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Revision History

Revision	Date Released	Description of Change
R0	12/12/2019	Original Release.

Table of Contents

1 Overview

1.1 Scope

This specification defines the technical fabrication requirements for the fundamental power couplers (FPCs) that will be used to couple rf power into the 1.3 GHz cavities in the LCLS-II continuous wave superconducting linac. The design follows from that of the DESY TTF3-style couplers, which operate at a lower average power. Two modifications to this design were made for the LCLS-II application: shortening the antenna length to increase the cavity Qext range and thickening the copper plating on the warm section inner conductor to reduce its temperature rise.

This document describes the material requirements, parts fabrication methods, cleaning procedures, assembly steps, bake-out process and packaging requirements to produce 'deliverable' couplers.

It is to be used in conjunction with the SLAC National Accelerator Laboratory (SLAC) coupler model. This model is provided as reference except where specific requirements or dimensions are required per this specification.

Final configuration includes two couplers assembled onto a stand for vacuum bake-out processing. After completion of bake-out, couplers are to be disassembled and packaged for shipment per and Section 9.

Also included are quality assurance requirements, recommended procedures and lessons learned from previous coupler assembly work.

This document does not address the fabrication and deliverables for the wave-guide assembly that attaches to the input end of the couplers. These parts are not required to achieve the vacuum integrity of the couplers. They are specified in a separate engineering design document.

1.2 Technical Requirements

The subcontractor shall be responsible to provide FPCs that conform to all requirements of the Subcontract and the Incorporated Documents or references, without exception, unless authorized by SLAC. The requirements shall extend through all tiers of lower-tier subcontractors as applicable. The Subcontractor shall furnish all labor, facility, material, supplies, documents, project management, and any other support services, unless otherwise specified. No deviation is permitted without prior written approval from SLAC.

2 Definitions

The following definitions apply throughout this specification document.

Term	Definition
AISI	The American Iron and Steel Institute. AISI is an association responsible for setting standards and creating numbering systems for various ferrous metals
AMU	Atomic mass units
ASM	ASM International is a professional organization for materials scientists and engineers working with metals. ASM provides several information resources, including the ASM Handbooks, a series of reference books that provide data on various types of metals. These handbooks are recognized as a standard reference in the field of materials science.

Term	Definition
ASTM	ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM), is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.
ATA	Air Transportation Association of America
EB	Electron beam welding is a fusion welding process in which a beam of high-velocity electrons is applied to two materials to be joined. The work pieces melt and flow together as the kinetic energy of the electrons is transformed into heat upon impact. EBW is often performed under vacuum conditions to prevent dissipation of the electron beam.
EFS	Electropolish Finish Standard
OFE	Oxygen free electronic grade copper
RGA	Residual Gas Analyzer
TIG	Gas tungsten arc welding (GTAW), also known as tungsten inert gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas (argon or helium), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it. A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as a plasma.
UNS	Unified numbering system is an alloy designation system widely accepted in North America. It consists of a prefix letter and five digits designating a material composition.
UHV	Ultra high vacuum is the vacuum regime characterized by pressures lower than 10−9 torr.

3 References

The following references apply throughout this specification document.

Associated Document(s) Reference Number	Document Title
DESY Tech. Spec. DESY 06.04.2006	High Power Input Coupler TTF-III
DESY Tech. Spec. No. Vacuum 005/2008	Guidelines for UHV-Components at DESY
LCLS-II-4.5-EN-0270	FPC Ultra Sonic Cleaning Process
LCLS-II-4.5-EN-0271	TTF3 Coupler Assembly Process
LCLS-II-1.1-ES-0476	LCLSII Particle Free Engineering Specification

4 Material Specification

This section provides specifications for the materials used to fabricate the couplers.

4.1 Stainless Steel

4.1.1 Coupler Components

All coupler stainless steel parts must be made using 316L austenitic steel UNS alloy S31603 per AISI 316L. All CF flanges shall be made using 316LN austenitic steel UNS alloy S31653 per AISI 316LN. In addition, stainless steel must meet appropriate ASTM specification for forms and shapes applicable to the individual parts, and must meet any additional requirements indicated in the drawings. All stainless steel parts, except the bellows are to be hydrogen degassed at 950°C for 2 hours in a vacuum furnace. (Note: Weld Group Cold requires brazing of the bellows assembly). The vacuum level shall be better than $1x10^{-6}$ Torr at the start of the heat cycle and not exceed mid 10^{-5} Torr at 950° C.

4.1.2 Fasteners

All fasteners are to be made from Nitronic 60 UNS alloy 21800 per ASM 5848. All fasteners 4mm or greater must be rolled and not cut. All fasteners must be electro-polished to EFS-3 standard to lower particle generation during assembly. All fasteners will be stamped denoting that hardware is Nitronic 60. All washers shall be made from 316 stainless steel. Nuts shall be made of silicone bronze UNS C65500, H06 except for the 3/8-24 nuts used on the Coupler Processing Cavity Flange Assembly (CPC) shall be Nitronic 60. Approval of fasteners types (i.e. hex head bolt, Allen head bolt, and nut plate) will be done prior to first shipment of production FPC to confirm proper fastener configuration.

