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Technical Specifications (In-Cash Procurement)

**Technical Specification for Final Design of the Divertor
Remote Handling Connector**

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1 Purpose

This document is the Technical Specification for the Contract “Final Design of the Divertor Operational Instrumentation Remote Handling Connectors” (DOI RH Connectors). This Technical Specification contains the technical requirements for the final design, manufacturing and testing the mock-ups and prototype of DOI RH Connector for use inside the Vacuum Vessel of the ITER machine. The DOI RH Connector is required for assembly and disassembly of DOI cables during Divertor Cassettes scheduled maintenance by RH tools.

The Contractor is responsible for development of the final design of the DOI RH Connector, its prototype and mock-ups manufacturing and testing.

The ITER Organization (IO) will provide to the Contractor the preliminary design of the DOI RH Connector as well as related reference and applicable documents, e.g. CAD models and drawings at preliminary design maturity.

The Contractor shall demonstrate its capability to reproduce the design of the DOI RH Connector delivered and tested during the previous R&D phase and for which IO has confirmed positive results [RD1], [RD2].

Alternatively, in the case where the Contractor proposes a design significantly changed compared to that already qualified, the design shall be validated on sample products by the Supplier.

2 Scope of work

The scope of the contract is broken down into three tasks, as follow:

- **Task I:** Development of the final design of the DOI RH Connectors starting from a preliminary design issued by ITER.
- **Task II:** Mock-ups (for optical and electrical parts) and prototype manufacturing, testing and design qualification.
- **Task III:** Technical support during Final Design Review.

3 Definitions

For a complete list of ITER abbreviations see: ITER_D_2MU6W5 - ITER Abbreviations

APC	Angled Physical Contact
CA	Cassette Assembly
CAD	Computer-Aided Design
COTS	Commercial Off-The-Shelf
DC	Direct Current
DOI	Divertor Operational Instrumentation
DUT	Device Under Test
EC	Electrical Connector

IVH	ITER Vacuum Handbook
ITER	International Thermonuclear Experimental Reactor
FBG	Fiber Bragg Grating
MI	Mineral Insulated
NA	Numerical Aperture
OC	Optical Connector
PIC	Protection Important Component
RH	Remote Handling
RT	Room Temperature
SIC	Safety Importance Classification
VDE	Vertical Displacement Event
VV	Vacuum Vessel
VQC	Vacuum Quality Class

4 Background

ITER is a large-scale magnetic fusion device that aims to demonstrate the technological and scientific feasibility of fusion energy. ITER is identified in France as a Nuclear Facility according to the INB order 7th February 2012 (“Installation Nucléaire de Base”).

During its operational lifetime, ITER will test key technologies necessary for the next step: the demonstration fusion power plant that will prove that it is possible to exploit fusion energy for commercial use. ITER is based on the 'tokamak' concept of magnetic confinement, in which the plasma is contained in a doughnut-shaped Vacuum Vessel (VV). The fuel — a mixture of deuterium and tritium, two isotopes of hydrogen — is heated to temperatures in excess of 150 million °C, forming a hot plasma. Strong magnetic fields are used to keep the plasma away from the walls; these are produced by superconducting coils surrounding the vessel, and by an electrical current driven through the plasma.

The VV is a hermetically-sealed steel container that houses the fusion reaction and acts as a first safety confinement barrier. It operates at 100°C and can be baked up to 240°C to guarantee clean ultra-high vacuum needed to operate plasmas.

Internal components such as the Blanket, Divertor and First Plasma Protection Components are located inside the VV. They are equipped with Operational Instrumentation for measurement of thermal, mechanical and electromagnetic parameters during operation. These measurements are performed by two types of sensors:

- Optical – strain sensors, linear displacement sensors, temperature sensors;
- Electrical – Rogowski coils, magnetic flux loops, thermocouples.

4.1 Divertor Operational Instrumentation

Three Divertor Cassettes #15, #33, #51 installed in the three VV Sectors #3, #6, #9 are equipped with set of instrumentation for measurement of mechanical, electromagnetic and

temperature parameters of the Divertor structural components. DOI allocation is shown on Figure 1.

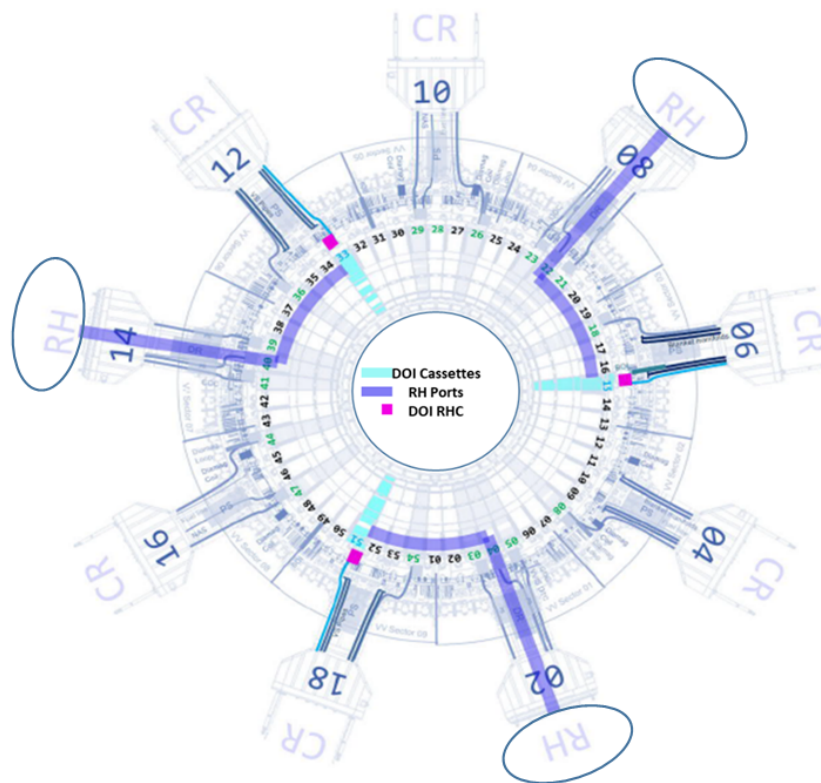


Figure 1 – DOI location on Divertor Cassettes on the tokamak layout (RH – Remote Handling Ports; CR – Cryopump Ports)

The main functions of the DOI system are:

- Monitoring of the electromagnetic, mechanical and temperature fields of structural components.
- Measuring of experimental data required for the validation of the numerical models during ITER operation.
- Estimation of EM loads acting on the Divertor structural components during plasma disruptions/VDEs via electromagnetic and mechanical experimental data.

DOI comprise different types of components which ensure full implementation of the system functions within ITER project:

1. Optical sensors: strain, displacement and temperature sensors (sensors based on Fiber Bragg Gratings (FBG) technology);
2. Electromagnetic sensors – thermocouples, Rogowski coils and magnetic flux loops;
3. Optical and electrical cables;
4. Attachment components – junction boxes, bosses, clips;
5. Optical Fiber Feedthroughs;

6. Control cubicles and data processing equipment.

The signal trace for in-vessel part of DOI is shown on Figure 2. The cables from optical and electrical sensors are routed on the Cassette Body and attached to the DOI RH Connector. From the DOI RH Connector the cables are routed in the diagnostic's in-vessel cable looms up to the port connectors located in the Lower Ports of the Vacuum Vessel. DOI cables from port connectors are passed through electrical and optical feedthroughs to cross the vacuum boundary and to connect with ex-vessel part of the DOI.

