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Technical Specification for the Procurement of RF Components for the High-Power Test Bed of DTTU

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Abstract	This document is the technical specifications for the procurement of radiofrequency components, required to set up a high-power testbed for solid-state transmitters within the DTTU (Divertor Tokamak Test facility Upgrade) project	

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1.0	First issue
1.1	Addition of specification for packing and marking (PRC-PRO-07000) Minor adjustments and typo corrections according to workflow comments

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1 Introduction

ENEA – National Agency for New Technologies, Energy and Sustainable Economic Development – is responsible for the fulfilment of the project "Divertor Tokamak Test facility Upgrade" (DTTU), submitted to the public call D.D. 3264/2021 "Rafforzamento e creazione di Infrastrutture di Ricerca". This project, approved on August 8th, 2022, is aimed at upgrading the Divertor Tokamak Test facility (DTT), a tokamak device allowing for the magnetic confinement of a deuterium plasma.

DTT will be installed at the ENEA research centre in Frascati, hereinafter abbreviated as DTT site, and is conceived to study innovative solutions to the problem of power exhaust in next-generation nuclear fusion reactors, like ITER and DEMO, under a technological and scientific viewpoint. To this aim, DTT needs a significant amount of additional heating that will be partially provided by an Ion Cyclotron Heating (ICH) system, able to inject electromagnetic waves into the plasma at the cyclotron frequency of the ion species. The radiofrequency (RF) transmission lines of ICH systems are mainly constituted by RF components in rigid coaxial cable which have low attenuation in the typical ICH frequency range from 30 to 100 MHz.

The DTTU project includes the development and test of a RF amplification system in the frequency range from 60 to 90 MHz, consisting of two solid-state transmitters, each one with a nominal power of 1.2 MW. The test of such RF source requires to set up a High Power Test Bed (HPTB) that shall allow Enea to carry out the acceptance tests of the solid-state transmitters. The latter comprise RF operations at the maximum power and duty cycle (50 s every hour) with some load mismatch, i.e., the HPTB shall allow for the variation of Voltage Standing Wave Ratio (VSWR) and reflection coefficient phase at the transmitter output.

The HPTB consists of RF components that will interface with some auxiliary units required for their operation, as for example power supplies, local control units, pressurization and cooling units. The present technical specification (TS) pertains to a supply contract for the procurement of RF components for the HPTB of the DTTU project. As explained in the associated project and quality management specification (MS) [1]:

- A Bidder (candidate to become contractor), in the response to the call for tender, shall submit a Technical Proposal, describing the items to be supplied ad their compliance with the present technical specification.
- The Contractor, during the execution of the contract, shall issue a Technical Design Report (TDR) including the thorough description of the items to be supplied and their interfaces.
- The Contractor shall deliver an Acceptance Data Package (ADP) including the as-built description of all items to be supplied and their parts.

2 Acronyms, abbrevations and definitions

AC	Alternating Current
ADP	Acceptance Data Package
Bidder	Tendered for the supply of the present specification
CE	Conformité Européenne
CODAS	Control and Data Acquisition System
Contractor	Party appointed by Enea to perform the supply of the present specification
CW	Continuous Wave
DTT	Divertor Tokamak Test facility
DTT site	ENEA Frascati research centre – Via Enrico Fermi 45 – 00044 Fractal (RM) – Italy
DTTU	Divertor Tokamak Test facility Upgrade
EC	European Commission
EU	European Union
f	Frequency
FAT	Factory Acceptance Test
HMI	Human Machine Interface
HPTB	High Power Test Bed
ICH	Ion Cyclotron Heating
IEC	International Electrotechnical Commission (Commissione Elettrotecnica Internazionale
LCU	Local Control Unit
KOM	Kick-Off Meeting
MPS	Machine Protection System
MS	Project and quality management specification [1]
P	Power
PLC	Programmable Logic Controller
RF	Radiofrequency
SAT	Site Acceptance Test
Subcontractor	Party (if any) responsible to perform part of the contract task in place of the Contractor
TDR	Technical Design Report
TS	Technical Specification (the present document)
Vendor	Party that manufactures or supplies equipment and services to the Contractor or to the subcontractors
VSWR	Voltage Standing Wave Ratio

3 References

[1] "Project and quality management specification for the procurement of RF Components for the High-Power Test Bed of DTTU ", DTT ID: TLM-SPT-52021.

[2] “General Specification for Power, Instrument, Telecommunication and Fibre Optic Cables”, DTT ID: TEC-SPT-44015.

[3] “General specification for instrument and installation”, DTT ID: TEC-SPT-44016.

[4] “Document Coding & Item Numbering”, DTT ID: QMS-PRO-20000.

[5] “Packing & Marking Procedure for Material and Equipment”, DTT ID: PRC-PRO-07000.

4 Contract scope

The contract scope consists in the supply of radiofrequency (RF) components for the High Power Test Bed (HPTB) of the DTTU project, which will be based on 9 3/16'' or equivalent rigid coaxial cables with characteristic impedance of 50 Ω. The supply shall include the items listed in section 4.1 and the activities listed in section 4.2. The items are grouped in two batches, whose delivery time can differ (see section 5).

4.1 List of deliverables

4.1.1 Batch #1

Item	Quantity	Reference
Straight Line with length=2 m	3	§ 7.1
Straight Line with length=1.5 m	4	§ 7.1
Straight Line with length=1 m	5	§ 7.1
Straight Line with length=0.5 m	5	§ 7.1
Straight Line with length=0.2 m	4	§ 7.1
Unflanged Straight Line with length=1 m	4	§ 7.2
Flange for welding	16	§ 7.2
Coupling Element with accessories for its connection, e.g., O-rings and sets of nuts, screws and washers for tightening	40	§ 7.2
90° Elbow	15	§ 7.3
Bi-Directional Coupler	2	§ 7.4
Adapter to type N	2	§ 7.5
Cable Testing Section	2	§ 7.6
Flexible Line Section	1	§ 7.7
Gas Barrier and pressurization-relevant instruments	1	§ 7.8
Gas Inlet and pressurization-relevant instruments	1	§ 7.8
Phase Shifter with Electrical Motor (variable length = 2.6 m)	1	§ 7.9
Variable Stub with Electrical Motor (variable length = 2.6 m)	1	§ 7.10
Control Unit for Phase Shifter and Variable Stub	1	§ 7.11
Dummy Load with P=2.5 MW	1	§ 7.12
Soda unit for P=2.5 MW	1	§ 7.13

This batch shall also include any special tool required to connect the RF flanges of the components.