4.1.3 Magnetic Permeability

The magnetic permeability of all stainless steel components must be less than 1.06 Mu measured per ASTM A342. This limit must be met after all forming, welding, brazing or other manufacturing processes.

4.1.4 Material Certification

Material certifications, including actual physical and chemical test reports traceable to the mill heat lot number must be included in the coupler documentation package for all stainless steel materials.

4.2 Copper

Parts made from wrought copper forms (bar, plate, sheet, tube) must be OFE copper UNS alloy C10100 per ASTM F68 metallographic Class I or II. Acceptable mill source for this material are limited to Hitachi, Mitsubishi or Luvata.

Material certifications, including actual physical and chemical test reports traceable to the mill heat lot number, and which specially note conformance to ASTM F68 Class I or II, must be included in the coupler documentation package for all copper materials.

Copper plating material requirements are covered in Section 5.3.

4.3 Bellows

Bellows are to be manufactured from 316L stainless steel. No nicks, dents or other deformations in bellows surface are acceptable. Bellows are as follows: Outer Warm Bellows wall thickness is.25mm +/-.05mm with 9 outer convolutions over the 42.75 mm dimension with a 5 mm pitch; Inner Warm Bellows wall thickness is .15mm +/- .025mm with 14 outer convolutions over the 35.1 mm dimension with a 2.6 mm pitch; Push Rod Bellows wall thickness is .1mm +/-.025mm with 18 outer convolutions over the 33.35 mm dimension with a 1.9 mm pitch; and Cold External Bellows wall thickness of .2mm +/-.025mm with 10 outer convolutions over the 38.2 mm dimensions with a 4 mm pitch.
Fatigue testing of Cold External Bellows is required, a minimum of one sample. Bellows are to be plated and welded/brazed into test assembly simulating the actual assembly. The bellows are cycled at the free length (axial displacement = 0) with a lateral (perpendicular to bellows axis) amplitude of +/-3.0mm. The cycles to failure must exceed the number predicted by EJMA (~15,000 cycles) with a safety factor of 2.0.

4.4 Ceramics

All ceramic components are to be made from high purity alumina (Al_2O_3) meeting the following requirements discussed in the sections below. All ceramic windows will be degased at 800°C for a minimum of 1 hour in a clean oven under vacuum before TiN coating.

4.4.1 Composition

The material must be 97.6% pure Al_2O_3, dielectric constant $\varepsilon = 9.0$; dissipation factor $\tan \delta = 3X10^{-4}$ at room temperature for 1.3GHz.

One chemical analysis must be supplied for each batch of isopressed material delivered. Results shall specify the alumina and other material contents to the minimum detectable limits of the instrument, which must be better than 20 ppm.

4.4.2 Density

Ceramic bodies purchased to this specification must be isostatically pressed to provide high density and uniformity. The density, expressed in grams per cubic centimeter must be measured on a sample from each firing lot of each batch of isopressed material. Density may be determined on a weight difference apparatus suitable for making measurements in water and air. The weight and dimensions of the specimen may also be used as a basis for calculating the density. Results shall specify the density measurements to two decimal places (i.e. 3.76). Densities must be in the range of 3.71 to 3.79 g/cm3.

4.4.3 Voids

Bodies must be free of surface voids and free of interior porosity larger than 100 microns in size. Localized concentrations of such defects may not exceed the 100 micron limit when combined over a 1000 micron region.

4.4.4 Grain Size

The maximum, minimum and average grain size, expressed in microns, must be determined on a sample from each firing lot of each batch of isopressed material. Grain size may be determined by analysis of the fired material with a scanning electron microscope. Average grain size must be no larger than 25 microns.

4.4.5 Gas Impenetrability

The impenetrability to gas must be tested using a helium mass spectrometer leak detector with a minimum sensitivity of $2x10^{-10}$ mbar-l/sec, Helium. The vacuum volumes must not have any detectable helium at this sensitivity. The vendor must specify that all supplied parts meet this requirement at final assembly as specified in section 5.6.

4.4.6 Metallization

Metallization zone must not extend beyond the groove edge as dimensional specified per the drawings.

4.4.6.1 Molybdenum-Manganese Layer

The molybdenum-manganese layer in the braze area must be uniform and the thickness must be between .0008 and .0015 inches after firing.

4.4.6.2 Nickel Layer

The moly-manganese layer is to be coated with a uniform layer of nickel, between .00010 to .00025 inches thick if sulfamate nickel plating is used, and between .0001 to .0004 inches thick if nickel oxide paint is used. After coating or plating, the nickel must be sintered in wet hydrogen or other appropriate atmosphere at 800-850 °C. Blisters, peeling, surface voids, cracks, and other defects are not acceptable.

