PIP-II Solid State Amplifier Statement of Work

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1. INTRODUCTION

Fermi National Accelerator Laboratory (FNAL) is building a new linear accelerator (linac) to improve its capabilities for high-energy particle physics research. The linac will accelerate ionized protons using superconducting cavities. The ionized proton beam runs through the cavities and is accelerated by the RF fields provided by the RF system. Each cavity receives its power from a dedicated RF amplifier through its own distribution system.

The Linac requires a variety of RF Amplifiers (SSAs) operating at different frequencies and peak power levels. FFDG is requesting proposals for various combinations of frequencies as identified in Section 3, Scope and Deliverables.

2. ACRONYMS, TERMS AND DEFINITIONS

The following acronyms, terms and definitions will be used to describe items identified in this Statement of Work.

Table 1: Document Acronyms

AC	Alternating Current
CW	Continuous Wave
DC	Direct Current
FCC	Federal Communications Commission (US)
FNAL	Fermi National Accelerator Laboratory
HB650	High Beta 650 MHz
FFDG	Fermi Forward Discovery Group, LLC
HPRF	High Power Radio Frequency
LB650	Low Beta 650MHz
LBS	Pounds
LLRF	Low Level Radio Frequency
PA	Power Amplifier
PIP-II	Proton Improvement Plan II
PS	Power Supply
RF	Radio Frequency
RFP	Request for Purchase
SRF	Superconducting Radio Frequency
SSA	Solid State Amplifier
SSR	Single Spoke Resonator
TRS	Technical Requirements Specification

Table 2: Glossary of Terms

SSR2 SSA	Solid state amplifier with a center frequency of 325 MHz and peak power specification of 20kW
LB650 SSA	Solid state amplifier with a center frequency of 650 MHz and peak power specification of 40kW
HB650 SSA	Solid state amplifier with a center frequency of 650 MHz and peak power specification of 65kW
Power Variation	Peak power specification attribute used to differentiate the different sets of SSAs

Delivery Batch	A subset of the required quantity of SSAs that are packaged for delivery
Optional Batch	A delivery batch not included in the base pricing but may be requested as a cost addition after the contract is awarded

Table 3: SSA Technical Requirement Document Enclosures

Attachment No	Cavity	Peak Power Level	Configuration	Document Title	File Name	File No.
1	SSR2	20 kW	CW	PIP-II CW Beam RF Amplifier for SSR2 Cavities Technical Requirements Specification	”PIP-II RF Amplifier TRS for SSR2 Cavities – CW beam.docx”	ED47317
2	LB650	40 kW	CW	PIP-II CW Beam RF Amplifier for LB650 Cavities Technical Requirements Specification	”PIP-II RF Amplifier TRS for LB650 Cavities – CW beam.docx”	ED47313
3	HB650	65 kW	CW	PIP-II CW Beam RF Amplifier for HB650 Cavities Technical Requirements Specification	”PIP-II RF Amplifier TRS for HB650 Cavities – CW beam.docx”	ED47315

3. SCOPE AND DELIVERABLES

FNAL requires the quantities of each SSA power variation specified in Tables 4, 5, and 6. For each power variation supplied, the subcontractor shall provide a Design Documentation Package (see Section 3.2), Quality Control Documentation (see Section 3.3), and an Operations Manual and Control Documentation package (see Section 3.4).

In addition, the subcontractor shall maintain pricing for up to one (1) year for the potential procurement of up to five (5) additional units of each power variation type.

Each power variation shall comply with its associated Technical Requirements Specification (see Table 3, Items 1–3), as detailed in Section 4 of this Statement of Work.

Table 4: List of Subcontract Deliverables – SSR2 SSA Power Variation

Item	Quantity
20kW peak power, 325MHz SSA - Production – See Section 3.1	26
20kW peak power, 325MHz SSA – Optional Batch – See Section 3.1	5
Design Documentation Package – See Section 3.2	NA
Quality Control Documentation – See Section 3.3	NA
Operations Manual and Controls Documentation – See Section 3.4	NA

Table 5: List of Subcontract Deliverables – LB650 SSA Power Variation

Item	Quantity
40kW peak power, 650MHz SSA - Production – See Section 3.1	15
40kW peak power, 650MHz SSA – Optional Batch – See Section 3.1	5
Design Documentation Package – See Section 3.2	NA
Quality Control Documentation – See Section 3.3	NA
Operations Manual and Controls Documentation – See Section 3.4	NA

Table 6: List of Subcontract Deliverables – HB650 SSA Power Variation

Item	Quantity
65kW peak power, 650MHz SSA – Production – See Section 3.1	11
65kW peak power, 650MHz SSA – Optional Batch – See Section 3.1	5
Design Documentation Package – See Section 3.2	NA
Quality Control Documentation – See Section 3.3	NA
Operations Manual and Controls Documentation – See Section 3.4	NA

3.1. SSA Units- Deliverables

The subcontractor shall provide all hardware and software required to assemble and operate an SSA unit as described in the relevant TRS, (Table 3, 1-3).