If the Contractor opts for a different solution from the IEC standard (see section 6.1.1), the following items shall be also provided:

Item	Quantity
Transition from the standard IEC flange to the equivalent flange adopted by the Contractor	2
Coupling element of the IEC flange with accessories for its connection, e.g., O-rings and sets of nuts, screws and washers for tightening	2

4.1.2 Batch #2

Item	Quantity	Reference
Straight Line with length=2 m	2	§ 7.1
Straight Line with length=1.5 m	2	§ 7.1
Straight Line with length=1 m	3	§ 7.1
Straight Line with length=0.5 m	3	§ 7.1
Coupling Element with accessories for its connection, e.g., O-rings and sets of nuts, screws and washers for tightening	15	§ 7.2
90° Elbow	5	§ 7.3
Bi-Directional Coupler	2	§ 7.4
Adapter to Type N	2	§ 7.5
Cable Testing Section	1	§ 7.6
Flexible Line Section	1	§ 7.7
Gas Barrier and pressurization-relevant instruments	1	§ 7.8
Gas Inlet and pressurization-relevant instruments	1	§ 7.8
Dummy Load with P=0.25 MW	1	§ 7.12
Voltage Probe	2	§ 7.14
Short-circuit Flange	2	§ 7.15
3 dB Hybrid Coupler	1	§ 7.16
Two-Way Switch	1	§ 7.17

4.2 Activities covered by the contract

The contract scope includes the following activities:

- Verification of the performance of RF components by means of calculations and simulations.
- Detailed layout of the piping system for the soda solution.
- Manufacturing and assembling.
- Checks and tests at Contractor/Subcontractor premises.
- Delivery of all items to the DTT site.
- Supervision during installation and tests at the DTT site and technical consulting (see section 9.4).
- Transportation back to the factory if needed to make a component compliant with specifications.
- Documentation (see section 5 of the MS and section 11 of the present specification).

5 Contract shedule

Contract activities officially start at the Kick-Off Meeting with the signature of a "Start of activities" declaration by the parties. The KOM shall be held within two months from the contract signature. The contract is structured in milestones, whose timing is summarized in Table 1. The activities associated to the milestones are clarified in the TS and in the MS. A possible time evolution of the contract is graphically exemplified in Figure 1.

In its reply to the call for tender, the Bidder shall propose a schedule for the milestones M06, M07, M08, M09, M13, M14, and M15.

Table 1: list of contract milestones with their timing.

M#	Milestone	Duration from predecessor unless otherwise specified
M01	Kick-Off Meeting (KOM)	-
M02	Issue of the TDR by the Contractor for comments	1 month
M03	Comments and/or modifications to the TDR by Enea	2 weeks
M04	Issue of the TDR by the Contractor for approval	1 week
M05	Acceptance of the TDR by Enea	1 week
M06	Manufacturing and FAT of Soda Unit and 2.5-MW Dummy Load	
M07	Manufacturing and FAT of Phase Shifter, Variable Stub, and their control unit	
M08	Manufacturing and FAT of the remaining components of batch #1	
M09	Batch #1 delivered to the DTT site	within 15 months from KOM
M10	SAT of batch #1 completed	within 21 months from KOM
M11	Issue of the ADP by the Contractor for batch #1	2 weeks
M12	Acceptance of the ADP by Enea for batch #1	2 weeks
M13	Manufacturing and FAT of 3 dB Hybrid Coupler and Two-Way Switch	
M14	Manufacturing and FAT of the remaining components of batch #2	
M15	Batch #2 delivered to the DTT site	within 20 months from KOM
M16	SAT of batch #2 completed	within 21 months from KOM
M17	Issue of the ADP by the Contractor for batch #2	2 weeks
M18	Acceptance of the ADP by Enea for batch #2	2 weeks

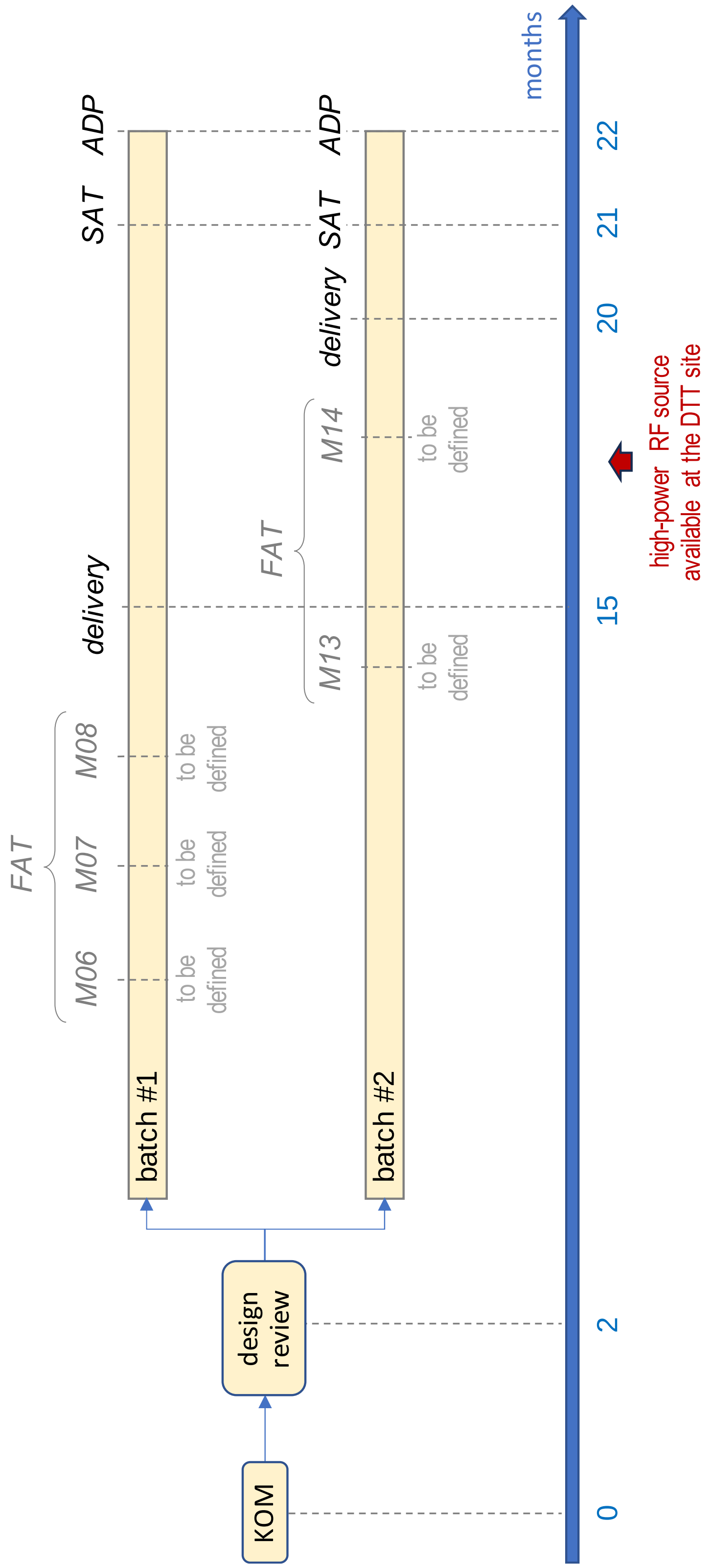

Figure 1. Example of contract schedule assuming the maximum allowable duration of the activities.

6 General Specifications

The contract goods shall be realized and tested in agreement with the law in force, the applicable standards, the best engineering practice, and the state of the art in the corresponding technical areas. In particular, unless otherwise stated in the present specification, they shall comply with the international standards IEC 60339-1 and IEC 60339-2 as regards the terminology, the definition of parameters, the designation of components, the procedures and test conditions, the marking, the mechanical and electrical specifications.

Components and materials shall be selected considering DTT operational and environmental conditions, parasitic parameters, and expected lifetime as well as taking adequate safety margins from their nominal maximum operational values.