4.4.6.3 Strength

A pull or peel test must be performed on a sample from the ceramic and metallization firing lot. The test should quantify the strength of the metallization. If appropriate measurement equipment is not available, an un-instrumented test may be conducted. The minimum acceptance standard is that the joint must not fail between metallization layers. A production lot must share all key manufacturing processes including ceramic batch, pressing, firing, metalizing, sintering, plating, and firing.

4.4.7 Surface Finish

The faces shall be ground to a surface finish between 25 and 63 micro-inch rms.

4.4.8 Cleanliness and Quality Control

Windows shall be carefully cleaned and be free of all contaminates. Cracks, chips, pits, pocks and porosity are not allowed. Foreign particles, contaminants or inclusions visible to the unaided eye are not acceptable.

Windows must be 100% visually inspected on both faces at 30X magnification using appropriate illumination. A fiber optic light source is recommended. Inclusions visible at this 30X magnification which are identifiable as metallic are not acceptable. Windows should be free of adherent foreign particles, contaminants and inclusions. The maximum total allowable when inspected at 30X magnification are ten per face.

4.4.9 Test Reports:

The vendor shall supply test reports which are traceable to the ceramic/metallizing/firing batch/lot numbers as required by this specification, including:

Chemical Analysis

Density

Grain Size

Gas Impenetrability

Metallization Test and Inspection

5 Manufacturing Process Specification

This section provides specifications for the manufacturing processes used to fabricate the couplers.

5.1 Welding

5.1.1 Allowed Welding Processes

The welding processes between stainless steel parts will be only of the TIG and EB type. The last assembly welds between copper collars will be of the EB type. Process to account for weld shrinkage to achieve final dimensions.

5.1.2 Welding Overview

All parts and associated tooling must be cleaned to UHV cleanliness standards prior to welding and welding must take place in a clean industrial environment. UHV standards must be followed after initial cleaning, during handling and welding of parts. All welds must be full (100%) penetration. Welds must be made from the vacuum side, whenever possible. When exterior welding is required protect the interior surface from weld spatter. Use of copper ring to cool the interior surface and prevent adhesion of molten metal on the vacuum surface is recommended. Use an inert gas, such as Argon to avoid corrosion of the surfaces.

Inspect all welds and remove all spikes, points and weld spatter on either side of the weld. Weld surfaces may be cleaned only with wire brushes appropriate to each material in order not to leave any residues harmful to UHV. The use of sanding discs, grinding wheel or abrasives is prohibited.

5.1.3 Welding by EB

The ceramics must be protected by removable sheets of zirconium or tantalum (or other approved material) during the EB welding of the final assembly. Penetration must be a minimum 85% and the weld surface must be a smooth as possible. Before each welding, remove any loose dust or particulates with dry nitrogen.

5.1.4 Vendor Validation of Welding Process

The contractor must perform validation tests for each type of welding used in the manufacturing of the couplers.

For each type of welding joint, the contractor will establish an operational method (material, tools, chemicals, procedures, qualified personnel) and will perform two similar welding tests for validation; these two samples will be subjected to mechanical, metallurgic and imperviousness analysis.

Re-validation is required for any process changes and must be approved by SLAC.

5.2 Brazing

5.2.1 Brazing Processes

All parts must be degreased and cleaned for UHV prior to brazing. All brazing must be performed in vacuum furnace. The vacuum level shall be better than $1x10^{-6}$ Torr at the start of the heat cycle and not exceed mid 10^{-5} Torr at brazing temperature. Recommended alloys for the copper to stainless steel brazes are CuAu with braze temperature of 1020°C (35Au65Cu) or 1040°C (50Au50Cu). For the metalized ceramic to copper brazes the recommended alloy is CuAg with braze temperature of 780°C. The outgassing process (Section 4.1.1) for the stainless steel parts may be included in the brazing thermal cycle.

Ensure protection of the inner and outer surfaces of the ceramic during brazing to avoid all contamination by metal vapors: for this, the ceramic will be inserted between two other concentric ceramics which will be removed after brazing.

All parts and associated tooling must be cleaned to UHV cleanliness standards prior to brazing and assembly must take place in a clean industrial area. Before each brazing, any dust must be removed with dry nitrogen.

Inspect all braze joints to ensure joint has uniform fill without excessive braze material and no evidence of porosity or spikes.

5.2.2 Vendor Validation of Brazing Process

The contractor will have to perform preliminary validation tests for each type of brazing used for the manufacturing of the couplers.

For each braze joint: the contractor will establish an operational method (material, tools, chemicals, procedures, qualified personnel) and will perform 3 similar brazing tests for validation; these 3 samples will be subjected to mechanical, metallurgic and imperviousness analysis.

Re-validation is required for any process changes and must be approved by SLAC.