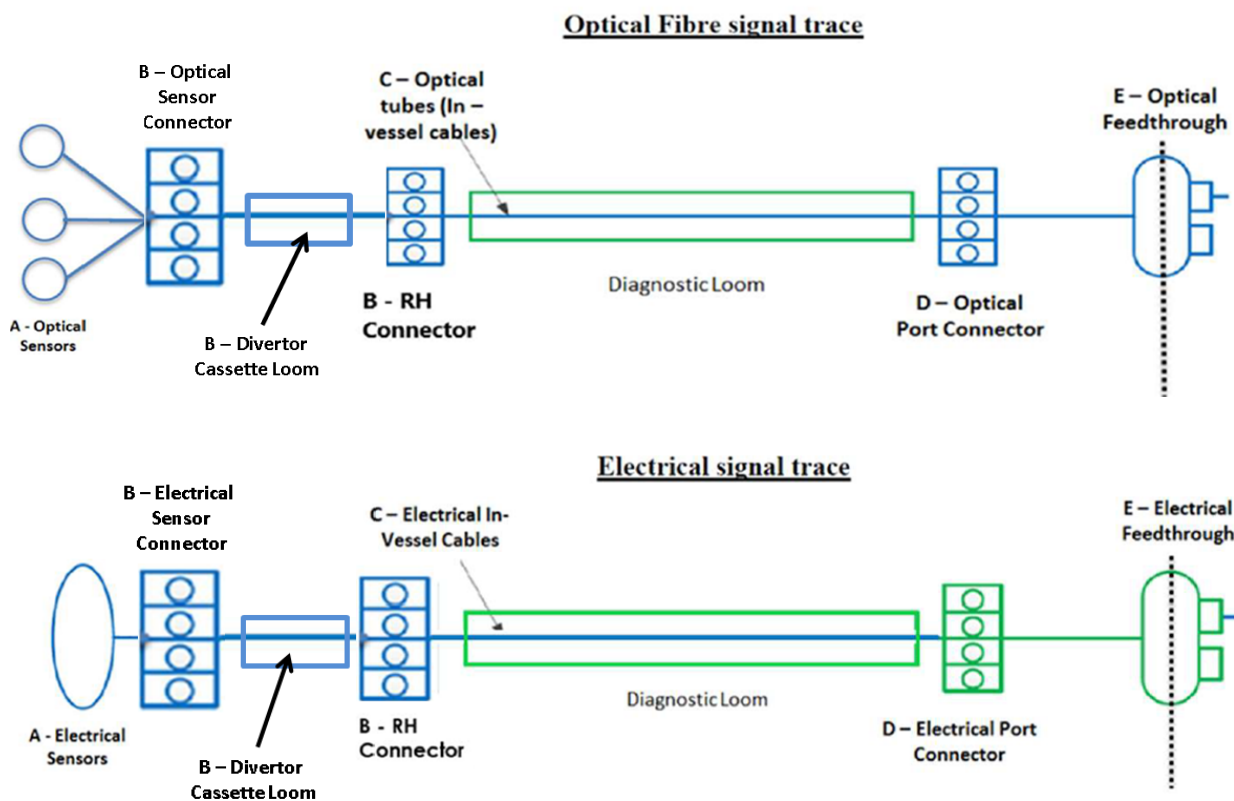


Figure 2 – DOI signal trace (in-vessel part)

4.2 DOI Remote Handling Connector

4.2.1 Purpose

Divertor Cassettes will be handled by RH during installation and removal sequence. The DOI RH Connector will allow connection and disconnection of DOI cables during Divertor Cassettes remote maintenance.

Divertor Cassettes will be replaced up to 3 times in the life time of ITER.

4.2.2 Classification

Classification of DOI RH Connector is identified in the Table 1.

Table 1: DOI Remote Handling Connector classification

Classification	Class
Safety Class	Non-SIC
Quality Class	QC 3
Vacuum Quality Class	VQC-1B
Seismic Class	Non-classified
Tritium Class	Non-classified
ESPN	Non-classified
Remote Handling Classification	RH class 1 ¹

4.2.3 Operating Conditions

The parameters of the scenarios during normal operation are shown in Table 2.

Table 2: Operating conditions during normal operation

Configuration	Scenario	Temperature	Pressure	Radiation dose rate-Gy/h
Normal operations	Maintenance	20°C ± 5°C	1 atm	-
	Baking*	350°C	< 10 ⁻⁵ Pa	-
	Start-up (D-D plasma)	100°C	< 10 ⁻⁵ Pa	-
	Pulse (D-T plasma)	280°C	< 10 ⁻⁵ Pa	500

* Two baking scenarios exist currently:

- (1) during first phase baking out at 240 °C within 48 hours (~ 300 cycles);
- (2) during second phase baking out at 350 °C within 48 hours - (~ 200 cycles).

5 Preliminary Design Description

The RH Connector assembly consist of three main structural parts (see Figure 3 for identification of the parts):

- 1) The Vacuum Vessel Socket (VS). This is the part of the connector permanently fixed on the Vacuum Vessel inner wall (see section 5.1).
- 2) The Cassette Socket (CS). This is the part of the connector permanently fixed on the Divertor Cassette Body (see section 5.2).
- 3) The Extending Link (EL). This is the extending mechanism that allows engagement and disengagement of the Connector's pins under operation by RH tooling (see section 5.3).

¹ The Remote Handling classification is assigned to the maintenance tasks of the RH Connector

As well, the electrical and optical pins for detachable contact joints of the cables are positioned on each socket of the RH Connector.

This preliminary design [RD2] was validated by prototype manufacturing and testing [RD1], it confirmed the feasibility of such choice. It shall be used as a basis for development of the final design in combination with the requirements defined in this technical specification.

The preliminary design will be provided to the Contractor in a format of the 3D CAD models. The Configuration Management Model (CMM) of the preliminary design will be provided by IO together with the environment of the ITER tokamak with relevant for the design interfaces.

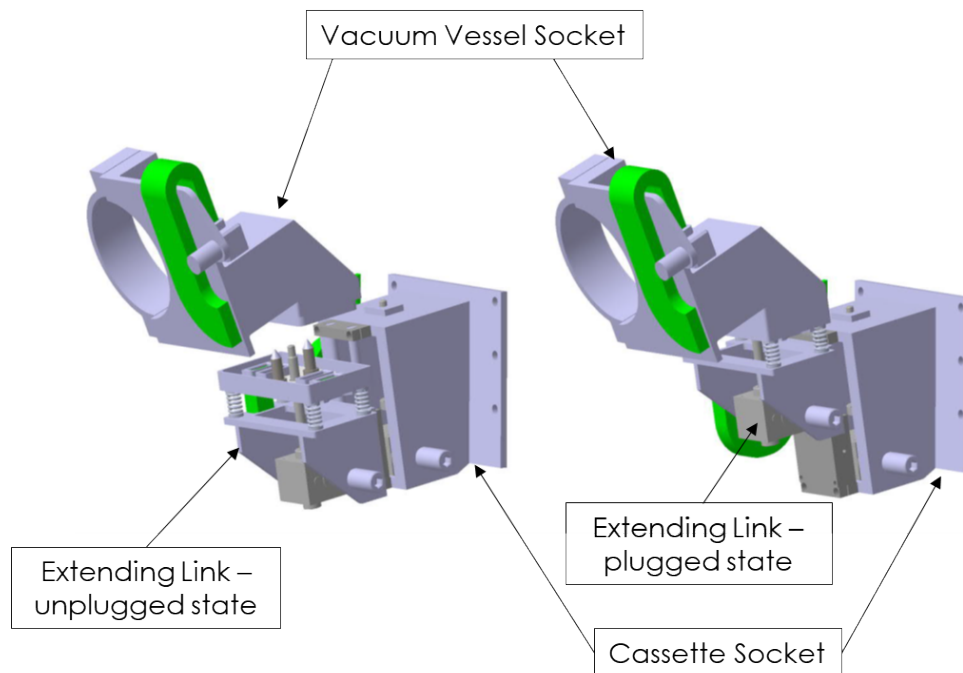


Figure 3 Main structural components of the RH Connector assembly

5.1 Vacuum Vessel Socket design

The Vessel socket is located under the triangular support of the Vacuum Vessel. The Vessel Socket is installed on the Vacuum Vessel wall with one boss welded to the Vacuum Vessel and a fixing collar, a bolted clamp, around the Blanket cooling pipe.

Structure of the Vacuum Vessel Socket is depicted on Figure 4.

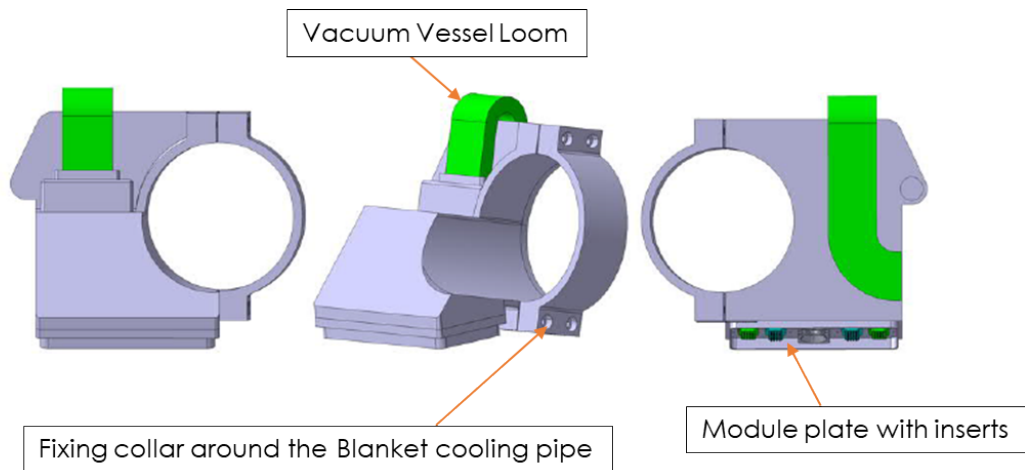


Figure 4 Vacuum Vessel socket of the RH Connector

The Vessel Socket doesn't include any motion mechanism. The Vessel Socket is considered to stay permanently in the tokamak for the entire ITER lifetime.