6.1 Mechanical specifications

6.1.1 Cross-section and mating interface

The reference cross-section and mating interface of RF components shall be

- Line: 339 IEC 50-233-1 or equivalent.
- One-piece flange connector: 339 IEC 50-233-2 or equivalent.
- Swivel type flange connector: 339 IEC 50-233-3 or equivalent.

The chosen reference shall be uniform throughout the supply. If the 339 IEC 50-233-1 line is chosen, the diameters, thicknesses and relative tolerances shall comply with the part of the IEC 60339-2 recommendation pertaining to the 9 3/16'' line with characteristic impedance of 50 Ω. Different choices are considered “equivalent” if they comply with all provisions of the present specification and they have been routinely used in similar high-power applications, preferably in other ICH plants. In such cases, the supply shall also include at least two adapters for the connection with the 339 IEC 50-233-2 flange, whose interface type (male/female) will be defined by Enea during the preparation of the TDR. In any case, the flanges shall ensure the proper alignment between connected components, e.g. by means of holes and alignment pins or through an adequate number of holes provided with a calibrated diameter, so that the alignment is ensured with the insertion of screws having calibrated heads.

6.1.2 Pressurization

The pressurization is the application of a positive pressure, relative to the atmospheric pressure, of dry air to the interior of a coaxial line. Unless otherwise stated, each RF element of the supply shall withstand a maximum pressurization of 3 bar without damage or deformation.

6.1.3 Straight line specifications

- Ellipticity: not higher than specified in Table I of IEC 60339-1.
- Curvature: the external curvature for a transmission line length of 3 m shall not exceed 12.7 mm.

6.1.4 Flanges

- Maximum deviation of flatness: 0.03 mm.
- Perpendicularity to the axis of the coaxial lines: 90° ±0.25°.

All male interfaces shall be provided with accessories for their connection, e.g., O-rings and sets of nuts, screws and washers for tightening. The Contractor can propose a different type of interface (male/female) and flange connector (one-piece/swivel) from those specified in sec. 7. Enea will assess the change request and decide whether to accept it or not.

6.2 Materials

The Bidder shall specify the bulk and coating materials of the RF components. The materials shall ensure high RF performance and reliability. Possible choices are:

- Inner conductor: high conductivity copper or copper alloy.
- Outer conductor: copper or its alloys or aluminium.
- Flanges: brass or other material compatible with that of the external conductor.
- Inner connector: copper alloy with high resilience characteristics.
- Spacers: ceramic material with a configuration up to the Bidder allowing for the passage of dry gas.

6.3 Radiated field

Maximum intensity of electric field (RMS) from 60 to 90 MHz: 61 V/m at a distance of 1 m from any RF component.

6.4 Electrical specification

- Operating frequency range: (60-90) MHz, unless otherwise stated;
- Characteristic impedance: 50 ± 0.3 Ω;
- Proof voltage for high-power components: 25 kV in air at sea level and 45 kV with a pressurization of 3 bar;
- Minimum RF shielding ≥ 100 dB.

6.5 HPTB requirements

As a minimum, unless otherwise stated, all RF components shall be usable, with a pressurization of 2 bar, in the following conditions between 60 and 90 MHz:

- Pulsed operations: 2500 kW with VSWR up to 3 for a duty cycle of 50 s every hour.
- CW operations: 250 kW with VSWR up to 3 for a duty cycle of one hour every two hours.

6.6 Finishing treatments

The internal surfaces of all RF components and the contact surfaces between the flanges shall be free from scratches, burrs, cracks, dust, grease and other imperfections. These surfaces shall have a bright glossy appearance according to good current practice. The contact surfaces of all components shall be adequately treated if there is the possibility of corrosion phenomena.

External corners and edges shall be adequately rounded off. The external surfaces shall be painted with coloured epoxy paint. The colour will be agreed during the TDR.

Paiting and protective finishing shall ensure item protection against environmental conditions, the effect of process fluids, normal wear and the handling during installation, erection, and commissioning.

6.7 Environmental conditions

The Contractor shall specify the range of ambient temperature and relative humidity that ensure normal operations of the contract goods. Such ranges shall be compatible with the following ambient conditions:

- temperature range between 10 °C and 40 °C;
- relative humidity < 95%.

For specific needs, the Contractor can ask to modify the above mentioned ambient conditions, justifying its request. Enea will assess the change request and decide whether to accept it or not.

Equipment that is liable to suffer from internal condensation shall be fitted with proper devices to prevent condensation in the worst ambient conditions. The operation of these devices shall be monitored and an alarm shall be generated in the form of an output electrical signal in the case of fault. Local visible indication of fault shall be provided too.

Ventilation systems, if any, shall be equipped with dust filters. The Contractor shall take any possible precautions to avoid dust accumulation upon dust-sensitive components. In particular, openings and possible fans shall be located taking into account the position of such components.

All components will be installed indoor in an unclassified area as to ionizing radiations and ATEX.

7 Detail Specifications

7.1 Straight lines

Type of flange connectors: one-piece;

Interface type: female;

Precision of line length: ±0.5 mm;

VSWR ≤ 1.03;

Insertion loss ≤ 0.006 dB/m.

The straight line with length=0.2 m is meant as a male-to-male adapter. Shorter lengths than 0.2 m or specifically-designed adapters are acceptable too, provided that they allow for an easy connection of two male RF interfaces.

7.2 Unflanged straight lines with separate mating interfaces

Unflanged straight lines are required to make sections of transmission line with custom length to fit specific needs dictated by the currently unkown HPTB layout.

Unflanged straight lines consist in outer and inner conductors with length of 1 m ±0.5 mm for subsequent cutting, flanging, and assembling by Enea.

To this aim, the supply shall also include flanges for welding, coupling elements with accessories for their connection, e.g., O-rings and sets of nuts, screws and washers for tightening, as per the quantity given in section 4.1.

Type of flange connectors: one-piece.

7.3 90° elbows

Type of flange connectors: swivel type.

Interface type: male/male;

VSWR ≤ 1.03;

Insertion loss ≤ 0.03 dB.

7.4 Bi-directional couplers

Main line (high power) interface:

- Type of flange connectors: one-piece;
- Interface type: female.

Secondary line (probe) interface: two, type N, 50 Ω, female connectors (IEC 61169-16), terminated with precision 50 Ω/20 W load.

Forward power coupling at 75 MHz: 64 ±0.2 dB;

Reflected power coupling at 75 MHz: 58 dB ±0.2 dB;

Bi-directional couplers with adjustable forward and reflected coupling, respectively in the range (63-80) dB and (55-76) dB at f=75 MHz, will be preferred;

Directivity ≥ 30 dB;

VSWR at the ports of the main line, with the others matched, ≤ 1.03;

VSWR at the ports of the secondary line ≤ 1.05;

Insertion loss of the main line ≤ 0.05 dB;

The HPTB requirements of section 6.5 do not apply to the secondary line of bi-directional couplers.

7.5 Adapters to type N

Interfaces:

- N, 50 Ω, female, (IEC 61169-16),
- 339 IEC 50-233-2 or equivalent (one-piece), female;

VSWR ≤ 1.04;

Insertion loss ≤ 0.05 dB;

The HPTB requirements of section 6.5 do not apply to this component.