5.3 Copper Plating

5.3.1 Pre-Plating Cleanliness

All metal parts must be sufficiently cleaned prior to electroplating. ASTM B322 is recommended as a baseline for cleaning metals prior to electroplating. Cleaning processes include solvent cleaning, hot alkaline detergent cleaning, electro-cleaning, and acid treatment, etc. A waterbreak test, in which the surface is thoroughly rinsed and held vertical, will be performed to validate that each part is thoroughly cleaned prior to electroplating. Hydrophobic contaminants such as oils cause the water to bead and break up, allowing the water to drain rapidly. Acceptably clean metal surfaces are hydrophilic and will retain an unbroken sheet of water that does not bead up or drain off. Surfactants such as soap reduce the sensitivity of the test and must be thoroughly rinsed off prior to testing.

5.3.2 Plating Process

Copper plate areas specified using a cyanide generic process with periodic reversal. Plating shop lab reports documentation must be provided for plating tested at the beginning of qualification and production runs and when any of the chemical baths for the copper plating process have been fully replaced. The tables below are example reports. De-ionized water resistivity testing for 1MΩ minimum must be performed and recorded prior to plating.

All parts that have been copper plated must be stored under nitrogen or in vacuum in order to minimize oxidization of the copper.

Lab Reports for impurities

Material	***Date of test***	***Findings summary of impurities (%)***	***Comments***
Nickel Strike			
Copper Strike			
Copper Plating			

Lab Reports

Material (oz/gal)	***Date of test***	***Limits: min & max***	***Comments***
Free Cyanide			
Total Copper			
Potassium hydroxide			
Rochelle Salt			

5.3.3 Plating Thickness

For the Inner Conductor Warm Assembly, the thickness of the copper plating will be 150µm with a tolerance of ± 30µm. All other parts that are to be copper plated will be 10µm with a tolerance of ± 5µm as noted in the drawings.

SLAC is to be provided two plating samples at beginning of qualification and production runs and when any of the chemical baths for the copper plating process have been fully replaced. One sample will be a 150µm copper plating on the exterior of Ø31.8 Bellows welded to Tube Insert and one sample will be 10µm copper plating on interior of Ø82 Bellows Assembly.

5.3.4 Plating Quality

Plating needs to be of the highest quality in order remain intact (e.g., no delaminating or flaking) at temperatures that range from 4 ºK to 450 ºK. The copper plating shall be smooth, fine grained, adherent, free from blisters, pits, scale, nodules and other defects that can affect the coupler rf performance. There needs to be smooth transition between the plated and non-plated regions. All knife-edges need to be free of plating.

5.3.5 Plating Adhesion

The following tests are required to check the adhesion between the copper plating and base material. Sample testing to validate the copper adhesion is required at the beginning of qualification and production runs and when any of the chemical baths for the copper plating process have been fully replaced. In addition, all copper plated parts must undergo a vacuum bake-out test.

Sample testing:

<u>Bend test per ASTM B571 of one test coupon:</u> Bend the specimen with a vice clamp or other appropriate equipment. After bending the test piece to greater than 90 degrees, visually inspect with microscope (10X magnification). No evidence of swelling and peeling of plating layers provides acceptable bend test.

> <u>Peel test per ASTM B571 on one test coupon:</u> The test piece is fully covered with tape. The tape is then removed in one motion. Visually inspect with microscope (10X magnification). No evidence of any peeling of plated parts, or copper deposit on the tape provides acceptable tape test.
>
> <u>Bellows test on one of each of the plated bellows assemblies:</u> Expand and compress bellows full stroke length 10 times in the cleanroom over white ISO 3 Class 1 Cleanroom Wipes. Inspect wipes under 2X magnification. Any copper flaking noticed is a failure of the bellows adhesion test. Bellows should be cleaned prior to test to avoid false positive.

Vacuum bake-out testing for all copper plated parts:

Copper plated parts must be cleaned for UHV prior to bake. Vacuum bake at 400° C for 2 hours in clean vacuum oven. Bake must be conducted under vacuum while actively pumping the hot zone with a cryogenic or turbo molecular pump. After bake, visually inspect each part for evidence of delamination or flaking. Perform close inspection of masked areas to make sure copper plating is adherent and smooth at edge. Acceptable bake-out test will show no evidence of any blistering or flaking of the copper plating.

5.3.6 Plating Electrical Conductivity (RRR)

A random sampling of four test coupons to validate the RRR is to be done at the beginning of qualification and production runs and when the chemical baths for the copper plating process have been fully replaced. Allowable values are in the 10-100 range. Two of these tested coupons are to be sent to SLAC for verification of RRR.

5.3.7 Plating Surface Roughness

The copper plating is to have a surface roughness of Ra < 1.6µm. Surface roughness may be measured using either contact or non-contact methods. Contact methods (profilometer) involve dragging a measurement stylus across the surface. Non-contact methods include interferometry, confocal microscopy, focus variation, structured light, electrical capacitance, electron microscopy, and photogrammetry. Sampling of surface roughness is to be performed at the beginning of qualification and production runs and when any of the chemical baths for the copper plating process have been fully replaced.

Four surface roughness test coupons each will be randomly generated for both 150µm and 10µm copper plating thickness called out per Section 5.3.3.