The SSA unit may include, but is not limited to racks, cabling, RF amplifier slices, DC power supplies, PLCs/Controls units, control panels, transformers, cooling systems, RF distribution items internal to the SSA, etc.

3.2. Design Documentation Package – Deliverables

The subcontractor shall provide the following design documentation as part of the subcontract award. The completed documents are required **prior to the shipment of any SSA units**. Some documents will be requested earlier as described in Section 4.

The Design Documentation Package shall include, but may not be limited to:

- Mechanical 3D CAD model of the final design showing external dimensions and connection points in .stp format and as .pdf drawings.
- Schematics of the electrical distribution for the purpose of review by our on-site, electrical safety committee.
- Final test results of each SSA as measured at the subcontractor site (Factory acceptance test, FAT). The minimum set of documentation for these test results are defined in the SSA technical requirements specifications (TRS) documents (Table 3, 1-3).
- General operating manual for the SSAs.
- Remote programming manuals for the SSAs, including register maps.
- Maintenance manual that describes necessary maintenance and component replacement procedures.

- Assembly manual if SSA will be delivered in components that require on-site assembly.

3.3. Quality Control Documentation – Deliverables

Prior to the shipment of any SSA unit, the subcontractor shall provide Quality Control (QC) documentation to FNAL for review and approval, which at a minimum includes, but is not limited to:

- As-built documentation (drawings, schematics, etc.) as relevant
- All QC documentation including travelers, discrepancy reports, etc. sufficient to demonstrate that the deliverable and all sub-components have been validated per the required subcontract with established verification methods. This must comply with all requirements and measurements in Section 8 of the respective TRS documentation (Table 3, 1-3).
- All QC documentation, including testing plans, hold points, and audits, to ensure that the "Applicable Standards" in the TRS documentation (Table 3, 1-3).

NOTE: All acceptance criteria and validation techniques are included in the relevant TRS documentation (Table 3, 1-3).

3.4. Operations Manual – Deliverables

Prior to shipment of any SSA unit, the subcontractor shall provide to FNAL the documentation required for standard operations and integration of the units, including:

- An Operations Manual documenting all standard functions, safety information, and user controls functions (local and remote)
- All Programming Manual required for FNAL to integrate the unit into the existing FNAL Controls system (e.g., registry maps, signal lists, etc.)

4. SUBCONTRACT MILESTONES AND HOLD POINTS

At a minimum, the subcontractor shall provide the following milestones:

4.1. Kickoff Meeting

A virtual Kick-off Meeting between the subcontractor and FNAL will be held to ensure that the objectives and requirements of the deliverables are understood and that the proposed approach will meet said requirements. The emphasis will be on the requirements and how they affect the design, the proposed design concept, and the definition of the major system interfaces.

The Kick-Off Meeting will provide the subcontractor with a clear understanding of the requirements and specific details of the deliverables to the subcontractor to begin the initial design effort.

The kick-off meeting shall address at a minimum, the following items:

- Design Objectives
- Technical Requirements
- Technical Interfaces
- Consideration of major design solutions
- Risk Areas
- Review of major contract milestones and schedules
- Logistics of future communications and document transfer

The completion of the Kick-Off Meeting and closure of all action items shall constitute the basis for establishing the baseline design and allow the design effort to proceed to the preliminary design phase.