7.6 Cable testing sections

A cable testing section is meant here as a component that provides a direct access to the coaxial transmission line for measurement purposes. It allows for the replacement of a short line section with a measurement insert, equipped with two adapters for the simultaneous measurement of both branches of the main line.

Main line (through-line) interface:

- Type of flange connectors: swivel type;
- Interface type: male.

Measurement insert interface: two, type N, 50 Ω, female connectors (IEC 61169-16). The use of a different interface is acceptable, but adapters from this interface to type N shall be also provided.

VSWR of through-line ports ≤ 1.03;

VSWR of measurement ports ≤ 1.04;

Insertion loss of the through-line ≤ 0.06 dB;

Insertion loss between measurement port and main line ≤ 0.06 dB;

Average power rating of the measurement insert ≥ 1 kW with a pressurization of 0 bar.

The cable testing section should be preferably equipped with a means to prevent the RF power transmission before the removal of the measurement insert. Such means can be for example in the form of an electrical contact that is open (closed) when the measurement insert is present (absent).

The HPTB requirements of section 6.5 and the pressurization requirements of section 6.1.2 do not apply to the measurement insert.

7.7 Flexible line section

Type of flange connectors: one-piece;

Interface type: male;

Maximum length: 1 m;

Maximum axial movement: ±5 mm;

Maximum lateral movement: 4 mm;

VSWR ≤ 1.06;

Insertion loss ≤ 0.05 dB;

Protection against excessive deformation.

7.8 Gas barriers and gas inlets

A gas barrier is meant here as a component able to separate a straight coaxial line in two independent environments as regards filling gas and pressurization, while being continuous and almost transparent to RF waves. It generally consists in a line section equipped with a dielectric barrier, e.g. in the form of a ceramic disk perpendicular to the line axis. A gas inlet is meant as a straight line section with an interface allowing for the pressurization of the coaxial cable. The mechanical interface, i.e. the gas injection nozzle, will be agreed between Enea and the Contractor during the preparation of the TDR.

For the scope of the present contract, gas barriers shall be equipped with two gas inlets, respectively placed upstream and downstream the ceramic layer.

RF interface:

- Type of flange connectors: one-piece;
- Interface type: female;

VSWR ≤ 1.1;

Insertion loss ≤ 0.05 dB;

Maximum pressure difference between input/output coaxial lines: > 3 bar;

Each gas barrier and each gas inlet (supplied as separated item) shall be provided with

- 1x manually-operated pressure regulator;
- 1x pressure safety valve;
- 1x pressure gauge transmitter (2-wire type, minumum scale: 0-6 bar, accuracy ≤ 0.1%, output: 4 to 20 mA, indoor use) with local pressure indicator.

Instruments shall be compatible with the mechanical interface of the gas inlet and comply with TEC-SPT-44016 [3]. Should any conflict arise between the TEC-SPT-44016 [3] and the other documentation, the latter prevails.

7.9 Phase shifter with electrical motor

Type of flange connectors: swivel type;

Interface type: female;

VSWR ≤ 1.1;

Insertion loss ≤ 0.06 dB;

Electrical length variation: 2.6 m;

Minimum variation step: 1 mm;

Precision ≤ 1 mm;

Travelling speed: 3 m/45 s;

Maximum value of the longest dimension ≤ 4 m;

Suitable for installation with the longest dimension parallel as well as perpendicular to the room floor;

Operation: motorized tuning via electrical drive;

Motor electrical interface: 400/230 V AC ±10%, 50 Hz ±5%;

The phase shifter shall be equipped with a graduated scale and a mechanical pointer indicating the current position of the travelling part with respect to some reference position to be agreed.

The definitive drawings must show the strokes of the moving parts with the minimum and maximum dimensions and the characteristics of the motor.

7.10 Variable stub with electrical motor

Type of flange connectors: swivel type;

Interface type: female;

Stub termination: short circuit;

Electrical length variation: 2.6 m;

Minimum variation step: 1 mm;

Precision ≤ 1 mm;

Travelling speed: 3 m/45 s;

Maximum value of the longest dimension ≤ 7.6 m;

Suitable for installation with the longest dimension parallel as well as perpendicular to the room floor;

Operation: motorized tuning via electrical drive;

Motor electrical interface: 400/230 V AC ±10%, 50 Hz ±5%;

The variable stub shall be equipped with a graduated scale and a mechanical pointer indicating the current position of the travelling part with respect to some reference position to be agreed.

The definitive drawings must show the strokes of the moving parts with the minimum and maximum dimensions and the characteristics of the motor.

7.11 Control unit of phase shifter and variable stub

The supply shall include a Local Control Unit (LCU) to drive the motors of at least six tunable components such as phase shifters and variable stubs. The LCU shall be mountable on a standard 19” rack.

The Contractor shall provide cables and/or optical fibers between LCU and RF components. The maximum distance between the LCU and controlled components will be 25-30 meters. Enea will communicate the exact distance to the Contractor during the preparation of the TDR. Cables and optical fibres shall comply with the provisions of TEC-SPT-44015 [2].

The LCU shall have redundant power supplies.

Electrical interface: 230 V AC ±10%, 50 Hz ±5%.

The LCU shall have an interface allowing for its remote control by the DTT control system (see the guidelines in section 8); its details will be agreed between Enea and the Contractor during the preparation of the TDR.

7.12 Dummy loads

A dummy load is meant here as a one-port RF component that employs a solution of deionized water and sodium carbonate (hereinafter referred to as *soda-water solution*) to achieve an almost perfect absorption of the incoming RF wave. The mechanical interface, i.e. the inlet/outlet flanges for the soda-water solution, will be agreed between Enea and the Contractor during the preparation of the TDR.

RF interface:

- Type of flange connectors: swivel type;
- Interface type: female;

VSWR ≤ 1.1;

RF power ratings from 50 to 100 MHz:

- for the dummy load of batch #1:
  - at least 2.5 MW with duty cycle of 50 s every hour and
  - at least 250 kW with duty cycle of one hour every two hours;
- for the dummy load of batch #2:
  - at least 250 kW with duty cycle of 50 s every hour and
  - at least 25 kW with duty cycle of one hour every two hours.

7.13 Soda unit

A Soda Unit is meant here as the primary cooling system of the dummy loads for the first ICH cluster of DTT. It is connected with the secondary water cooling system of DTT and consists in a reservoir for the soda-water solution (see section 7.12), capable of absorbing the RF power transmitted to the loads, and all equipment, such as pumps, resistor, heat exchangers, electrical panel, etc., required to distribute and cool the soda-water solution.

In its final configuration, the first ICH cluster of DTT will require the following dummy loads:

(a) 1x dummy load of 2.5 MW, distance from soda unit ≤ 30 m.

(b) A set of 4 dummy loads, which can consist either in
  - 2x dummy load of 1.0 MW, distance from soda unit ≤ 65 m.
  - 2x dummy load of 0.25 MW, distance from soda unit ≤ 40 m.

  or in

  - 1x dummy load of 1.0 MW, distance from soda unit ≤ 65 m.
  - 2x dummy load of 0.625 MW, distance from soda unit ≤ 65 m.
  - 1x dummy load of 0.25 MW, distance from soda unit ≤ 40 m.