Surface roughness test coupons will be supplied to SLAC with the following data:

- Test Coupon Number 1-4 at 150µm and 5-8 at 10µm copper plating thickness (8 coupons total)
- Date of copper plating
- Date of surface roughness testing
- Surface roughness machine make and model and calibration date

5.4 TiN Coating of the Ceramic Windows

Titanium Nitride (TiN) shall be applied to vacuum surfaces of the ceramic windows. Coating is by physical vapor deposition of titanium, in a partial pressure of ammonia or nitrogen to create TiN. Once the TiN coating has been applied the ceramic window must never be subjected to temperatures exceeding 400°C. Care must be exercised while handling ceramic to avoid contamination. TiN coating must be protected by a suitable cover during the final joining operations in order to prevent contamination by metal vapors and damage. A sample of the TiN shipped under nitrogen will be provided to SLAC at the beginning of the qualification run.

5.5 Metrology Inspection Report

Each completed Warm Assembly and Cold Assembly is to be inspected prior to final assembly. A metrology inspection report showing compliance to required acceptance criteria must be generated by the vendor for each coupler Warm Assembly per DSG-000001166 and DSG-000001507 and Cold Assembly per DSG-000000663. Per Section 1.2, no deviation or non-compliance is permitted without prior written approval from SLAC.

5.6 Leak Rate Specifications

All assemblies shall have a total leak rate of less than $2x10^{-10}$ mbar-l/sec He as measured with a helium mass spectrometer with a minimum sensitivity less than $1x10^{-10}$ mbar-l/sec He. This mass spectrometer shall be calibrated and data recorded as the beginning and ending of each work shift. The leak test shall be carried out with internal vacuum of less than $1x10^{-4}$ mbar while the leak check zone is immersed in one atmosphere helium. Vacuum subassemblies will be vacuum leak checked at the appropriate time during the assembly process. The final assemblies must be leak checked without elastomers using CF flanges, copper and aluminum gaskets as specified per the drawings.

Leak detection process must only use pumping systems without hydrocarbons to avoid any contamination of internal surfaces by hydrocarbons. All pumps used for pump down and leak check must be oil free. The use of silicone grease is prohibited.

Documentation specifying no indicated leak or response to helium is required for all final assemblies.

5.7 Parts Labeling

All parts will be labeled using a Laser etching engraver for a permanent, high-quality marks are required. No vibration etching will be done on any part (leaves a rough surface profile and is hard to clean).

6 Final Assembly Specification

This section provides requirements and specifications for the final assembly processes used to fabricate the couplers.

6.1 UHV and Cleaning Process

All components must be cleaned prior to assembly to meet UHV and particle count requirements. UHV components must be hydrocarbon free. The use of sanding discs, grind wheels or abrasives (including bead blasting) is prohibited unless specifically approved by SLAC. Use of molybdenum wool is acceptable. Vendor shall provide specification or process plan for meeting these clean requirements. SLAC Engineering Note: LCLS-II-4.5-EN-0270 Ultra Sonic Cleaning Process and DESY Technical Specification No. Vacuum 005/2008 Guidelines for UHV-Components at DESY are provided for reference.

In a class 100 clean room, two couplers are first ultrasonically cleaned. Then, in a class 10 clean room, they are rinsed, dried and assembled onto a stand for a final leak check prior to bake-out. For reference, the SLAC Engineering Notes and sub-sections below list of some of the SLAC equipment used, and the cleaning, assembly and leak check procedures.

6.2 Particle Count Specification

All internal surfaces of the coupler assembly must meet the particle count specifications as defined in the table below. Particle detection will be performed using boil-off nitrogen or bottled nitrogen (Ultra High Purity 99.9999%). Gas delivery system must have a filter at the dewar and an air ionizer that has a point of use 0.02 µm or better filter. When qualifying all parts, the air ionizer pressure is to be 4 bar (58 psi) and the isokinetic sample probe will be positioned no more than 2.5 to 5 cm away from the part being sampled. For Cold and Warm Assemblies, the isokinetic sample probe will be 2.5 cm away from e-pickup port with nitrogen blowing inside antenna or center conductor area during particle count.

Internal surfaces are defined as all surfaces that are in a vacuum environment. All internal surfaces must be particle count inspected prior to assembly. Ion pumps typically cannot be cleaned to meet this internal particle count requirement and should be cleaned to lowest achievable particle level.

An additional particle count is required for the assembly of the two Cold Assemblies onto the Coupler Processing Cavity. This shall be performed using one Cold Assembly e-pickup port for blowing in the filtered ionized boiled-off nitrogen gas and the other Cold Assembly e-pickup port shall be used to measure final particle count on assembly. It is critical that this assembly meet internal particle count specification at the completion of this assembly.

External parts are defined as all parts or surfaces outside the vacuum envelopes. External parts must meet the particle count requirement specified in the table below and with a sampling of 100% of the parts.