5.2 Cassette Socket design

Cassette Socket is a frame which is attached to the Divertor Cassette Body and houses the interface for fixation of the Extending Link. The Cassette Socket doesn't include any motion mechanism.

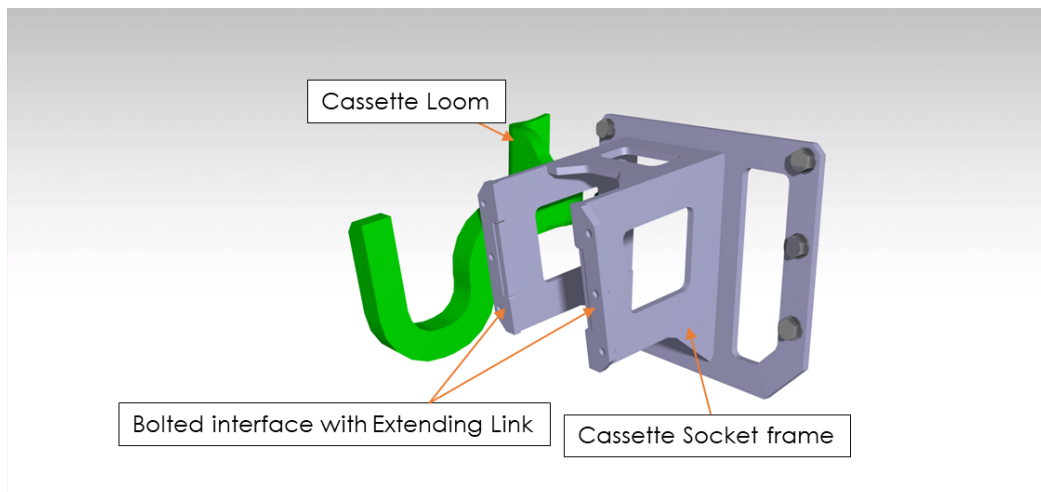


Figure 5 Cassette Socket of the RH Connector

5.3 Extending Link design

The Extending Link is physically fixed on the Cassette Socket. It allows engagement and disengagement of the inserts by linear motion actuated by the RH tooling with the Vacuum Vessel Socket.

The Extending Link contains the RH features for the bolting tools, guides for linear motion and Cassette Socket module plate with inserts for the optical fiber and electrical MI cables.

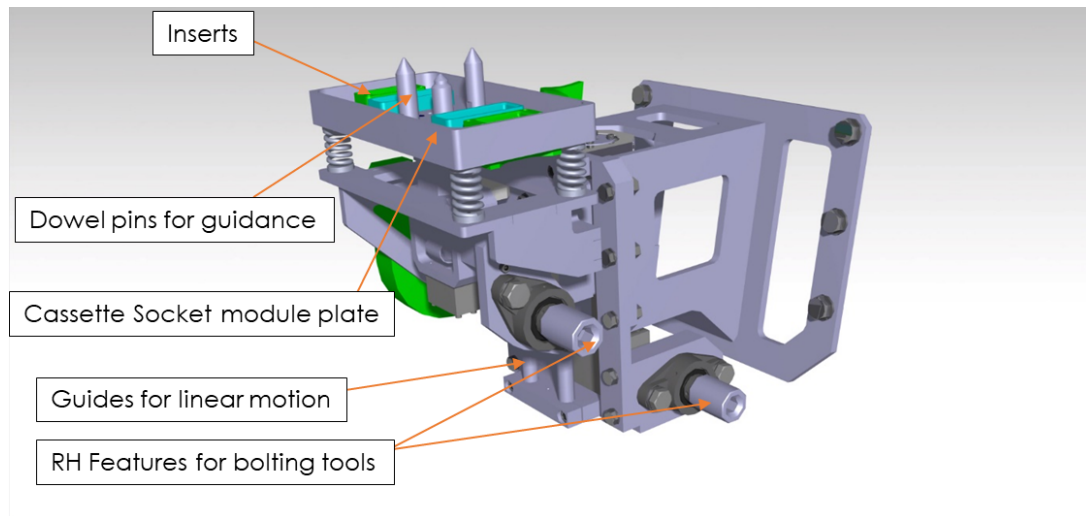


Figure 6 Extending Link of the RH Connector

6 Applicable Standards

The standards applicable for execution of the work in scope of this Technical Specification are defined in Table 3.

Table 3: Applicable standards

Standard	Description
EN 50395:2005+A1:2011	Electrical test methods for low voltage energy cables
EN 50289-1-8:2017	Communication cables - Specifications for test methods - Part 1-8: Electrical test methods - Attenuation
IEC 60793-1-40:2019	Optical fibres - Part 1-40: Measurement methods and test procedures - Attenuation
IEC 60793-1-31:2019	Optical fibers – Measurement methods and test procedures - Tensile strength

Equivalent national or international standards can be proposed by the Contractor provided its implementation is preceded by an acceptance from IO processed through a deviation request (DR). The justification section of the DR shall include the differences between the quoted standard of the present specification and the standard proposed.

7 Technical Requirements

7.1 Task I: Design Development

7.1.1 Design Requirements of parts of DOI RH Connector

7.1.1.1 General Design Requirements

[REQ-1]

The final design of DOI RH Connector shall correspond to available space envelope. The related Configuration Management Model (CMM) will be provided by IO together with the environment of the ITER tokamak for verification of integration with the surrounding system.

[REQ-2]

Design of the RH Connector shall consider sufficient clearances for Divertor RH System operations. Toroidal trajectory of the Divertor Cassette (including cooling pipes) during the maintenance period shall be taken into account to avoid collisions with Vessel part of RH Connector.

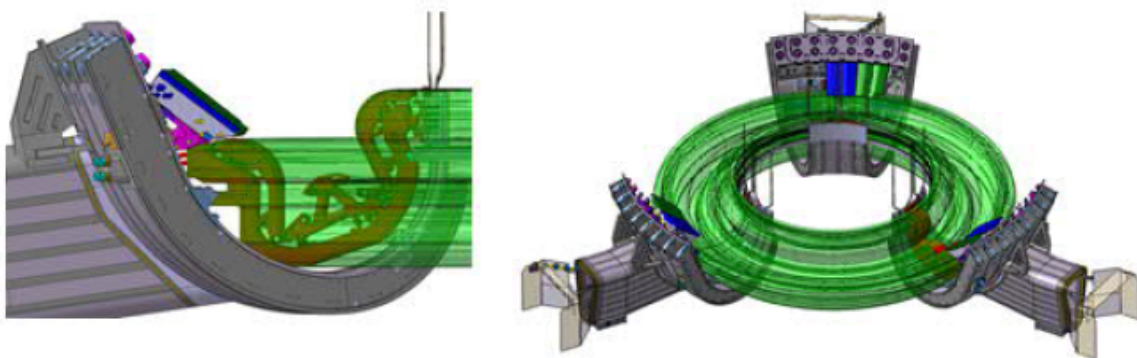


Figure 7 Sweep model of the toroidal trajectory of the Divertor Cassette during maintenance

[REQ-3]

The RH Connector shall withstand a minimum of 10 connections and disconnection cycles.

[REQ-4]

The DOI RH Connector components shall be passively cooled through conduction to the VV or Divertor Cassette.

[REQ-5]

The contractor shall preferably use COTS (Commercial Off-The-Shelf) equipment and components catalogues identified by IO where feasible.

[REQ-6]

One DOI RH Connector shall accommodate as minimum of 34 electrical \varnothing 4mm diameter MI cables accommodating total of 68 cable cores, and 5 optical 4mm diameter cables accommodating total of 101 optical fibres.

[REQ-7]

The number of pin contacts shall consider the number and type of the DOI optical and electrical signals. If the space envelope allows, as minimum 5% of spare pins of each type shall be included in the design.

[REQ-8]

The pin contact inserts shall be mountable to the connector module plates.

[REQ-9]

The pin contacts shall engage and disengage by simple pushing and pulling.

[REQ-10]

DOI RH CAD design shall take into account that 5 mm radial Divertor Cassette compression is not included in the ITER CATIA models.

[REQ-11]

The connecting elements of the cassette and vessel socket shall have minimum gap of 25 mm to the surrounding vacuum vessel environment.

[REQ-12]

Vessel socket shall utilize one 30 mm diameter boss to attach to the vacuum vessel.

[REQ-13]

The Cassette Socket shall utilize Hexagonal Bolts DIN 933 M18x30 and Washers DIN 125 M18 for mounting on the Divertor Cassette. The connection shall be done through the M18 threaded holes on the back plate of the Cassette.

[REQ-14]

The connection/disconnection forces for all the mock-ups and the DOI RH Connector prototype shall be measured.

7.1.1.2 Vacuum Design Requirements

[REQ-15]

The Contractor shall design the DOI RH Connector according to the requirements applicable for the VQC-1B components. The main vacuum quality requirements are incorporated in this Technical Specification.