The choice between the two sets of 4 dummy loads will be taken during next years. The chosen set will be progressively deployed and, during different stages of deployment, some dummy loads may be relocated. The soda unit shall include all equipment to operate the two dummy loads that are within the scope of the present supply. This equipment shall include the amount of sodium carbonate required to prepare the soda-water solution for the first startup as well as the piping between the soda units and such dummy loads.

At the same time the soda unit shall be upgradable to work with either of the abovementioned sets of dummy loads (i.e., point (b) of the previous list). For instance the reservoir shall be sized and provided with suitable connectors to cover all configuration cases and the frame shall be conceived for the future installation and connection of other pumps to set up the hydraulic circuits for the chosen set of dummy loads. The electrical panel shall be also adaptable to the different configurations.

With reference to the previous list, the dummy load (a) and the dummy loads (b) will not absorb their rated power simoultaneously. In brief, the power dissipation capability of the soda unit shall be ≥ 2.5 MW for RF pulses of 50 s every hour and ≥ 250 kW for RF pulses of one hour every two hours.

The soda unit shall be installed on a steel frame. It can be delivered pre-assembled or in few parts accompanied with detailed assembly instructions. The access door to the room where the soda unit will be located has a width of 2.5 m and a height of 2.8 m. The available space in the room does not allow the Soda Unit to exceed door size and be longer than 6.5 m.

The Contractor shall design the piping system between the soda unit and the two dummy loads of this supply. The Contractor shall provide all items of such piping system with instruction for their installation that will be up to Enea. During the preparation of the TDR, Enea will provide information about the building and about the location of the soda units and the two dummy loads. In any case, the maximum distance between the soda unit and the two dummy loads will be shorter than 30 m.

The piping materials shall be compatible with the process fluid in terms of chemical corrosion and rating. As a minimum, instrument wetted parts shall be AISI 316 as long as the process fluid does not require more suitable materials. For the connections to the process (primary connections either hydraulic or pneumatic), AISI 316L stainless steel tubing and instrument manifold, AISI 316 stainless steel compression fittings (double ferrule type), isolation valves and accessories (such as separation cylinders and siphons) shall be used as minimum and in any case suitable for the process conditions. Tubing and fitting materials shall be suitable with the fluid characteristics, made of compatible material, to avoid galvanic corrosion and selected for the worst process conditions.

Instrument included in the soda unit shall comply with sections 3 of TEC-SPT-44016 [3]. Should any conflict arise between the TEC-SPT-44016 [3] and the other documentation, the latter prevails.

The soda unit shall be equipped with a control panel reporting a visual indication of the unit status, e.g., by means of colored LED lights, and allowing for local operation of the unit and the change of the segregation state (local/remote). Further details regarding such aspects are given in section 8.

The soda unit shall have the following

- Electrical interface:
    - 400 V AC ±10%, 50 Hz ±5%.
- Cooling interfaces:
    - 2x connection (inlet + outlet) with the secondary cooling water system of DTT. The latter will provide softened water with hardness in the range 7 – 15 °f, temperature of 15 °C and pressure of 5 barg. For specific needs, the Contractor can ask to modify such features, justifying its request. Enea will assess the change request and decide whether to accept it or not. Interface details such as flange type, pipe diameter, flow rate and other process data, will be agreed between Enea and the Contractor during the preparation of the TDR. Flanges should be preferably based on EN/ISO standards.
    - Connections with the pipes that bring the soda-water solution to the dummy loads. This interface depends on the primary cooling circuit proposed by the Contractor for the abovementioned configurations of dummy loads for the first ICH cluster of DTT. Connection details will be agreed between Enea and the Contractor during the preparation of the TDR.
- Control interfaces:
    - 1x emergency push button, clearly visible and easily accessible, that Enea will connect to the DTT emergency loop.
    - 1x local/remote key switch.
    - A set of signals, alarms and/or interlocks to be agreed between Enea and the Contractor during the preparation of the TDR along with their logics, characteristics, and protocols. This set should include:
        - An output signal proportional to the soda-water solution temperature. Enea will use this signal to set up a feedback control of the water flow entering the soda unit from the secondary cooling water circuit.

    - An input signal with two logical values, which enables the activation of the soda unit. It notifies that the external machine protection system is alive and no external interlocks are present.
    - An output signal with two logical values, which notifies the presence of an internal fault or alarm, e.g. when the temperature of the soda-water solution, its flow or its level in the reservoir are out of the allowable ranges.
- Interface with the building:
    - The design shall be optimized to ensure equipment recovery after faults and/or malfunctioning due to seismic actions in line with the nominal seismic hazard of the geographic zone of installation (type 2B, peak ground acceleration of [0.15–0.20] g, 10% probability of exceedance in 50 years according to the DGR no. 387/2009) without damage. The seismic resistance refers to the soda unit integrity, i.e., operating continuity during a seismic action is not required. If chemical or mechanical anchorages are required to secure the equipment, the Contractor shall provide them.

7.14 Voltage probe

Main line (through-line) interface:

- Type of flange connectors: swivel type;
- Interface type: female;

Probe interface: one, type N, 50 Ω, female connector (IEC 61169-16);

VSWR of through-line ports ≤ 1.04;

Insertion loss ≤ 0.05 dB;

Voltage ratio: 1 : 5000.

The HPTB requirements of section 6.5 do not apply to the probe line.

7.15 Short-circuit flange

The short-circuit flange terminates the radiofrequency port with a short circuit. It will be used to carry out the high voltage test of the RF components installed on the HPTB.

Type of flange connector: one-piece;

Interface type: male;

Maximum current: 1 kA.

7.16 3 dB hybrid coupler

Type of flange connectors: swivel type;

Interface type: female;

Coupling: (3.01 ±0.35) dB;

Phase shift between the coupled and through ports: 90° ±3°;

Insertion loss (without coupling loss) ≤ 0.06 dB;

Isolation between coupled and through ports ≥ 27 dB;

VSWR ≤ 1.1 at the input of each port when other ports are matched;

Maximum power rating on one input/output (divider/combiner): 2.5 MW.

7.17 Two-way switch

A two-way switch is meant here as a kind of motorized double-pole double-through (DPDT) RF switch with 4 ports. Different ports can be internally paired through the electrical motor.

Type of flange connectors: swivel type;

Interface type: male;

VSWR ≤ 1.06 at the input of each port with other ports matched;

Insertion loss < 0.06 dB;

Switching time < 30 s;

Operation: motorized via electrical drive;

Motor electrical interface: 230 V AC ±10%, 50 Hz ±5%;

The switch shall be remotely controlled by the DTT control system; the control interface will be agreed between Enea and the Contractor during the preparation of the TDR.

8 Guidelines for control interfaces

This section provides some information about the interfaces of the DTT Control and Data Acquisition System (CODAS), addressing slow control, fast data acquisition and control, timing and machine protection. It is not intended to represent a full interface specification, but to provide guidelines the Contractor can comply with, i.e., the use of different interfaces from those described hereinafter is acceptable too. If relevant to the execution of the contract, Enea will provide details regarding the implementation of next interfaces as well as the naming convention of signals and variables during the preparation of the TDR.

Slow interfaces involve the communication between the DTT CODAS and the local control units with a refresh rate up to 100 Hz (also possibly not synchronous), such as communication with local PLCs. Such communication will be performed via Ethernet by means of a set of OPC-UA Process Variables (PVs).