External Particle Count Requirement and Monitoring Process:

The vendor shall blow off and monitor external coupler parts at 4 bar (58 psi) with nitrogen gun positioned 2.5 to 5 cm from the part being cleaned and with the isokinetic cup positioned 2.5 cm from the part. Nitrogen gun and isokinetic cup are to be held still during monitoring. External monitoring should be done in an ISO 5 (class 100) or better cleanroom until the part reaches the specification as listed in the table below. Particle monitor should be done with ionized air gun (.02um filter) and a 1CFM particle counter. When external surfaces are prepared to meet particle count requirement the assemblies are to be double bagged per section 9.2 prior to shipment.

Incoming inspection at FNAL, JLAB or SLAC will include the following steps to verify external particle count requirements are met. Remove first outer bag in ISO 7 (class 10,000) or better cleanroom, then move into ISO 5 (Class 100) or better cleanroom and remove second bag. Blow off and monitor external coupler parts at 4 bar (58 psi) with the nitrogen gun positioned 2.5 to 5 cm from the part being cleaned and with the isokinetic cup positioned 2.5 to 5 cm from the part. Nitrogen gun and isokinetic cup are to be held still during monitoring. External monitoring should be done in an ISO 5 (class 100) or better cleanroom until the part reaches the specification as listed in table below. Exterior blow off and monitoring should be performed starting at the top of the assembly and working towards the bottom. The maximum time required for blow off of any particular area is 15 minutes. Wiping exterior with isopropanol cleaning is acceptable, but not required. Following blow off (and wiping) steps, particle monitoring will be done for 1 minute per area to access if particle count meets specification. Particle monitor should be done with ionized air gun (.02um filter) and a 1CFM particle counter and must meet external surface counts as specified as below.

Particle Size	0.3µm	0.5µm	1µm	3µm	5µm	10µm
Internal Surface Counts	10	5	0	0	0	0
External Surface Counts	1000	500	100	10	10	10

6.3 Clean Room Assembly Standards

Assembly of components shall be performed in class 10 or ISO 4 cleanroom in order to prevent particle contamination.

6.4 Assembly Process

Reference Coupler Assembly model for assembly components and details for component deliverable.

Reference SLAC Engineering Note: LCLS-II-4.5-EN-0271 TTF3 Coupler Assembly Process for recommended instructions to be followed during the assembly process.

It is critical that during the assembly of the two Cold Assemblies onto the CPC) the e-pickup port be used for blowing in the filtered ionized boiled-off nitrogen gas to generate a positive pressure during assembly that blows out particles generated during the fitting and fastening of the Cold Assemblies to the test waveguide.

6.5 Final Leak Check of Coupler Pair

Once Coupler Assembly is complete, first leak check the assembly of the two Cold Assemblies onto the CPC . With the helium gas blower set at a low flow rate, all gasket and joint areas are probed using a slow circular motion. If no leak is detected, then the Cold Assembly ion pump is turned on and the gate valve is shut to isolate the couplers from the leak detector. The process is then repeated for each of the two Warm Assemblies. The final leak levels need to meet the same requirements as discussed in Section 5.6.

The ion pumps are to be run for a minimum of 24 hours before bake-out.

7 Bake-out Specification

This section provides process and specifications used for the vacuum bake-out of the couplers.

All coupler pair assemblies are to be baked under vacuum at a temperature of 150ºC (±5ºC) for 48 hours. The bake out vacuum system configuration should be such that there is one ion pump and one RGA sensor head for each of the three vacuum volumes: the two warm sections and the volume that connects the cold sections through the rf coupling box (CPC). Each volume is to be isolated from the others, and the three pumping systems are each to include a valve that allows the RGA probe to be isolated from the coupler volume. Valves should be placed as close to the coupler as possible. The oven atmosphere must be nitrogen to avoid oxidation of the exterior coupler parts.

Thermocouples are to be placed on the outside of one cold section and on each warm section to validate that the components are at the required temperature. No tape should be used to attach the thermocouples to the couplers. Use a low outgassing cable tie or tie-wrap that is bakeable to 200ºC.

Temperature must be increased to 150 ºC gradually to avoid exceeding a pressure of $1x10^{-6}$ Torr which could result in tripping off the ion pumps. The temperature and vacuum history are to be recorded and a plot for all three systems shall be provided in the coupler document package (i.e., one linear plot showing all the temperatures, and one log plot showing the three vacuum pressures, both with the same time range). The plots should also show the initial and final pressures at room temperature. The acceptable post-bake vacuum pressure at room temperature is less than $1x10^{-8}$ Torr for each of the three volumes. Note: Vacuum pressure at temperature after 24 hours should be less than starting pressure at room temperature. During bake, provide adequate local inert gas protection (N2 or Ar) to the exposed copper parts (copper rings near the warm ceramics, 5K copper ring near the cold coupler cavity flange).

8 RGA Scan Criteria

This section defines the process and acceptance criteria for the RGA scan of the couplers.

