of failure.
Return loss:	The ratio of the total reflected power to the incident power, from an optical fibre link or system.
Screening:	The process of performing 100 percent inspection on component lots and removing defective units.
Severity class:	A range of value of each quality, characterising the environmental parameter.
Splice holder:	A splice holder (splice organiser and splice closure) is a device in which a number of protected fibre splices are stored and which may or may not be a part of the splice organiser.
Stabilised temperature:	When the specified temperature for equipment and sub-system tests has been achieved and has not exceeded ±1°C during the previous one hour.
Ultimate load:	Is the maximum load for which the flight unit and sub-system will be designed with margin.

F. Abbreviations, symbols and units

F.1 Abbreviations

BW	:	Bandwidth or bandwidth per unit length
CW	:	Continuous wave
DFB	:	Distributed feedback
EIA	:	Electronic Industry Association
FO	:	Fibre optic
FOTP	:	Fibre optic test procedures
IEC	:	International Electrotechnical Commission
HCS	:	Hard clad silica
LA(T)	:	Lot Acceptance (Test)
LED	:	Light-emitting diode
NA	:	Not applicative (-general); Numerical aperture (-optical)
OTDR	:	Optical time domain reflectometry
PM	:	Polarization maintaining
PCS	:	Plastic clad silica
PCVD	:	Plasma chemical vapor deposition
SOP	:	State of polarization
TBD	:	To be decided
TIA	:	Telecommunication Industry Association
TLD	:	Thermoluminescence dosimetry
UV	:	Ultra-violet
WDM	:	Wavelength devision multiplexing

F.2 Symbols

D	:	Dispersion (-optical); Dose (-radioactivity)
IL	:	Light immunity
L	:	Length
n	:	Neutron (-radioactivity); Stress susceptibility constant (-mechanical)
n_i	:	Refractive index in medium *i*
P	:	Power
T	:	Temperature (-heat); Transmittance (-optical)
t	:	Time
α	:	Attenuation, loss
β	:	Propagation constant
λ	:	Wavelength
σ	:	Mechanical stress

F.3 Units

atm	:	Atmosphere (=101325 N/m^2)
bar	:	Unit for pressure, (=100 kPa)
dB	:	Decibel (=10 $\log_{10}(P_1/P_2)$)
°C	:	Centigrade temperature (Celcius)
g	:	Unit for acceleration due to gravity, (=9.81 m/s^2)
Gy	:	Unit for dose (=1 J/kg); (1 Gy=100 rad)
h	:	Hour
Hz	:	Hertz, (Frequency)
m	:	Metre
min	:	Minute
N	:	Newton
Pa	:	Pascal (=1 N/m^2)
rad(Si)	:	Unit for absorbed dose of ionizing radiation of a particular substance, Si = silicon
s	:	Second
Torr	:	Unit for pressure used in the field of high vacuum, (=133.322 N/m^2)
yr	:	Year
Å	:	Ångstrom (Length, wavelength, =10^{-10} m)