Slow interfaces will include the change of segregation states. At least two segregation states will be implemented in the DTT CODAS and most of its units: *local* and *remote*. A third condition where no interface is fully active will be also foreseen. From this condition the full control of the unit can be requested from either local or remote interface. When the control is taken from an interface, the segregation state cannot be changed until that interface releases the control. Specifically:

- *Released*: the unit is not controlled by anybody but it accepts requests to change its segregation state to either local or remote. Commands sent from the DTT CODAS can only enable the remote mode. Commands sent from the local HMI can only enable the local mode.
- *Local*: the unit is controlled by commands issued by the local HMI. Should more local panels or local screens be available to issue commands, the arbitration between them will be handled by the Contractor software logic. Remote commands from the DTT CODAS are ignored, but the remote monitoring of the unit status and parameters is allowed.
- *Remote*: the unit is controlled by commands issued by the DTT CODAS. Commands from the local HMIs are ignored.

When the local control unit is powered on (e.g. during its bootstrap), it will enter the local segregation state or the released condition. In no case the local control unit will enter directly the remote segregation state when powered up. At the restart or in case of a communication loss with the DTT CODAS, the local control unit will set the configuration data of the local mode and update the information on the DTT CODAS.

For the units of the present supply, the Contractor can alternatively opt for a hardware configuration of the local/remote segregation state, based on a clearly visible key switch on the front panel of the unit.

All HMIs shall be in English. If graphic pages are conceived to control a unit, they shall be agreed between Enea and the Contractor during the preparation of the TDR as regards the specifications for standard functions (start, stop, reset, etc.), visualization (colour convention, browsing, graphic layout, alarms, etc.), diagnostic messages, user privilege policies, etc.

Fast interfaces involve the communication between the DTT CODAS and the local control units with a refresh rate above 100 Hz. Such communication will not be carried out via OPC-UA PVs, but, depending on the signal features, possible methods will be:

- UDP Ethernet communication, for output signals requiring a sampling speed up to 5 kHz. Specific data format and header will be agreed.
- TCP/IP Ethernet communication, for bulk data acquisition with high sampling speed and/or a large number of channels.
- Digital and analog links can be agreed, preferably with galvanic insulation and a range of ±10 V in the case of analog signals.

As far as time synchronization is concerned, for the slow interfaces the Network Time Protocol (NTP) normally active on PLCs is enough. More precise time synchronization is required for signals with higher bandwidth. DTT will adopt the IEEE1588 (Precision Time Protocol or PTP) synchronization among different units. Otherwise DTT CODAS will provide external synchronization signals such as clock and triggers. The preferred communication for clock and triggers is fibre optics.

The interface with the Machine Protection System (MPS) of DTT will be used to handle fast recovery actions. A unit is supposed to handle all internal faults without involvement of MPS by detecting internal fault and alarm conditions and activating the necessary protective actions. MPS will be involved to handle fault conditions that affect other DTT units. MPS is also responsible for enabling units during startup.

A solution for the functions of the equipment protection could consist in transmitting frequency-coded binary signals with fail-safe logic over optical fibres. In general, solutions that are as simple as possible and easy to be integrated, e.g., through dry contacts with fail-safe logic, will be preferred.

The most important protections will have a back-up detection system, e.g. a secondary protection chain relying on different transducers, acting if the primary protection is not triggered. A safety integrity level SIL 3 is necessary for functions relating to personnel safety . The protections (interlocks) will be of latched type, i.e., a reset command shall be given to the unit after an interlock event to bring it back to its normal states. As to alarms, no reset is required: the alarms will disappear after being acknowledged (“Ack” command) via local HMI or remotely, if the alarm cause is no longer present.

9 Further provisions

9.1 Component identification

Except for interchangeable assembling hardware such as O-rings, nuts, screws, washers, etc. that do not need to be tagged, each component shall be identified with a suitable tag consistent with the technical documents. The components with considerable size shall be also identified by means of external metallic or plastic plates. For some components such as flanged and unflanged straight lines and elbows, the tag can consist in name, manufacturer's symbol, and identification code given to that component by the manufacturer. For other components such as variable stub and phase shifter tag numbering and labelling shall comply with the procedure QMS-PRO-20000 [4] and be submitted to Enea for approval. Enea will provide the Contractor with clear directions regarding the component identification during the preparation of the TDR.

Component identification does not relieve the Contractor from the implementation of marking prescriptions coming from international standards. Directional couplers shall be also provided with a label indicating the values of the coupling, of the directivity and the direction of the incident power.

9.2 Delivery site

The Contractor shall deliver the RF components at the DTT site. Should the site be unavailable for unpredictable reasons, Enea will communicate an alternative location for delivery to the Contractor and will bear additional expenses relating to the new site.

9.3 Storage, packing and transportation

The Contractor shall ensure that all components to be dispatched to the DTT site are properly stored until their delivery to destination so as to avoid possible damage, deterioration or contact with contaminant agents. Upon Enea request, the Contractor shall provide "free warehousing" for two months. In the case of longer warehouse storages, Enea will pay to the Contractor a daily allowance for the period exceeding two months. The cost and duration of the warehouse storage will be agreed between Enea and the Contractor during the execution of the contract only if necessary.

The Contractor shall organize and deal with the transportation of the contract goods to the DTT site. The Contractor shall comply with the applicable provisions of the procedure PRC-PRO-07000 [5]. Should any conflict arise between the PRC-PRO-07000 [5] and the provision of the present section, the latter prevails.

The packing shall provide adequate mechanical and environmental resistance for the adopted transport means together with component protection from dust and transport environment. It shall ensure that the characteristics of the components are not altered during transport. The packing shall be made and managed in order to avoid and prevent component contact with any contaminant agent. Clamp screws, coupling elements and O-rings must be supplied inside protective envelopes in plastic material. Each component shall be supplied with protective covers in plastic material applied to each termination. In addition, the use of wooden packing for the heavier components is suggested.

The packing shall provide adequate attachments for loading and unloading by crane or equivalent lifting/moving tools and for its stable fixation on trucks and ships. Packing material shall be in agreement with UE rules and with international sanitary rules. For instance, if wooden packing is used, phytosanitary certificates shall be provided where prescribed by regulations.

The packing shall ensure a clear identification outside it as well as traceability of transported components. The indication of the content must be shown on the outside of the packaging. In any case the Contractor shall take any possible precaution to avoid damages and consequent delays in the supply. For example, the Contractor shall include stress sensor/shock recorder or other provision in each package to allow for an effective and easy monitoring that the package itself and anything included is substantially sound. The Contractor shall bear all costs relating to packing, shipment, possible custom clearance, insurance, necessary documentation and procedures as well as possible damages during packing, transportation and delivery. The shipment shall be DDP (Incoterms). Enea assumes the absence of oversize loads in road transport; the Contractor shall inform Enea in the case of oversize loads.

The Contractor shall allow Enea to inspect components packing to check that packages to be dispatched are adequate and intact. The Contractor will be allowed to perform similar inspections once the packages are delivered to the DTT site. An official note documenting the list of checked packages and possible issues shall be prepared after each inspection. Heavy goods shall be fitted with structures, supports, and devices that facilitate their handling. For example, rods or feet may be needed to move some equipment with elevation platforms or pallet trucks. Enea will provide no tools for unloading operations.