After initial pump down, while the coupler assembly is at room temperature, record RGA scans of all three vacuum systems as soon as the pressures allow for the operation of the Electro-Multipliers (< $1.0x10^{-6}$ Torr). Record each vacuum system's total pressure. Repeat RGA scans at completion of bake cycle, but while system is still at 150°C. Final RGA scans shall be performed when assembly has returned to room temperature. Acceptance criteria for UHV vacuum qualifications are:

Conditions/Criteria	Limits
Temperature of entire vacuum system and RGA head ionizer	150° C
Ratio of partial pressures of water vapor, (18 AMU) to hydrogen (2 AMU)	$P_{18} < \frac{P_2}{2}$
Partial pressure from **sum of all peaks >44 AMU**	$P < 1 X 10^{-11}$ Torr
Maximum **single-peak partial pressure for >44 AMU**	$P < 5 X 10^{-12}$ Torr

Each RGA scan will be part of the coupler document package.

9 Disassembly, Packaging and Shipping

This section provides specifications for disassembly, packaging and shipping of the fabricated and vacuum baked couplers.

After completion of bake-out, the couplers outer surfaces are to be cleaned to conform with external particulate requirements and the sections disassembled and packaged for shipment. It is important that during disassembly, packaging and shipping that Assembly #1 is not vented and remains under vacuum as achieved in the bake-out step and as qualified with the RGA scan.

9.1 Shipping Configuration

Each coupler pair shall be shipped in per the following two configurations as defined below.

Assembly #1: A pair of Cold Assemblies will be shipped installed in CPC under vacuum, with ceramic covers and in a structural stand sound for shipment of components without damage.

Assembly #2: Warm Assemblies will be shipped, back-filled with filtered ionized boiled-off nitrogen gas, with ceramic covers, and center conductor cover flange. Structural support rods to constrain the Warm Assembly bellows movement during shipment will be of electro polished 316 stainless steel threaded on ends only. Two warms are to be shipped in one ATA shipping container.

9.2 Packaging

Assemblies #1 and #2 must each be cleaned to meet exterior particle count of Section 6.2. Then packaged in 2 layers of MIL-PRF-131K, Class 1 (>4mils thick) bagging material that is heat sealable and superior tear and puncture resistance as well as protection from light, air and moisture vapor. Each layer of bagging material is to be back filled with filtered ionized boiled-off nitrogen gas and sealed Specify usage of the clean room vacuum, to purge the nitrogen out before sealing the bags.

A desiccator that is class 100 cleanroom environment approved and exceeds requirement of MIL-D-3464D will be taped inside second layer of bagging material prior to sealing. Label the content of the second bag with serial numbers of the parts inside.

Cold Top Hat must be purged with filtered ionized boiled-off nitrogen gas for >1 minute prior to closing and sealing for shipment of Assembly #1. Use Viton gasket for sealing the CF100 flange to the Top Hat.

No paper will be used as shipping material. All loose hardware that is not installed in the main shipping container is to be packaged with MIL-PRF-131K, Class 1 (>4mils thick) Ziploc style bags. This hardware will be shipped in a plastic molded ATA approved shipping container with foamed filled (closed cell foam only) to support hardware. All sealing O-ring material will be of Viton and not Buna-N or rubber in any of the shipping configuration assemblies.

Each hardware package will have a vinyl or plastic label (not paper label) on it. Labeling will be of the following:

- BOM Number
- Quantity
- Cleaned Date
- Operator Name

9.3 Shipping Container

Shipping container will be ATA molded of high density polyethylene. They are to be reused multiple times and must be able to withstand all transportation harsh conditions (rain, snow, shock & vibration). Each container will be custom fitted for each configuration with polyethylene foam (closed cell, white, and 2.2 lbs. per cubic ft. rated for safety of hardware). All parts shall be surrounded by a minimum of 2 inches of foam with no gaps and placed to limit movement. Foam will be lined with MIL-PRF-131K, Class 1 (>4mils thick) bagging material to prevent abrasion of foam during installation and removal of parts.

Shock indicators will be mounted outside of each shipping container included in Assembly #1 and #2 shipping containers to track 3-axis conditions during transit. Type will be Drop-N-Tell 5G & 25G Resettable Indicators in X, Y & Z axis.

9.4 Shipping

Vendor will notify SLAC National Accelerator Laboratory of shipment via email with tracking information and delivery date. All shipments will be of two-day delivery by air.

10 Quality Assurance and Deliverables Specification

10.1 Quality Assurance Requirements

Travelers and/or work orders will be created for each major subsystem, and record files will be generated and maintained. The recorded data should include all material certifications, kitting lists, dimensional inspections, assembly check-offs, and test data. All of the above quality data will be available for inspection by SLAC. If the manufacturer encounters any uncertainty related to the requirements within this specification, at any time, the manufacturer will contact the LCLS-II Procurement group and ask for clarifications before continuing. Vendor will upload required data in location provided by SLAC. Vendor will archive this data for at least 7 years. If a part does not pass incoming inspection, it will be returned to vendor for corrective actions or replacement.