4.2. Preliminary Design Review (PDR)

The PDR will be held once the design is advanced and understood sufficiently to begin design modeling and engineering analysis of the deliverables. For the design's interface components, including fluids, power, controls, RF Distribution, and other critical elements, the subcontractor must submit a status update and preliminary design review document that thoroughly addresses the specified requirements. The preliminary design review documentation will include, at a minimum:

- Closure of action items from the Kick-Off Meeting
- Documented technical requirements
- Interface requirements
- Preliminary mechanical and structural design and analyses
- Preliminary layouts, drawings, and 3-D models
- Assessment of risk areas and potential delays
- Updated schedule
- Design documentation demonstrating alignment of the design to requirements (specific required technical information listed in associated TRS documentation – See Table 3: SSA Technical Document Requirement Enclosure)
- QC documentation that verifies the plan to achieve "Applicable Standards" as defined in TRS documentation.
- Remote controls interface specifications
- Integrated layout of SSAs demonstrating final interfaces (i.e., footprint, stay-clear access areas) including utilities (RF Distribution, AC Power, cooling water).

Completion of the PDR and closure of all action items shall constitute PDR approval of the deliverable.

4.3. Final Design Review (FDR)

The FDR will be held to present the final, detailed design using substantially completed drawings, 3-D models, and analyses to demonstrate that the design will meet the performance and interface specifications and the required design objectives. The FDR shall present a complete and comprehensive final design and interfaces by means of detailed drawings, including, but not limited to, layout and assembly drawings, modeling results, engineering analysis results and all changes to the design presented at the PDR.

The FDR shall include all the items specified for a PDR, updated to the final, present stage of the development process, plus the following additional items:

- Closure of action items from the PDR
- Any revised technical objectives and requirements
- Final interface requirements
- Final QC plan
- Specific required technical information listed in the TRS documentation
- Assembly procedures and planning documentation, including verification and validation planning (travelers), including verification methods to be used for FAT in alignment with the TRS
- Final results of mechanical and structural design and analysis
- Final detailed design with 3-D models, layouts, and analyses
- Preliminary fabrication, assembly, test and shipment plans
- Assessment of risk areas and potential delays
- Updated schedule

- Final schedule for Manufacturing and Test Hold/Witness points
- Status of long lead procurements
- Specific required technical information listed in the TRS documentation

Completion of the FDR and the closure of all action items shall constitute the final design for the deliverable. A successful FDR shall allow for the procurement of all required materials and the assembly of the first, production SSA unit.

4.4. Factory Acceptance Testing (FAT) of First SSA Unit

The FAT will be performed to demonstrate all requirements using the agreed upon verification methods (see Section 4.3). FNAL reserves the right to view this validation in person. This milestone is intended to gate-keep shipment preparation of the first SSA unit and subsequent units from the subcontractor to FNAL.

Completion of the FAT shall include delivery of the following items:

- Closure of action items from all previous reviews
- Final design, fabrication, and assembly drawings
- SSA unit-specific verification and validation documents (e.g. completed travelers)
- General operating manual for the SSAs
- Remote programming manuals for the SSAs, including register maps
- Maintenance manual that describes necessary maintenance and component replacement procedures
- Assembly manual if SSA will be delivered in components that require on-site assembly
- Final shipping plan with analysis of transport loads and design of shipping fixtures
- Final schedule and quantities of delivery batches
- Installation and handling plan at FNAL site.

Completion of the FAT and closure of action items shall constitute the completed design approval for the deliverable to be prepared for shipping to the FNAL site. Successful completion of the FAT is required before start of the full production run at the subcontractor.

4.5. Factory Acceptance Testing of Production Units

Each production unit must undergo factory acceptance testing equivalent to the First SSA Unit (see Section 4.4). Upon completion of testing the vendor should provide the following documentation for each unit:

- SSA unit-specific verification and validation documents (e.g. completed travelers).

4.6. Shipping/Transportation Readiness Review (TRR)

The TRR shall be held with each delivery batch shipment that has completed FAT, to present a final review of all documentation to establish that the delivery batch, with its constituent components, has been fabricated successfully and is ready to ship.

The TRR shall include, at a minimum, the following items:

- Shipment plan and procedures
- Notice of departure, tracking information and expected delivery date to FNAL
- Packing list for the shipping of components
- Complete component list for deliverable, along with documentation

A successful TRR allows for the shipment of the deliverable.

4.7. Delivery Schedule and Hold Points

The hold points for this subcontract are described above and include the Kickoff Meeting, the PDR, the FDR, the FAT of First Article, and the TRRs for each batch delivery.

The offeror shall provide a project plan, including a proposed schedule, key milestone dates and batch sizes, as part of its proposal submission. The draft schedule in Table 7 may be used as a reference example.

PLEASE NOTE: TRR, delivery and SAT are required for each batch.