The exhaustive list of vacuum quality requirements is established in the ITER Vacuum Handbook and its Appendices [AD1]-[AD5].

[REQ-16]

Crevices, blind holes, cracks, trapped volumes, etc., shall be avoided as these will act as dirt and liquid traps and will prevent pumping performance.

[REQ-17]

The bolts for use in vacuum shall be locked after loading to prevent them becoming free and causing damage to other parts of the vacuum system.

[REQ-18]

The design of bolts used in the RH Connector shall be compatible with high vacuum environment (e.g. to have additional holes to avoid trapped volumes and to ensure pumping).

[REQ-19]

Bolts shall be treated to prevent seizing. The bolts shall be coated with copper (purity of 99.9 %) by the process of electrodeposition. An intermediate nickel bond coat may be deposited prior the copper coating if needed.

The Nickel plating shall have 1 μm average thickness (+/- 10%).

The Copper coatings shall have 5 μm average thickness (+/- 10%).

[REQ-20]

The outgassing rate of materials used in the RH Connector shall not exceed maximum steady state outgassing rate at outgassing temperature 100° C:

- $1 \times 10^{-7} \text{ Pa}\cdot\text{m}^3\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for Hydrogen isotopes
- $1 \times 10^{-9} \text{ Pa}\cdot\text{m}^3\cdot\text{s}^{-1}\cdot\text{m}^{-2}$ for impurities

7.1.1.3 Optical Connector Requirements

[REQ-21]

Copper-coated radiation-resistant optical fiber with NA=0.17 and cutoff wavelength of $1.45 \pm 0.05 \mu\text{m}$ shall be used in the optical part of the DOI RH Connector.

[REQ-22]

The design of the pins for connection of the fibers in the DOI RH Connector shall be similar to that used in standard fiber-optic connector (OC) of the angled physical contact (APC) type (Figure 8):

- the connected optical fibers shall be glued by high-temperature compound (for example, high-temperature epoxy glue, polyimide, etc – to be submitted for IO acceptance) in the fiber-optic zirconia ceramic ferrules;
- the ferrule end faces shall be angled polished with the proper polishing quality;
- alignment of the ferrules during the RH Connector actuation shall be done using a fiber-optic zirconia ceramic split alignment sleeve (Figure 9).
- for precise alignment of the connector ceramic elements (two ferrules and a split alignment sleeve) along the axis of fiber connection, it is necessary to constructively provide angle flexibility for all three elements, as well as transverse displacement of the moving ferrule. In addition, these degrees of freedom will allow good optical connection to be maintained in the event of thermally induced displacements of the DOI RH connector parts.
- a mechanical key shall be provided to fix the azimuthal position of the ferrules, which is necessary when using APC connectors.
- APC connector standard with ferrules of 2.5 mm in diameter is preferable (Figure 9, Figure 11).

The main geometrical characteristics of standard optical fiber connection elements are shown in Figure 10 - Figure 12.

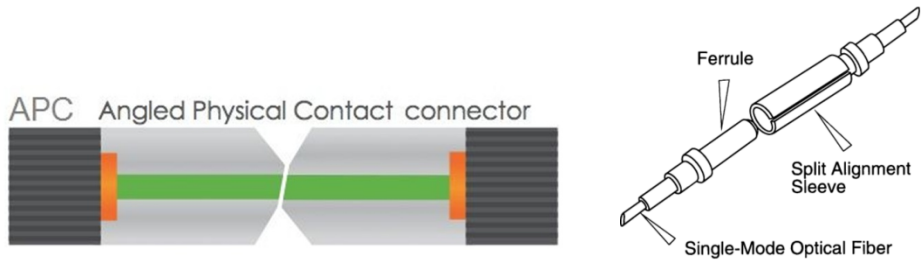


Figure 8. Angled physical contact connector



Figure 9. Zirconia ceramic split alignment sleeves (left) and APC type ferrules (right)

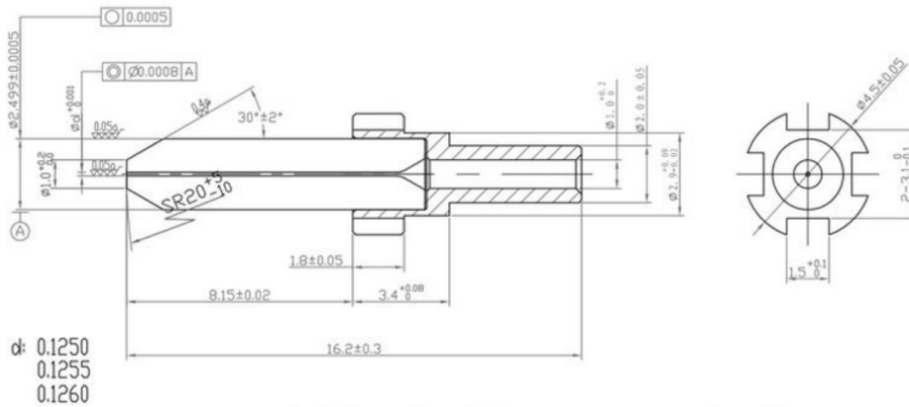


Figure 10. Drawing of a zirconia ceramic ferrule typically used for APC connectors

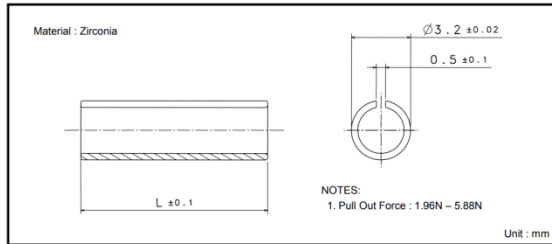
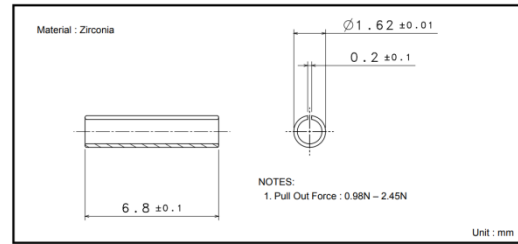
1. $\phi 2.5$ SPLIT SLEEVE4. $\phi 1.25$ SPLIT SLEEVE

Figure 11. Drawings of zirconia ceramic split alignment sleeves: 2.5 mm (left) and 1.25 mm (right)

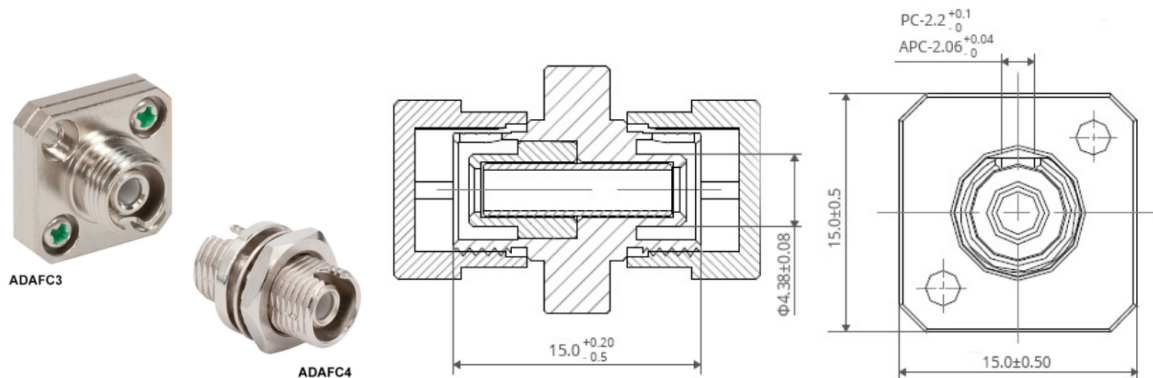


Figure 12. Photo and drawing of a standard FC/PC or FC/APC adapters with a split alignment sleeve inside.

[REQ-23]

The return loss from the end surfaces of the optical fibers in the **connected** state shall not exceed -60 dB over the entire operating temperature range (RT - 350°C)

[REQ-24]

The return loss from the end surfaces of the optical fibers in the **disconnected** state shall not exceed -50 dB over the entire operating temperature range (RT - 350°C)

[REQ-25]

The total insertion loss (bending loss, APC connection loss, etc.) in each optical channel of the DOI RH Connector shall not exceed 0.5 dB over the entire operating temperature range (RT - 350°C)

[REQ-26]

Mechanical protection of the fibers at the transition area from the ferrule to the optical fiber cable shall be implemented.

The proposed solution is to use stainless-steel capillary tubes with an outer diameter of 0.4-0.5 mm. One end of the tube is inserted in the metal ferrule housing and glued/welded/brazed therein, and the other end is inserted into the optical fiber $\phi 4$ mm cable tube. Fixation of the capillary tubes with fibers to the $\phi 4$ mm cable tube is carried out with a mechanical tip of a collet type.