10.1.1 Non-Conformance Identification and Reporting

Non-conformance is defined as a deficiency in characteristic, documentation or procedure that renders the quality of an item or activity unacceptable or indeterminate.
Whenever a non-conformance is identified a non-conformance report (NCR) must be prepared and submitted to SLAC within three working days of discovery. The NCR form and information format is to be submitted to SLAC for approval 20 working days before the start of manufacturing.
In the event of a non-conformance the part or process must be placed on hold and must be addressed by SLAC and written approval to proceed must be given prior the disposition and/or release of the part or process.

10.2 Deliverables

The supplier shall not ship any item without prior authorization or consent from SLAC. Authorization is contingent upon confirmation that all deliverables have met their acceptance criteria prior to shipping.

Table below shows detail of deliverables needed to be supplied by the vendor per this ESD.

Item #	ESD Section #	Requirement	Quantity/Frequency	Delivery Time
1	4.1.4 and 4.2	Material Certifications for all stainless steel and copper including physical and chemical reports	All stainless steel and copper	Documentation delivered with completed assembly

Item #	ESD Section #	Requirement	Quantity/Frequency	Delivery Time
	4.1.3	Magnetic Permeability	All stainless steel piece part and assemblies	Documentation delivered with completed assembly
2	4.3	Cold Bellow Fatigue Test	1 sample/one time	**HOLD POINT:** Delivery of samples required prior to release for production
3	4.4	**Ceramics**		
		Chemical Analysis	All ceramics	Documentation delivered with completed assembly
		Density	Each firing lot of each batch of isopressed material	Documentation delivered with completed assembly
		Grain Size	Each firing lot of each batch of isopressed material	Documentation delivered with completed assembly
		Gas Impenetrability	Each ceramic	Documentation delivered with completed assembly
		Metallization Strength Results from Pull/Peel Test	Each metallization firing lot	Documentation delivered with completed assembly
4	5.1.4	Weld Validation	2 samples/one time	**HOLD POINT:** Delivery of samples required prior to release for production
5	5.2.2	Braze Validation	3 samples/one time	**HOLD POINT:** Delivery of samples required prior to release for production
6	5.3.2	Copper plating impurity and material Lab report	One report at qualification	**HOLD POINT:** Delivery of report required prior to release for production

Item #	ESD Section #	Requirement	Quantity/Frequency	Delivery Time
			One report at production	Documentation delivered with completed assembly
			One report whenever process or plating bath changes	Documentation delivered with completed assembly
7	5.3.5	Adhesion of Copper Coating	2 samples (1 bend test, 1 tape test) at qualification	**HOLD POINT:** Delivery of samples required prior to release for production
			2 samples (1 bend test, 1 tape test) at production	Documentation delivered with completed assembly
			2 samples (1 bend test, 1 tape test) whenever process or plating bath changes	Documentation delivered with completed assembly
8	5.3.3	Copper Plating Thickness	2 samples (one sample 150um Cu plating on exterior of bellows welded to tube insert and one sample 10um Cu plating on interior at qualification	**HOLD POINT:** Delivery of samples required prior to release for production
			2 samples (one sample 150um Cu plating on exterior of bellows welded to tube insert and one sample 10um Cu plating on interior at production	Documentation delivered with completed assembly
			2 samples (one sample 150um Cu plating on exterior of bellows P/N PF 375-600-72 welded to tube insert P/N PF-375-600-73 and one sample 10um Cu plating on interior of P/N PF-375-600-43) whenever process or plating bath changes	Documentation delivered with completed assembly
9	5.3.6	RRR	Two samples at qualification	**HOLD POINT:** Delivery of samples required prior to release for production
			Two samples at production	Documentation delivered with completed assembly

Item #	ESD Section #	Requirement	Quantity/Frequency	Delivery Time
10	5.3.7	Cu Plating Surface Roughness	Two samples at qualification	**HOLD POINT:** Delivery of samples required prior to release for production
			Two samples at production	Documentation delivered with completed assembly
11	5.4	Titanium Nitride Coating	One sample/one time at qualification	Documentation delivered with completed assembly
12	5.5	Metrology Inspection Report	All Cold and Warm Assemblies	Documentation delivered with completed assembly
13	5.6	Leak Rate Report	All assemblies	Documentation delivered with completed assembly
14	6.2	Particle Count		
		Interior	All assemblies	Documentation delivered with completed assembly
		Exterior (post bake)	All assemblies	Documentation delivered with completed assembly
15	7	Bake Report: Plot of Pressure, Temperature verses Time	All assemblies	Documentation delivered with completed assembly
16	8	RGA scan at room temperature and 150°C	All assemblies	Documentation delivered with completed assembly

10.3 Supplier Qualification

The supplier and/or manufacturer awarded the contract to build the Fundamental Power Couplers, will undergo a Quality Systems Survey performed by SLAC. This survey may include an on-site visit to the manufacturing facility to determine if their staff, processes and test equipment are capable of meeting the quality requirements identified within this specification. The potential supplier will afford access to their facilities to perform this task. Results of the Quality System Survey will be officially conveyed to the supplier shortly after the survey is performed.