



Technical Specification

for

300 kW / 108.4 MHz Solid State RF Amplifier Systems

Abstract

This technical specification concerns the supply of
108.4 MHz pulsed 300 kW solid-state RF amplifiers
for accelerating structures.

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Glossary

Acronym	Definition
CDD	Conceptual Design Document
CDR	Conceptual Design Review
DTL	Drift Tube Linac
EMC	Electro Magnetic Compatibility
ESR	ExperimentierSpeicherRing (Experimental Storage Ring)
FAIR	Facility for Antiproton and Ion Research
FAT	Factory Acceptance Test
FDD	Final Design Document
FDR	Final Design Review
GSI	GSI Helmholtzzentrum für Schwerionenforschung
GUI	Graphical User Interface
HMI	Human Machine Interface
IEC	International Electrotechnical Commission
IH	Interdigital-H-Mode Structure
ISO	International Standards Organization
LLRF	Low Level Radio Frequency
PLC	Programmable Logic Controller
RFQ	Radio Frequency Quadrupole
SAT	Site Acceptance Test
SIS	Schwer-Ionen-Synchrotron (Heavy Ion Sychrotron)
TK	Transfer-Kanal (Transfer Channel)
TVS	TürVerriegelungsSystem (Door Interlock System)
UNILAC	UNIversal Linear Accelerator

Term	Definition
Solid State Power Amplifier (SSPA)	The Solid State Power Amplifier denotes the entire 300 kW / 108.4 MHz amplifier unit. It comprises power supply units, RF amplifier modules, RF components, safety circuits, monitoring circuits, measurement devices, voltage distribution, control, cooling, wiring, interfaces, mechanical infrastructure etc.
Power Supply Unit (PSU)	The Power Supply Units are swappable modules that deliver the required voltage and current for the appropriate RF Power Modules.
RF Power Module (RFPM)	The RF Power Modules are swappable units that contain the RF Power transistors, circulators and first-stage combiners. Following stages combine the power of each module to the desired output of the amplifier.
RF Pallet (RFP)	The RF Power Modules consist of a certain amount of RF Pallets, custom designed RF-PCB-boards with mounted RF-transistors.

1. Introduction

1.1. GSI and FAIR

The GSI Helmholtz Centre for Heavy Ion Research in Darmstadt, Germany, operates a unique ion accelerator complex, currently centred around the UNILAC (Universal Linear Accelerator), the SIS18 synchrotron or ring accelerator, and the ESR storage ring. Serving an international research community, GSI enables ground-breaking experiments in nuclear physics, materials science, and biophysics. Currently, GSI is transitioning to become the primary injector for the future FAIR (Facility for Antiproton and Ion Research), significantly increasing the requirements for beam intensity and system reliability. Figure 1 summarizes the existing GSI facility (blue) and the upcoming FAIR facility (red). The existing UNILAC, approximately 120 meters long, accelerates particles as high as twenty percent of the speed of light. The following SIS18 synchrotron, which has a circumference of 216 meters, accelerates all kind of particles to ninety percent of the speed of light. This is the precondition to inject particle beams into the upcoming FAIR facility, where particles will be accelerated in a superconducting ring accelerator (SIS100) with a circumference of 1,100 meters to almost the speed of light with outstanding intensity and quality. This will allow researchers to solve secrets regarding the structure of matter and the evolution of our universe.