7.1.1.4 Electrical Design Requirements*[REQ-27]*

The electrically conducting parts of the DOI RH Connector shall be electrically bonded to the Divertor Cassette or the Vacuum Vessel wall.

[REQ-28]

The RH Connector shall be designed to ensure that voltage breakdown does not occur.

[REQ-29]

The RH Connector shall be designed to prevent large induced currents and arcs during normal and off-normal events.

[REQ-30]

The electrical cabling and electrical pins of the RH Connector shall be designed in such a way to minimize the crosstalk and attenuation of signals carried via electrical cables.

7.1.1.5 Materials Selection Requirements*[REQ-31]*

Materials for the RH Connector design shall comply with ITER Materials Properties Handbook.

[REQ-32]

The following grade of Stainless Steel shall be considered for the RH Connector design:

AISI	EN 10028-7
316, ASTM240	X5CrNiMo18-10 1.4401, EN 10028-7
316L, ASTM240	X2CrNiMo17-12-02 1.4404, EN 10028-7
304, ASTM240	X5CrNi18-10 1.4301, EN 10028-7
304L, ASTM240	X2CrNi18-09 1.4307, EN 10028-7

[REQ-33]

The brazing/soldering alloys used in the DOI RH Connector shall be selected in compliance with provisions of IVH Appendix 3 Materials [AD2] for VQC-1B components.

[REQ-34]

If materials other than those stated above are proposed, details of materials to be considered for acceptance shall be submitted to the IO using the Material Acceptance Request Form (made available on demand). The Contractor shall agree in advance with the IO a plan detailing the type and method of testing to be used to qualify the material for use. The Materials Acceptance Request Form along with the test data, report and supporting documentation, including any Contractor's data (Certificates of Conformity, etc.), shall be submitted to the IO.

7.1.1.6 Remote Handling Requirements

[REQ-35]

The design of the RH Connector shall be compatible with the ITER Remote Handling Code of Practice [AD12].

[REQ-36]

The contractor shall assess the Remote Handling compatibility with RH Compatibility Procedure [AD13].

[REQ-37]

DOI RH Connector design and handling operations shall be compatible with the RH installation and removal of Divertor Cassettes cinematics.

[REQ-38]

IO RH authorised techniques e.g. elimination of all non-captive parts, use of removable/replaceable threaded inserts to facilitate alignment shall be used.

[REQ-39]

Suitable clearances and materials to facilitate viewing and sensing by the RH equipment shall be provided.

[REQ-40]

Sensitive and delicate component items during RH operations shall be protected.

[REQ-41]

Highly reflective surfaces shall be avoided where possible.

[REQ-42]

The RH Connector shall provide the RH interface features that are compatible with standard ITER General Manipulation RH tools as specified in the [RD3].

7.1.1.7 Cables Requirements

[REQ-43]

DOI RH Connector shall consider the minimum cables bending radius of 40 mm.

[REQ-44]

DOI RH Connector shall accommodate types and number of cables identified in the Table 4.

The design of the cables used in the DOI system on the Divertor Cassettes looms and Divertor Lower Ports looms is presented in the Appendix A.

Table 4: Type and number of DOI cables

Cable type	ITER cable code	Diameter	Cable description	Number
Electrical MI cables	MI0226LV	Outer Ø 4.0 mm Inner Ø 3.0 mm	Alumina or magnesia insulated twisted pair, copper wires, stainless steel sheath coated by	16

			copper, with leak tight termination at both ends	
	MX0222LV	Outer Ø 4.0 mm Inner Ø 3.0 mm	Thermocouple type N extension cable, alumina or magnesia insulated, stainless steel sheath coated by copper, with leak tight terminations at both ends	18
Optical fiber cables	FS1734LV	Outer Ø 4.0 mm Inner Ø 3.0 mm	Stainless steel tube accommodating 17 optical fibers	1
	FS2134LV	Outer Ø 4.0 mm Inner Ø 3.0 mm	Stainless steel tube accommodating 21 optical fibers	4

[REQ-45]

The optical fibers in the DOI RH Connector shall comply with the requirements in Table 5.

Table 5: Optical fibers requirements

Parameter	Requirement
Type of optical fiber	Single mode
Wavelength	1500 - 1600 nm
Attenuation at 1550 nm, dB/km	≤ 7
Cladding diameter	$125 \pm 5 \mu\text{m}$
Coating diameter	$160 \pm 5 \mu\text{m}$
Coating composition	>99% copper
Bending radius	> 15 mm

[REQ-46]

Optical cables tubes shall be made from stainless steel 316L.

[REQ-47]

Electrical cables cores shall be made of the following materials:

- Oxygen Free Copper
- Oxygen Free Electronic Copper
- Nicrosil/Nisil for thermocouple extension cables

[REQ-48]

The cabling of the RH Connector shall comply with the vacuum requirements for VQC1-B as per [AD4].

7.1.1.8 CAD Requirements

[REQ-49]

The Contractor shall produce the 3D CAD detailed models of the RH Connector final design. The 3D CAD models shall be provided to IO in the format of CATIA V5 or STP files. The models shall be transferred officially through the Data Exchange Task (DET).

[REQ-50]

The detailed Component Drawings of the final design of the RH Connector, and as well as mock-ups and prototype, shall be produced and supplied before the Final Design Review (FDR).

[REQ-51]

The Contractor shall ensure that all CAD Data (Schematics, Models and Drawings) delivered to IO comply with the [AD6] and [AD7]. IO DO (Design Office) and Contractor shall use the CATIA version indicated in the latest version of the ITER CAD Manual released by IO DO, CATIA V5 (R28 SP2 currently).

7.1.2 Design requirements of the mock-ups

Several mock-ups shall be developed to validate the design of the key elements of the DOI RH connector (electrical, optical, and mechanical).

7.1.2.1 Mock-up A – APC connectors assembly

Mock-up A shall be comprised of five optical APC connectors (separate or assembled in N-channel connector, $N \geq 5$). Each fiber pigtail should be protected by a short (~10 cm) stainless steel tube with an outer diameter of 0.4-0.5 mm, attached to metal ferrule housing.

The main goals of creating and testing Mock-up A is to check the suitability of the used technologies of fixing the fiber in the ferrule, the protective tube in the ferrule housing, as well as to prove the quality of the connections in terms of ensuring the required optical characteristics (insertion and return loss).

The Mock-up A shall be tested in accordance with Section 7.2.2.

7.1.2.2 Mock-up B – Multi-channel optical pins plates

Mock-up B, being a prototype of the set of optical APC connectors mounted on the pins plate, shall be composed by all minimum 20 optical APC connectors (20 optical channels). Each fiber pigtail should be protected by a stainless steel tube with an outer diameter of 0.4-0.5 mm, attached to metal ferrule housing. The other end of the protective tube shall be inserted into the optical fiber cable tube (FS1734LV, FS2134LV, see Table 4) and fixed therein with a mechanical tip of a collet type, for example.

It should be noted that friction force at the surface of ferrule-sleeve contact can be as large as 10 N, therefore connecting/disconnecting force of approximately 200 N is required for each multi-channel optical pins plate (e.g. approx. 1 kN for optical part of DOI RH Connector).

The main goals of creating and testing Mock-up B is to prove the quality of the connections (insertion and return loss) in the multi-channel optical mock-up, as well as to check the reliability of fixing thin protective tubes inside the 4-mm optical cable tube.

The mock-up B shall be tested according to the Section 7.2.2.

7.1.2.3 Mock-up C – Multi-channel electrical pins plates

Mock-up C, being a prototype of the complete electrical pins plate, shall be composed by all multi-channel electrical cables connectors. Each cables shall be fixed in electrical connector. For Mock-up C the termination of electrical cables shall be similar to the cable termination presented on the drawings in the Appendix A, but it is possible to deviate from the requirement of vacuum tightness and to propose another design of termination for IO acceptance (or a dummy termination representing the space reservation).

The main goals of creating and testing Mock-up C is to prove the quality of the connections (electrical resistance) in the multi-channel electrical mock-up, as well as to check the reliability of fixing cables inside the electrical part of the RH Connector.

The Mock-up C shall be tested according to the Section 7.2.2.

7.2 Task II: Design qualification. Manufacturing and tests of mock-ups and prototype

7.2.1 Manufacturing of the mock-ups and prototype

[REQ-52]

Totally three mock-ups and one full scale prototype shall be manufactured and tested in order to qualify the final design of the RH Connector.

The mock-ups manufacturing include the following steps:

Table 6: Manufacturing of mock-ups and prototype

Mock-up #	Description
<p>Mock-up A : Manufacturing of Mock-up A (min 5 single channel APC connectors)</p>	<p>Manufacturing of high temperature optical APC connection includes:</p> <ul style="list-style-type: none"> - gluing the stripped part of the fiber into the ferrule; - end polishing at the required angle; - fixation of the protective tube in the metal ferrule housing; - fastening the ferrules in their support structures with the required degrees of freedom; - fastening the split alignment sleeve in its support structure with the required degrees of freedom.