Table 7: Delivery and Hold Points Schedule Template

Description	Duration	Weeks ARO
Kick-off Meeting		
Preliminary Design Review (PDR)		
Final Design Review (FDR)		
Factory Acceptance Test (FAT) of First Article		
Shipping/Transportation Readiness Review (TRR)		
Delivery to FNAL Site		
Site Acceptance Test (SAT) at FNAL site		
Contract Closeout		

4.8. Delivery of Production SSAs to FNAL

Delivery from the subcontractor will proceed in agreed-upon batches. FNAL will perform a visual inspection to ensure that the delivered SSA has arrived without visible damage or missing components.

A satisfactory visual inspection at FNAL determines confirmation of delivery. Delivery confirmation shall not be construed as acceptance

4.9. Site Acceptance Test (SAT) at FNAL Site

FNAL will first verify that mechanical transport interfaces are in place prior to any required assembly. Other infrastructure interfaces will be verified after assembly. Local operation will be verified along with verification of the interlocks function. Remote control and status readback will also be verified. Table 8 lists the tests and their criteria for acceptance upon arrival at FNAL.

FNAL will complete acceptance testing within 4 weeks of batch arrival for batch quantities that do not exceed 5 SSAs. For batch quantities greater than 5, longer times will be required for acceptance.

To meet qualifications for acceptance, the SSAs, at a minimum, must meet the following:

Table 8: Site Acceptance Tests and Criteria

Test	Criteria
Visual inspection of delivered components	No visible damage of shipping containers or components, all components listed in shipping manifest are present
Visual inspection of mechanical transport interfaces	Confirmation of rigging hardware and their certification as described in TRS, confirmation of space for forklift as described in TRS, confirmation of castor wheels as described in TRS
Visual inspection of external interfaces	Confirmation that electrical power, water cooling, RF input and output, external interlock, external status, and network connections meet specifications described in TRS

Visual inspection of internal power distribution	Confirmation that internal electrical power distribution meets national electrical codes as defined in the TRS
Turn on using local controls	Verification of operations manual procedures, confirmation that local controls function and show status as defined in TRS
Test of interlocks with no RF drive	Confirmation that SSA shows status of trip when water flow is interrupted, control power is removed, safety system enable is removed, or RF permit is removed.
Test of remote access and control	Verification that FNAL control system can access the remote status and control, confirmation that remote status and control features defined in TRS are available
Full rated power operation for 8 hours	Confirmation that SSA can run at full rated power, confirmation that RF instruments are visible on local and remote controls, confirmation of stability of gain and phase as defined in TRS, RF leakage below threshold defined in TRS

Any non-conformance revealed in the inspection and testing process will be communicated to the subcontractor in writing. The process for resolving the non-conformance may occur through the methods described below.

- FNAL and the subcontractor may schedule virtual meetings with subcontractor personnel at the subcontractor's expense to discuss and potentially repair the non-conformance remotely. FNAL will be the sole determiner of when to escalate to the following resolution paths:
  - The non-conforming component or entire SSA may be returned to the subcontractor for repair or replacement, and returned to FNAL at the subcontractor's expense.
  - The subcontractor may send personnel to FNAL to assist with the local repair process at the subcontractor's expense.

SSA units are accepted upon successful completion of the site acceptance tests and successful resolution of all non-conformities.

5. REQUIREMENTS AND SPECIFICATIONS

Offerors shall provide unit pricing for the base bid quantities of SSAs identified in Table 9 and as defined in the RFP document. Pricing shall be provided for the following items:

Table 9: Bid Quantities for SSAs

Qty	Cavity	Peak Powers Level
26	SSR2	20 kW
15	LB650	40 kW
11	HB650	65 kW

Offerors may submit proposals for any or all power variations; however, submission for every power variation is not required.

For each power variation, offerors shall provide a delivery schedule. If an offeror can provide a more favorable schedule based on an award of multiple power variations, such information shall be submitted with your technical proposal. **PLEASE DO NOT INCLUDE PRICING INFORMATION IN THE TECHNICAL RESPONSE.**

If an offeror can provide a more favorable pricing based on an award of multiple power variations, such information shall be submitted with your price proposal. **PLEASE DO NOT INCLUDE PRICING INFORMATION IN THE TECHNICAL RESPONSE.**

As an option, FFDG requires that offerors provide unit pricing for up to five (5) additional units of each proposed power variation. Pricing for these optional units shall remain valid for a period of one (1) year from the date of an award.

PLEASE NOTE: Due to the critical importance of the delivery schedule, a subcontractor will not be considered for award of multiple SSA power variations unless its proposal includes an integrated delivery schedule covering all applicable items.