9.4 Supervision and consulting

When requested and not necessarily continuously, the Contractor shall provide on-site supervision regarding assembly, installation, and site acceptance tests for up to 20 person-days (meant as working days), starting from the delivery date of the batch #1 up to the end of the contract.

During the whole execution of the contract, upon Enea request, the Contractor shall provide technical consulting in particular with respect to:

- Advices concerning component assembly, installation, layout definition of the HPTB.
- Advices about cutting, welding, flanging, and assembling of unflanged straight lines.
- Support to interface the component control unit with the DTT CODAS.
- Testing and conditioning of RF components at the DTT site.

The competences requested for the technical consulting include at least: radiofrequency, cooling, mechanics, instrumentation and control systems.

9.5 Warranty and equipment lifetime

A 2-year warranty shall cover all components against defects in design and construction from the approval of the Acceptance Data Package. The warranty is limited to the direct costs of repair and component renovation. Any other warranty is excluded.

Except for wear-and-tear items, all components shall have a design life of at least 25 years.

9.6 Electric and electronic equipment

Electric and electronic equipment shall be certified in accordance with applicable directives:

- Directive 2011/65/EU (restriction of the use of certain hazardous substances in electrical and electronic equipment).
- Directive 2014/35/EU (low voltage).
- Directive 2014/30/EU (electromagnetic compatibility).

The equipment shall comply with the requirements provided for in the relevant regulations CEI / CENELEC and in the technical standards ISO/IEC (ISO International Organization for Standardization, IEC International Electrotechnical Commission) and IEEE (Institute of Electrical and Electronics Engineering).

The equipment shall also follow the direction of section 2 of TEC-SPT-44016 [3]. Should any conflict arise between the TEC-SPT-44016 [3] and the other documentation, the latter prevails. The details of the electrical connections, like wire scheme, earthing system and type of terminals, will be agreed between Enea and the Contractor during the preparation of the TDR.

9.7 CE marking

The Contractor shall determine EC/EU directives and/or regulations requiring CE marking that apply to components/equipment/assemblies in the scope of the contract.

For the components/equipment/assemblies in the scope of the contract, the Contractor/subcontractors shall perform conformity assessment, affix the CE marking and issue EC/EU declaration of conformity where EC/ EU directives and/or regulations that require CE marking apply. The Contractor shall ensure that purchased components/equipment/assemblies comply with EC/EU directives and/or regulations that require CE marking where applicable. This includes verifying CE marking, EC/EU declarations of conformity and operating and maintenance instructions.

The Contractor shall deliver components/equipment/assemblies certified and CE marked at the highest possible integration level, i.e. at the level of independent functional units (assemblies). Equipment/assemblies composed of CE marked components also require conformity assessment and CE marking on equipment/assembly level. Enea does not perform certification/CE marking or integration under national legislation for the components/equipment/assemblies of the present supply, unless otherwise specified in the contract.

The Contractor shall provide the following documents to Enea for review and acceptance:

- A Compliance Report with results of the Contractor assessment regarding applicability of EC/EU directives and/or regulations to the scope of the contract and a CE marking strategy for the complete scope of the contract at the level of independent functional units (assemblies). The Compliance Report shall be included in the TDR. Enea approval of the Compliance Report does not relieve the Contractor from its responsibility regarding the applicability of CE marking.
- EC/EU declarations of conformity and, if applicable, documents issued by Notified Bodies in the course of conformity assessment. These documents shall be included in the ADP.

9.8 Safety requirements

The Contractor is responsible for the implementation of all precautions relating to personnel safety. All components shall be designed, realized and tested in accordance with the safety standards IEC, any other applicable regulation and the good engineering practice. The design and realization of pressure equipment and assemblies shall comply with the directive 2014/68/EU and the corresponding legislative decree no. 26/2016.

Personnel safety shall rely on fail-safe hardware components (mechanical interlocks, grounding switches, shielding, etc.). Key interlocking shall be implemented where useful to prevent improper actions.

9.9 Equipment noise and vibrations

The equipment shall operate without unnecessary vibrations and with the minimum level of audible noise, trying to reduce any hazard and/or inconvenience for the staff. Noise and vibrations shall be measured keeping cabinet doors closed.

The noise level at a distance of 1 m from each equipment shall not exceed the following limits:

- 80 dB(A) during normal operational states,
- 105 dB(A) during emergency states.

For vibrations, the values, normalised for 8-hour exposure, are as follows:

- Arm-hand vibration:
    - Action value: 2.5 m/s2.
    - Exposure limit: 5 m/s2.
- Whole-body vibration
    - Action value: 0.5 m/s2.
    - Exposure limit: 1.15 m/s2.

10 Testing and approval

10.1 General conditions

In the response to the call for tender, the Bidder shall include a preliminary Test Plan describing all tests to be performed on the contract goods. Such plan shall include at least all tests listed in the following, abiding by all directions given hereinafter and all prescriptions of applicable standards.

The tests and procedures of the preliminary Test Plan will not be exclusive for the selected Contractor: Enea and the Contractor can agree additional tests during the preparation of the TDR. The final list of tests will be reported in the Final Test Plan to be approved at the end of the preparation of the TDR.

Three types of test are considered in the present supply:

1. Intermedial tests: the Contractor shall perform all further tests necessary for the development of RF components to ensure their compliance with the specifications.
2. Factory acceptance test (FAT): official tests at the Contractor/subcontractor premises.
3. Site acceptance test (SAT): official tests at the installation site.

The Contractor shall allow Enea to attend the three types of test. To this aim the Contractor shall inform Enea of the place and time of the tests in accordance with the MS. For each performed test, regardless of Enea attendance, the Contractor shall submit a Test Report to Enea for approval in accordance with the MS.

The tests can be performed on single RF components and assemblies. Testing conditions shall be as close as possible to the operational ones, but taking into account possible worsening in some parameters (for instance limit ambient temperature, maximum temperature of cooling water, noisy environment, etc.). All measurements shall be performed after the warm up time of the equipment and of the device under test.

Testing procedures shall specify which component shall undergo:

- Type test, to be performed on a typical component, proving that it effectively represents other items of the same kind. Should any doubt on its representativeness arises, each item shall be tested.
- Routine test, to be performed on every components.

The Contractor can ask Enea to be exempted from some tests if it can provide detailed documentation proving that equivalent or more stringent tests have been performed on an identical component. The exemption needs Enea approval.

The Contractor is responsible for all material, instrumentation, tools, auxiliary services, personnel and safety actions required for testing activities. In particular, the Contractor shall demonstrate that all adopted instrumentation is calibrated in accordance with its procedures and applicable regulations (see also section 11.4).

10.2 Preliminary checks

For both FAT and SAT, a general visual inspection of all RF components shall be carried out, aimed at checking aspects such as dimensions, connectors, earthing connections (where applicable), etc.

10.3 Minimal set of Factory Acceptance Test (FAT)

The RF components shall undergo a detailed testing at the Contractor/subcontractors premises. They shall be characterized under main aspects like electrical, mechanical and RF, checking the compliance with design specification and tolerances. The tests should be preferably carried out in the most critical conditions in terms of ambient temperature, input power, mismatching, etc. If the emulation of such conditions is unfeasible, a verification through calculations shall be provided.