<p>Mock-up B: Manufacturing of Mock-up B (multi-channel optical pins plates)</p>	<ol style="list-style-type: none"> 1. Manufacturing of the pins plates with minimum 20 pins. 2. Insertion of the capillary protective tubes containing the fibers into optical fiber cable tube and their mechanical fixation.
<p>Mock-up C: Manufacturing of Mock-up C (multi-channel electrical pins plates)</p>	<ol style="list-style-type: none"> 1. Selection of electrical cables attachment option 2. Installation of the electrical pins onto the plate 3. Connection of the electrical MI cables
<p>Full-scale prototype : Manufacturing of DOI RH Connector prototype</p>	<p>Manufacturing of fully functional prototype of DOI RH Connector with all optical and electrical elements and equipped with connection/disconnection mechanical nodes and interfacing parts for the RH actuation</p>

7.2.2 Mock-up tests

The objective of the tests is to demonstrate the feasibility of optical and electrical parts of DOI RH Connector possessing the required optical and electrical characteristics at the operation conditions.

7.2.2.1 T1: Insertion loss test

The total insertion loss value (α_I) of each connected optical channel of the investigated mock-up is measured in T1 test. This value is a ratio of optical power transmitted through the fiber with DUT (device under test) inserted (P_I) with respect to that with no DUT (P_0). The insertion loss is typically expressed in decibels:

$$\alpha_I = -10 \log_{10} \left(\frac{P_I}{P_0} \right) \quad (1)$$

The acceptance criterion: $\alpha_I < 0.5$ dB for all the channels.

7.2.2.2 T2: Return loss test

The return loss value (α_R) of each connected optical channel of the investigated mock-up is measured in T2 test. This value is a ratio of optical power reflected by the DUT (P_R) with respect to P_0 , measured in T1 test. Like insertion loss, return loss is expressed in decibels:

$$\alpha_R = -10 \log_{10} \left(\frac{P_R}{P_0} \right) \quad (2)$$

Return loss in both connected and disconnected states of the DUT shall be measured.

The acceptance criteria are as follows:

- 1) $\alpha_R > 60$ dB for all the channels in the connected state
- 2) $\alpha_R > 50$ dB for all the channels in the disconnected state

An optical scheme of the setup for multichannel measuring of the transmitted and reflected optical power (tests T1&T2) is shown in Figure 13. The initial power P_0 is measured as shown in the upper part (I) of the figure, whereas P_I and P_R value as shown in the lower part (II). Reference channel (P^{ref}) is used to correct possible instability of the light source power.

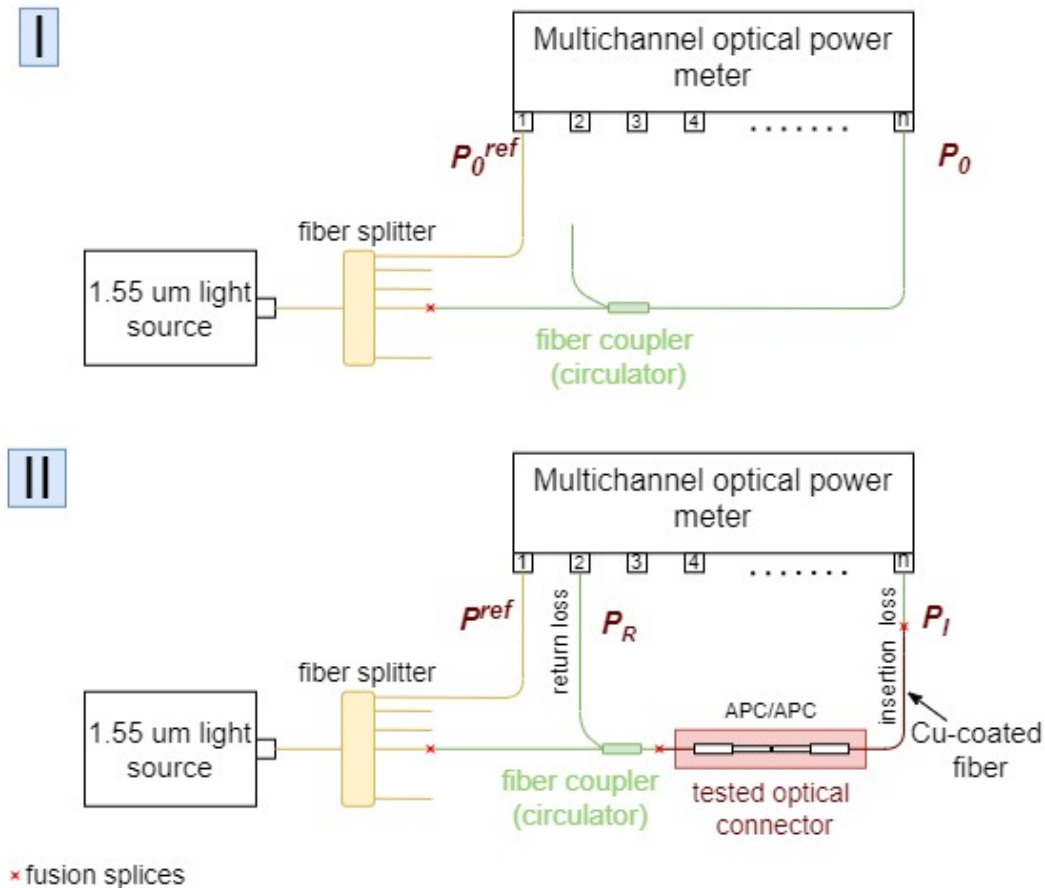


Figure 13. Optical scheme of the multichannel setup for measuring insertion and return loss in optical mock-ups A, B.

Thus, tests T1 and T2 require a comparison of transmitted and reflected power with and without the DUT inserted in the optical scheme. Correct measurements are possible with fusion splicing of the DUT in the optical scheme as shown in Figure 13(II). **Error! Reference source not found.**, since any mechanical connections are less stable and less repeatable. According to IEC 60793-1-40 cladding mode strippers should be used if necessary 10/14/2022 to remove light, propagating in the fiber cladding.

Tests T3-T6 are carried out in the connected state of all the tested optical channels. When performing these tests, measurements of the transmitted and reflected power in each of the

DUT optical channels should be carried out simultaneously (in-situ loss measurements of all the channels).

Time dependences of both insertion loss $\alpha_I(t)$ and reflection loss $\alpha_R(t)$ are measured in tests T3-T6 according the following equations:

$$\alpha_I(t) = -10 \log_{10} \left(\frac{P_I(t) \cdot P_0^{ref}}{P_0 \cdot P^{ref}(t)} \right) \quad (1a)$$

$$\alpha_R(t) = -10 \log_{10} \left(\frac{P_R(t) \cdot P_0^{ref}}{P_0 \cdot P^{ref}(t)} \right) \quad (2a)$$

where P_0^{ref} is the initial reference power, measured as P_0 at the very beginning of all the tests, $P_I(t)$, $P_R(t)$, $P^{ref}(t)$ are the current power values, measured in insertion, reflection and reference channels (Figure 13(II)).

7.2.2.3 T3: Thermal cycling test

The test is intended to check survival of the connectors in connected state at the maximum operation temperature in the location of DOI RH Connector at baking. It includes three thermal cycles from room temperature (20°C) to baking temperature (350°C) in the connected state of all the tested optical channels.

Time dependences of temperature and transmitted and reflected signals measured during the test allow one to estimate any degradation of the connections as well as to define the reason. Therefore the measured and analyzed parameters should be *additional* or *T3-induced* insertion and return loss values. The measurements shall be performed in-situ during the test.

The test shall be conducted in vacuum or in inert gas environment.

The acceptance criteria are as follows:

- 1) Visual inspection: absence of any mechanical deformation, melting, etc.
- 2) T3-induced insertion loss <0.5 dB;
- 3) T3-induced return loss in the connected state <60dB;
- 4) T7 as defined in section 7.2.2.7.

7.2.2.4 T4: Elevated temperature test

The purpose of the test is to confirm the ability of connections to transmit optical power at maximum operating temperature for a long time.

Test parameters: the DUT shall be kept at 350°C during 2 hours. Loss measurements should be performed in-situ.

The acceptance criteria are as follows:

- 1) Visual inspection: absence of any mechanical deformation, melting, etc;
- 2) T4-induced insertion loss <0.5 dB;
- 3) T4-induced return loss in the connected state <60dB;

4) T7 as defined in section 7.2.2.7.

7.2.2.5 T5: Connection test

The test target is to evaluate the connection quality (reproducibility of the optical and electrical parameters) for several connection/disconnection events.

Test parameters: 5 cycles of connection and disconnection of the optical and electrical contacts at RT. Loss measurements should be performed in-situ.