5.1. General Requirements

All offerors are required to provide the minimum requirement documentation as identified in the RFP document. This would include providing documentation that demonstrates its ability to handle a subcontract of similar size, scope and complexity.

The offeror must demonstrate successful completion of:

- Documentation demonstrating successful completion of similar size, scope and complexity projects in the past seven (7) years. Preference will be given to accelerator-based projects. The offeror must include the name of the organization, name of the project, awarded value, completion value, agreed-upon completion date, actual completion date, and a contact name, including phone number and email address for each reference provided. References that fail to provide any of the requirements identified above will not be considered when reviewing and/or will receive a lower evaluation score.
- Information about the potential subcontractor's major infrastructure required to deliver this contract (production facility size, utilities infrastructure, personnel, critical component supplier relationships).

For proposals that include two or more power variations of SSA, this information should address the subcontractor's capability to simultaneously execute all parts of the scope.

- Proposed team with names and project org chart.

5.2. Technical Proposals

All prospective subcontractors shall provide the following information for each proposal submitted:

- A technical proposal describing the proposed deliverables and demonstrating compliance with the applicable requirements identified in Table 3 and Section 2. Where requirements are expressed as performance thresholds (e.g., "better than," "less than," etc.), the proposal shall include the expected performance values of the proposed deliverables.
- A proposed schedule identifying the duration of all major contract phases, expressed in weeks from contract award, including the overall contract duration. (MS Project-style Gantt Chart or equivalent.)
    - For proposals that include multiple SSA power variations, the subcontractor shall provide an integrated master schedule identifying milestones for each power variation.
- Proposed quantities for all batch deliveries.
- A proposed SSA layout demonstrating compliance with the interface and configuration requirements identified in Section 7 of the applicable Technical Requirements Specification (TRS).
- An example of a Quality Control Plan identifying the critical inspections, tests, checks, and quality assurance processes proposed for this contract.

In addition, Table 10 identifies a subset of key technical requirements applicable to this procurement. All prospective subcontractors shall specifically address these requirements within their technical proposal and demonstrate how the proposed solution meets or exceeds them. These requirements apply to all power variations; detailed requirements are provided in the applicable TRSs.

Table 10: Subset of baseline technical requirements

Requirement #	Requirement Statement
A004	Minimum available CW output power
A005	Gain compression at maximum output power
A007	Minimum available output power with PAs down
A014	Small signal delay over amplifier bandwidth
A016	Gain variation over 30% - 90% specified peak output power
A017	Amplitude Modulation to Phase modulation (20%-90%)
B005	AC to RF output Efficiency at specified peak power
C004	Maximum permissible heat load dissipated to air at full rated average power.
D001-D006	Space Envelope Requirements
F001-F006	Reliability Requirements
H003-H006	Communication Protocols

6. REPORTING/MEETING REQUIREMENTS

The subcontractor will arrange biweekly status meetings with the FNAL Buyer and Technical Representative. The subcontractor shall submit a written subcontract status report to FNAL's Buyer and Technical Representative on a monthly basis. This should include notification of any potential schedule or technical issues that have arisen in the previous period.

The subcontractor shall designate a single point of contact for all communication between the subcontractor and the FNAL Buyer and Technical Representative.

Note: All official communication should include the FNAL Buyer, and only the Buyer is authorized to make modifications of any kind to the subcontract, including those affecting cost, schedule/delivery dates, or technical changes.

The Subcontractor shall provide FNAL personnel access to the subcontractor's manufacturing facility for observation of in-process work and testing activities as defined in this SOW upon receipt of 4 weeks' written notice from FNAL.

7. QUALITY REQUIREMENTS

A quality control plan and a manufacturing inspection plan shall be finalized and provided to FNAL prior to starting production of deliverables identified herein. The quality control plan should describe the inspections and tests to be performed.

7.1. Serialization

All units shall be engraved with a serial number. The numbering scheme **must** be approved by FNAL prior to fabrication.

8. WARRANTY

Contract deliverables shall be free of manufacturing defects for a period of 12 months after component acceptance.

9. SHIPPING

All items shall be adequately packaged to prevent damage during shipment and protect against exposure to weather related hazards and environmental conditions.

All items shall be clearly marked with contents [contract line item(s)], and weight (including units).

Delivery shall be pursuant to INCOTERMS 2020, and shipping shall be DAP, Batavia, IL.