Where applicable and feasible, the following tests, either type or routine depending on what agreed in the Test Plan, are required on components:

- Insulation tests between inner and outer conductors.
- RF signal tests, i.e., measurements of S-parameters through low-level RF signals.
- Check of full stroke, step, precision, and travelling speed of moving parts.
- Verification of safety measures (emergency button, key interlocking, etc.).
- Emulation of all faults and their protection (interlocks).
- Management of internal and external alarms.
- Switch between segregation states.

Depending on the measurement, RF signal tests can be done either on single components or on a cascade of components. If communication interfaces with the DTT CODAS are implemented and Enea can provide an emulator of the DTT CODAS, such interfaces will be tested too.

The following tests are required on a section of line with a length of at least 10 meters containing the most significant components:

- Pressure thightness: test for one hour at the maximum pressurization.
- RF signal tests, i.e., measurements of S-parameters through low-level RF signals.

10.4 Minimal set of Site Acceptance Test (SAT)

Enea will repeat most factory tests at the DTT site. Signal tests will be carried out randomly on a few components. Where applicable, the communication with the DTT CODAS will be tested.

Then the components will be installed, setting up the high-power test bed, and operated at high power. The RF operations will be carried out in the conditions referred to in the HPTB requirements of section 6.5, or in the closest possible conditions allowed by RF power availability of the DTT site. During such operations, Enea will test:

- component compliance with the HPTB requirements of section 6.5;
- component heating via direct and indirect temperature measurements in the most critical parts;
- reliability;
- RF shielding and radiated field.

11 Technical documents

The contents of the main technical deliverables are given in the following.

11.1 Technical Proposal

The Technical Proposal, subjected to evaluation for the selection of the Contractor, shall specify:

- Technical characteristics of each RF component, including approximate weight and dimensions, materials, geometry of coupling elements and the following component-specific features:
    - bi-directional couplers:
        - forward and the reflected coupling variation in the (60-90) MHz frequency range;
    - phase shifter and variable stub:
        - maximum travelling speed,
        - electrical characteristics;
    - local control unit:

- electrical characteristics;
- dummy loads:
  - type of connections,
  - process data for the soda-water solution;
- soda unit:
  - capacity (volume) of the tank,
  - duty cycle as a function of the RF power and of the pulse duration,
  - operational range of the soda-water solution in terms of concentration and temperature.
  - preliminary hydraulic diagram for the dummy loads of the present supply with their process data,
  - electrical scheme and characteristics,
  - description of the upgrade capabilities of the soda unit with reference to the configurations of dummy loads described in section 7.13,
- wideband 3 dB hybrid coupler:
  - definition of the output/input ports and phasing between them when the RF component is used as divider and combiner;
- Maximum temperature on the inner and outer conductor of a straight line in the conditions given in section 6.5;
- Thermal expansion per meter for the inner and outer conductor of a straight line in the conditions given in section 6.5;
- Description of all interfaces, including air cooling requirements, if any;
- Description of Local/Remote operations.

11.2 Technical Design Report

The Technical Design Report (TDR), detailing the components to be realized, shall include at least:

- CAD models of the external shape of each component.
- Detailed drawings and schemes of each components with dimensions and weight.
- Electrical characteristics (where applicable) such as inrush current, power absorption, power factor, and total harmonic distortion.
- Features, performances, tolerances, and operational limits of each component.
- User manuals, including for example the load to be applied to the tightening bolts, and all information required to remotely interface with components (when such feature is foreseen) and to safely operate them, including
  - minimum time interval between two RF pulses for a set of RF operating conditions (input RF power, VSWR, phase of the reflection coefficient, frequency and pulse duration) to be agreed during the preparation of the TDR;
  - acceptable thermal expansion.
- Detailed design description of the local control units and electrical drives, with diagrams showing the main functional blocks and signal flows, the list of exchanged signals with their properties, a table of fault conditions, which lists fault events, their detection, corresponding protections, and alarms. Faults involving fire or explosion hazards shall be clearly identified and described.
- Description of the acceptance tests and of the procedure to carry out all tests.
- Packing instructions and/or special care to be taken for component transportation.
- Compliance Report as per section 9.7.

11.3 Test Plan

The Test Plan shall include:

- List of tests to be performed whether in factory or somewhere else.
- Detailed description of the procedures to follow.
- Acceptance criteria.
- Required instrumentation and its minimum technical requirements.
- Possible applicable standards.
- Time schedule of each test; this schedule can be better defined later on.
- Testing place, which can be better defined later on.

The list of tests shall include at least those given in section 10.

11.4 Test Report

Each Test Report shall include all useful information to attest the test outcome, e.g. applied procedures, performed measurements, possible post-processing, relevant photos, and calibration certificates. In particular, each Test Report shall clearly describe all useful data to assess the compliance of the component under test with the TS, the acceptance criteria given in the Test Plan, and other requirements.

The Test Reports shall clearly specify adopted instrumentation and its calibration status. All relevant information concerning the proper use of instrumentation shall be easily available from the Test Reports or the references cited therein. Such information can include for example calibration certificates or reports, warranty period, metrological proof, operational range, accuracy, and format of output data.

11.5 User Manual

The Contractor shall draw up a User Manual that contains, where applicable for the given item,

- Instructions for handling, installation and connection of the components, including indications of the center of gravity of heavy components and recommendations for their lifting.
- Any instruction to follow or special care to take for their disassembling, packing and transportation.
- Any useful instruction for startup and commissioning.
- Any necessary information to arrange the reception, storing, and identification of contract goods.
- Operation procedures.
- Maintenance instructions.
- Calibration and adjustment procedures.
- Guide to perform check and troubleshooting operations in case of faults or alarms. The guide shall include comprehensive information for each electronic board, sufficient to understand its function and to perform necessary measurements, a list of test points, and the expected value and/or waveform at each test point in normal conditions.
- A Safety Manual that contains safety documentation. The Safety Manual shall also describes the operational limits of the components, prohibited operations, and safe environmental conditions.

11.6 Acceptance Data Package

The Acceptance Data Package (ADP) shall include:

- All documents that have been issued during the contract execution with proper updates.
- Final Quality Plan.
- Test Plan, Test Report, and test certificates.

- Collection of non-conformities and corresponding deviations or implemented modifications.
- Collection of Progress Report and minutes of progress meetings.
- List of recommended spare parts with useful information for their procurement.
- As-built drawings of the components.
- Electrical, electronic, and functional schematics of all subsystems.
- Wiring diagrams, including connections and interconnections.
- Interlock description.
- Description of the control system including the information for remote control.
- Source code of any software used in PLCs, microcontrollers, or other programmable devices, complete with documentation, software tools and licenses to modify it.
- Printout (in electronic format) of graphical pages.
- Printout (in electronic format) of software configurations.
- List of critical components.
- List of all supplied material, including spare parts.
- Collection of the technical data sheets of all used materials.
- Certificates of standard components, where applicable.
- CE marking.
- Technical documentation relating to hazard identification, risk evaluation and risk mitigation of the component/equipment/assembly.
- List of vendors of raw materials and standard components.
- Vendor qualification.
- All documents demonstrating the traceability of contract goods and their compliance with the TS.
- Summary of activities.
- Useful photos or movies (if any).