The acceptance criteria are as follows:

- 1) Visual inspection: absence of any mechanical deformation, etc;
- 2) T6-induced insertion loss <0.5 dB;
- 3) T6-induced return loss in the connected state <60 dB;
- 4) T7 as defined in section 7.2.2.7.

7.2.2.6 T6: Pull test

Pull test is performed after all the other thermal and mechanical tests to check the remaining tensile strength of the fiber and the strength of the fiber fixation inside the connector.

Test parameters: 3 cycle of 5N tension force applied to each fiber output at RT for 10 s. Loss measurements should be performed in-situ.

The acceptance criteria are as follows:

- 1) Visual inspection: absence of any mechanical deformation, etc.
- 2) T7-induced insertion loss <0.5 dB
- 3) T7-induced return loss in the connected state <60 dB.

7.2.2.7 T7: Electrical conductivity test

The objective of the test is to validate that:

- the electrical characteristics are achieved in the operating temperature range, otherwise proposals for design modification are made
- the electrical characteristics remain unchanged when connecting and disconnecting the pins plates multiple times.

The electrical conductivity shall be measured with acceptance criteria as following:

For copper conductors (per meter):

- 26 AWG²: $< 0.2 \Omega$
- < 26 AWG: $\ll 0.1 \Omega$

For Nicrosil conductors (per meter):

- 22 AWG: $< 3.0 \Omega$

For Nisil conductors (per meter):

² AWG – American Wire Gauge, standardized system for the diameter of the electrically conducting wires.

- 22 AWG: < 1.1 Ω

7.2.2.8 Test sequence

The sequence of the tests is shown in the diagram in Figure 14. As seen, measurements for optical tests T1 and T2 are carried out after manufacturing of the mock-ups and at the end of all the tests. This allows one to determine the degree of degradation of the connector optical parameters accumulated during the thermal and mechanical tests.

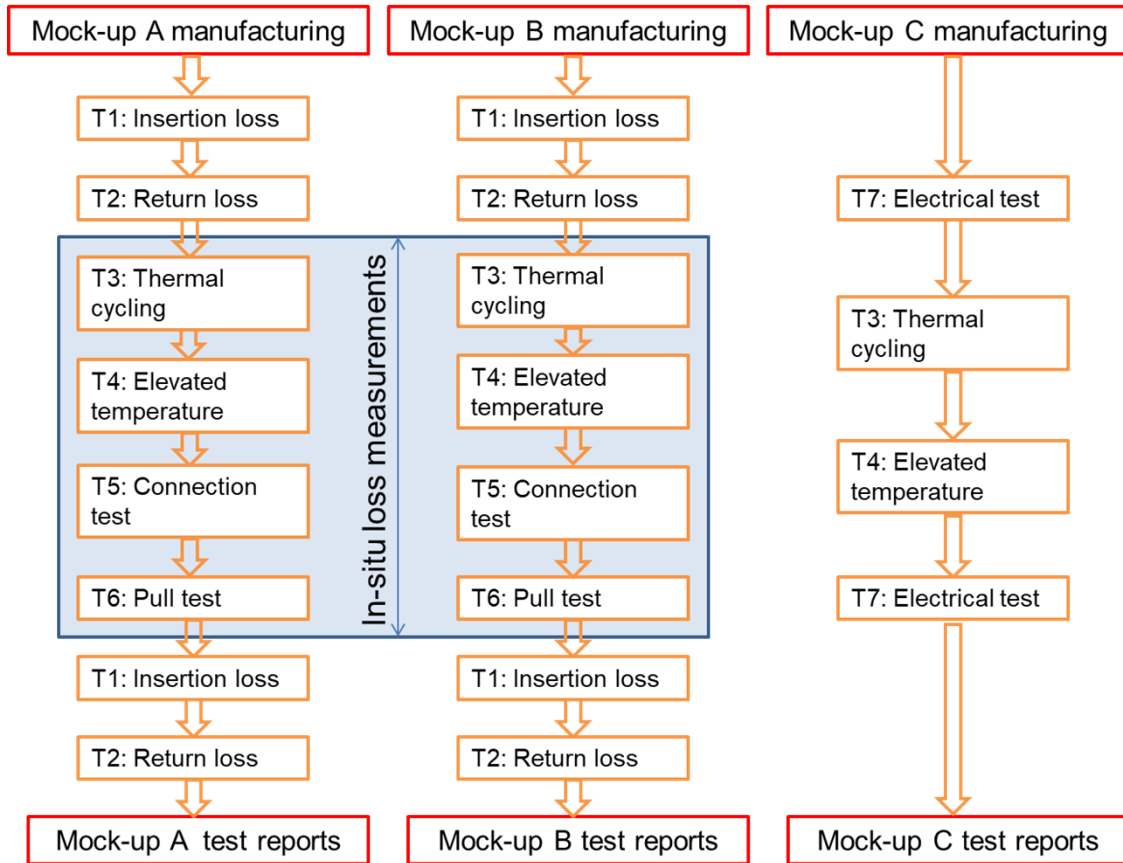


Figure 14. Diagram of the test performance for mock-ups A, B & C

Table 7: Test details

Test	Mock-up	Parameters	Acceptance criteria
T1: Insertion loss test (Section 7.2.2.1)	A, B	Measuring α_I for all the tested optical channels (Eq.(1), Figure 13)	$\alpha_I < 0.5$ dB for all the channels
T2: Return loss test (Section 7.2.2.2)	A, B	Measuring α_R for all the tested optical channels in the connected and disconnected states (Eq.(2), Figure 13)	1) $\alpha_R > 60$ dB for all the channels in the connected state 2) $\alpha_R > 50$ dB for all the channels in the disconnected state
T3: Thermal cycling test (Section 7.2.2.3)	A, B, C	Three thermal cycles from room temperature (20°C) to baking temperature (350°C). The time taken to reach the specified	1) Visual inspection: absence of any mechanical deformation, melting, etc. 2) T3-induced insertion loss <0.5 dB 3) T3-induced return loss in the

		bake temperature from ambient shall be less than 48 hours. In-situ loss measurements	connected state <60dB; 4) Electrical conductivity as defined in section 7.2.2.8
T4: Elevated temperature test (Section 7.2.2.4)	A, B, C	DUT is kept at 350°C during 2 hours. This test shall be combined with Thermal cycling test (T3). In-situ loss measurements	1) Visual inspection: absence of any mechanical deformation, melting, etc. 2) T4-induced insertion loss <0.5 dB 3) T4-induced return loss in the connected state <60dB; 4) Electrical conductivity as defined in section 7.2.2.8
T5: Connection test (Section 7.2.2.5)	A, B, C	5 cycles of connection and disconnection of the optical and electrical contacts at RT. In-situ optical loss measurements.	1) Visual inspection: absence of any mechanical deformation, etc. 2) T6-induced insertion loss <0.5 dB 3) T6-induced return loss in the connected state <60dB; 4) Electrical conductivity as defined in section 7.2.2.8
T6: Pull test (Section 7.2.2.6)	A, B	3 cycle of 5N tension force applied to each fiber output at RT for 10 s. In-situ loss measurements.	1) Visual inspection: absence of any mechanical deformation, etc. 2) T7-induced insertion loss <0.5 dB 3) T7-induced return loss in the connected state <60dB;
T7: Electrical conductivity test (Section 7.2.2.7)	C	Measurement of the electrical conductivity of the electrical channels in the engaged state	Electrical conductivity as defined in section 7.2.2.8

7.2.3 Prototype tests

[REQ-53]

The sub-components of the DOI RH Connector prototype shall be inspected before assembly of the mock-up. The minimal scope of the inspection shall be:

- Visual inspection of the mechanical parts. No visible damage (cracks, surface imperfections) shall be observed
- Dimensional inspection (the dimensions shall correspond to those indicated on the prototype manufacturing drawings)
- Verification of fitting with counterparts (for electrical and optical pins, guided pins, RH tooling)
- Electrical conductivity
- Optical signal transmittance

[REQ-53]

The prototype of the RH Connector shall undergo as minimum the tests listed in the Table 11.

Table 11: List of tests to be performed on the prototype

Test	Test objective	Acceptance criteria
Manual operation test	Plug and unplug manually the sockets of the RH Connector. The operation parameters shall be observed: - connection and disconnection	No jamming and visible damage is observed. Forces and torques values are obtained.

	forces, - tightening and untightening torques of the bolting operation,	The acceptance criteria of the optical and electrical tests shall be fulfilled in the end of qualification.
Remote Handling operation test	Applying the remote handling operation sequence. To perform 10 cycles of engagement and disengagement of the RH connector with RH interface and tooling. Adaptability of the RH operations. The operation parameters shall be observed: - connection and disconnection forces, - tightening and untightening torques of the bolting operation,	No jamming, jerking motion and visible damage is observed. Forces and torques values are obtained. The acceptance criteria of the optical and electrical tests shall be fulfilled in the end of qualification.
Insertion and reflection losses measurement	Measure the transmitted light power through the optical contacts of the RH Connector in engaged state	As per 7.2.2.1 and 7.2.2.2
Electrical conductivity test	The electrical conductivity of the electrical pins of the RH Connector shall be measured in engaged state	As per 7.2.2.7

[REQ-54]

The mock-ups and prototype shall be delivered to IO site in the end of the contract.

7.3 Task III: Technical services for Final Design Review

The Final Design development and design qualification activities shall be completed by the time of the Final Design Review (FDR) meeting and presented to the FDR panel members. IO is in charge in preparation and organization of the FDR and the Contractor will provide the support for the part dedicated to the RH Connector development and qualification.

The Contractor shall provide the technical services to IO for the FDR of the RH Connector. These services are limited to the scope of the RH Connector and consist as minimum of:

- Preparation of the documents requested in this technical specification,
- Consulting support for preparation of the DOI project documentation under responsibility of IO (like interface, assembly, commissioning, operation documentation, etc),
- Presentation of the result of the development at the FDR meeting,
- Support for chits closure, update the corresponding deliverables if needed.

The FDR meeting will be held at IO premises or remotely by videoconference. The date of the FDR is defined by IO Project Schedule and the meeting is planned to be conducted in **September 2023**.

8 Deliverables and due dates

The Contractor shall provide to IO the documentation and data identified in Table 12, where T0 is a date of signature of the contract.

Table 8: Documents to be delivered

Deliverable	Due date, months
D# 1 Work Plan and Schedule	Kick-off meeting
D# 2 Quality Plan	Kick-off meeting
Task I: Final Design Development	
D# 3 Intermedia report on the Final Design of the DOI RH Connector	T0+4
D# 4 Detailed Component Drawings for: <ul style="list-style-type: none"> - DOI RH Connector final design - Mock-ups A, B and C - Full scale prototype 	T0+6
D# 5 Remote Handling Assessment	T0+6
D# 6 Remote Handling Plant Definition Form	T0+12
D# 7 Final report on Final Design of DOI RH Connector	T0+12
D# 8 3D CAD models of the final design	T0+10
Task II: Mock-up manufacturing and design qualification.	
D# 9 Mock-ups Test Plan	T0+4
D# 10 Full scale prototype test plan	T0+4
D# 11 Mock-up Test Reports: <ul style="list-style-type: none"> - Mock-up A test report - Mock-up B test report - Mock-up C test report 	T0+10
D# 12 Full scale prototype test report	T0+18
D# 13 Delivery of the mock-ups and prototype to the ITER site	T0+22
Task III: Technical services during Final Design Review.	
D# 14 Report on Technical support during Final Design Review.	T0+10

D# 15 Report on the post-FDR support for chits resolution	T0+22
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9 Contract follow-up

9.1 Data management

The documents generated during the execution of this contract, which the Contractor and its Suppliers shall submit to IO (e.g. technical and QA documents, Minutes of Meetings) will be handled electronically in the ITER Document Management System (IDM).

9.2 Periodic meetings

[REQ-143]

The Contract shall start with an official Kick-Off Meeting where the following items (as a minimum) shall be discussed and agreed:

- Confirmation of the specifications, specific requirements and contractual input.
- The Contractor's Quality Plan.
- The Detailed Work Schedule of the contractual activities, including milestones.

[REQ-144]

Progress meetings shall be conducted throughout the whole duration of the Contract at a minimum frequency of one per calendar month. The meetings shall be held by video conference or in-person at the IO's premises or at the Contractor's premises.

[REQ-145]

The Minutes of Meeting (MoM) shall be prepared by the Contractor and submitted to the IO no later than one week after the meeting.

10 Quality Assurance Requirements

The Contractor conducting the presented activities shall have an ITER approved QA Program or an ISO 9001 accredited quality system. The general requirements are detailed in ITER Procurement Quality Requirements [ITER_D_22MFG4 - ITER Procurement Quality Requirements](#) [AD8].

Prior to commencement of the task, a Quality Plan must be submitted for IO approval giving evidence of the above and describing the organization for this task; the skill of workers involved in the study; any anticipated sub-contractors; and giving details of who will be the independent checker of the activities (see Procurement Requirements for Producing a Quality Plan [ITER_D_22MFMW - Requirements for Producing a Quality Plan](#)) [AD9].

Deviations and Nonconformities shall follow the procedure detailed in Procedure for the management of Deviation Request [ITER_D_2LZJHB - Procedure for the management of Deviation Request](#) [AD10] and Procedure for management of Nonconformities [ITER_D_22F53X - Procedure for management of Nonconformities](#) [AD11].

Prior to delivery of any manufactured items to the IO Site, a Release Note shall be signed in accordance with ITER requirements regarding Contractors Release Notes [ITER_D_22F52F - Requirements for Producing a Contractors Release Note](#).

Documentation developed as the result of this task shall be retained by the performer of the task or the DA organization for a minimum of 5 years and then may be discarded at the direction of the IO.

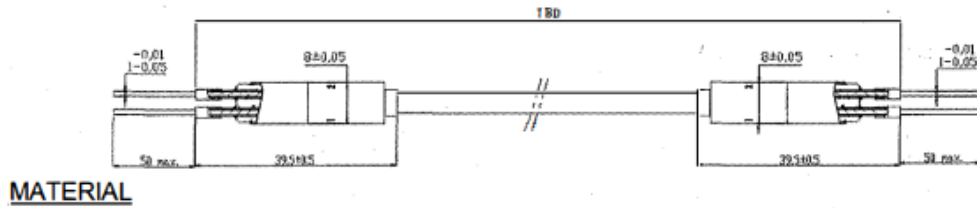
11 Applicable Documents

- [AD1] [ITER_D_2EZ9UM - ITER Vacuum Handbook](#)
- [AD2] [ITER_D_27Y4QC - Appendix 3 Materials](#)
- [AD3] [ITER_D_2ELN8N - Appendix 4 Accepted Fluids](#)
- [AD4] [ITER_D_2ETNLM - Appendix 10 Vacuum Cables](#)
- [AD5] [ITER_D_2ELUQH - Appendix 13 Cleaning and Cleanliness](#)
- [AD6] [ITER_D_2F6FTX - Procedure for the Usage of the ITER CAD Manual](#)
- [AD7] [ITER_D_2DWU2M - Procedure for the CAD management plan](#)
- [AD8] [ITER Procurement Quality Requirements \(22MFG4 v5.1\)](#)
- [AD9] [Requirements for Producing a Quality Plan \(22MFMW v4.0\)](#)
- [AD10] [Procedure for the management of Deviation Request \(2LZJHB v7.3\)](#)
- [AD11] [Procedure for management of Nonconformities \(22F53X v8.2\)](#)
- [AD12] [ITER_D_2E7BC5 - ITER Remote Handling Code of Practice](#)
- [AD13] [ITER_D_2NRTWR - Remote Handling Compatibility Procedure](#)

12 Reference Documents

- [RD1] [ITER_D_2NAG4Z - D4 - Mock-up Test Report](#)
- [RD2] [ITER_D_2N9QSK - D6 - Final Report of optical RH Connector Preliminary Design](#)
- [RD3] [ITER_D_X3EUJR - \[DDL-015-GMT\] General Manipulation Tools Sub-System Design Description Document](#)

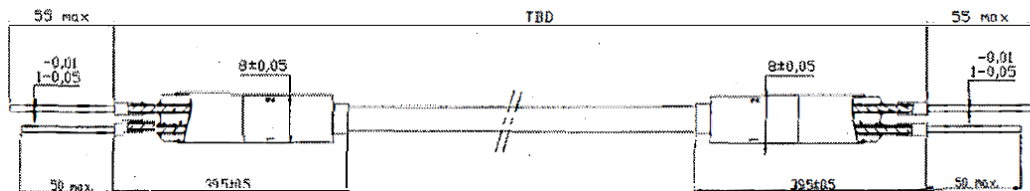
Appendix A – Design of the electrical MI cables



MATERIAL

- Sheath Stainless Steel 316L with $Co \leq 0.2\%$ $N \leq 0.1\%$ and $Ta \leq 0.05\%$ coated with copper (thickness : $5\mu\text{m} \pm 1\mu\text{m}$)
- Insulant $Al_2O_3 > 99.5\%$
- Conductors Oxygen free Copper Cu/C2; conductors twisted (pitch $\leq 100\mu\text{m}$)

Figure 15 Design of the mineral insulated electrical cable with copper conductors



MATERIAL

- Sheath Stainless Steel 316L with $Co \leq 0.2\%$ $N \leq 0.1\%$ and $Ta \leq 0.05\%$ coated with copper (thickness : $5\mu\text{m} \pm 1\mu\text{m}$)
- Insulant $Al_2O_3 > 99.5\%$
- Conductors Nisil / Nicrosil; conductors twisted (pitch $\leq 100\mu\text{m}$)

Figure 16 Design of the mineral insulated electrical cable for thermocouple extension