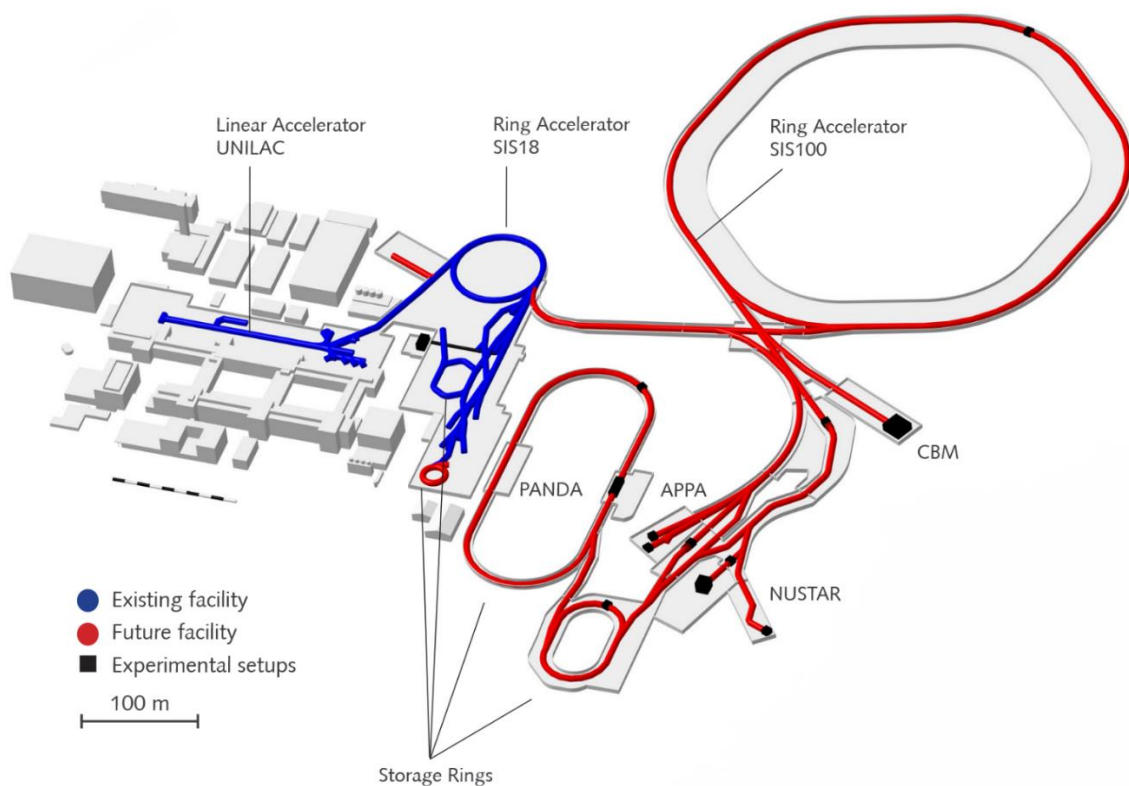


Figure 1: GSI and FAIR Accelerator Facility

1.2. UNILAC

The new Alvarez 2.0 Drift Tube Linac (DTL) will replace the more than 50-year-old UNILAC post-stripper cavities and will serve as an injector chain for FAIR. The 108.4 MHz Alvarez 2.0 DTL consists of five Alvarez cavities and several bunchers and single gap resonators. The future UNILAC operation with heavy ions will focus on producing short beam pulses with output energies up to 11.4 MeV/u. The proposed single gap resonators will allow beam tuning and adaption for the operators and users of the GSI/FAIR facility. For the RF operation of these single gap resonators solid state power amplifiers (SSPA) are required that are capable to produce RF pulses of 300 kW with a pulse duration of 2 ms and an average repetition rate of 10 Hz.

2. Scope

2.1. General Description

This tender concerns the design, manufacturing, testing at the contractor's premises, delivery to GSI and commissioning at GSI of SSPAs, which shall be designed according to this extended specification with a nominal output power of at least 300 kW at the operating frequency of 108.4 MHz. The amplifier systems shall be able to produce RF pulses with a length up to 2 ms and a repetition rate up to 10 Hz. The average duty cycle is 2 %. The SSPA comprises all components and modules required to amplify RF signals, including power supplies, RF amplifier devices and circuits, interlock circuits, monitoring circuits, cabling, interfaces and mechanical infrastructure.

2.2. Content of the Supply

GSI intends to place a contract for the supply of SSPAs. The contractor shall provide the supply as defined in this technical specification, including its annexes.

1. Layout and production of SSPAs (see chapter 3 & chapter 4)
2. Factory Acceptance Test (FAT) at the contractor's location (see section 7.1)
3. Delivery of the amplifier systems to GSI, installation and commissioning at GSI (see section 7.2)
4. Site Acceptance Test (SAT) at GSI (see section 7.2)
5. Complete technical documentation (see chapter 5)

2.3. Required Technical Bidding Documents

In addition to the bidding documents required in the commercial tender documents, the offer shall contain the following technical documents:

- System design overview,
- Preliminary bill of materials (BOM),
- Draft drawings of the amplifier system showing:
 - RF circuits, including the preliminary transistor RF pallet and the printed RF combiners,
 - wiring diagrams and
 - mechanical drawing of the amplifier system.
- Technical reports of the coaxial combiners including a breakdown strength analysis of the electrical fields (RF field simulation results and detailed calculations respectively),
- The design and the specification of the circulator technology shall be submitted. If the circulator is an in-house product, RF and magnetic field simulations are required to assess the performance of the circulator. If the circulator belongs to the purchased parts, a technical report that shows the circulator performance under the required RF parameters is mandatory.

Additional technical documents that verify the technical maturity and technological readiness of the provided SSPA will be positively assessed.

3. Technical Specification

3.1. Description

For future UNILAC operation state-of-the-art solid state power amplifiers featuring low maintenance are required to assure a continuous and reliable operation over the next decades. It has also to be assured that all implemented electrical circuits and devices as well as all mechanical parts of the SSPA system are repairable or replaceable for at least the next 25 years. Therefore, a modular design and a maintenance concept that guaranties low operational costs as well as reduced staff requirements will be favourably assessed. The usage of the newest LDMOS transistor type with RF power higher than 3 kW is preferred, e.g. Ampleon ART4K0FX.

A key feature of the required amplifier is its ability to resist fully reflected power at any phase and at any time. Due to impedance discontinuity, reflections will regularly occur at rising and falling RF pulse edges as well as during the RF pulse based on other mismatch effects like sparking in the cavity or beam load. It is mandatory to present a suitable proven concept for amplifier protection against fully reflected RF power at the output that includes the implementation of a circulator at the final RF output of the SSPA or several circulators in the RF path of the SSPA to protect each transistor. The final offer shall contain a detailed description of the amplifier protection concept, including test measurements obtained by previous amplifiers built for similar projects or by an equivalent demonstrator.

The future UNILAC operation does not only require different ion species and ion charge state, there will also be a significant beam load which requires a very high dynamic power range in a short time from the SSPA system. A separate and independent low-level RF (LLRF) system controls the variable RF pulse power by regulating the input power of the SSPA. The LLRF system also provides fast amplitude modulation during each RF pulse triggered by beam loading compensation. This LLRF system is not covered by this call for tender and will be provided by GSI.

An essential feature of the required SSPA system is highest reliability and maintainability to minimize downtimes and to increase durability. This includes the availability of appropriate spare parts and of individual components or subsystems during the desired long lifetime of the amplifier. As depicted in Figure 2 the SSPA comprises all components and modules required to amplify RF signals to the requested output power level including power supplies, RF amplifier devices and circuits, interlock circuits, monitoring circuits, cabling, user interface, control units and mechanical infrastructure.

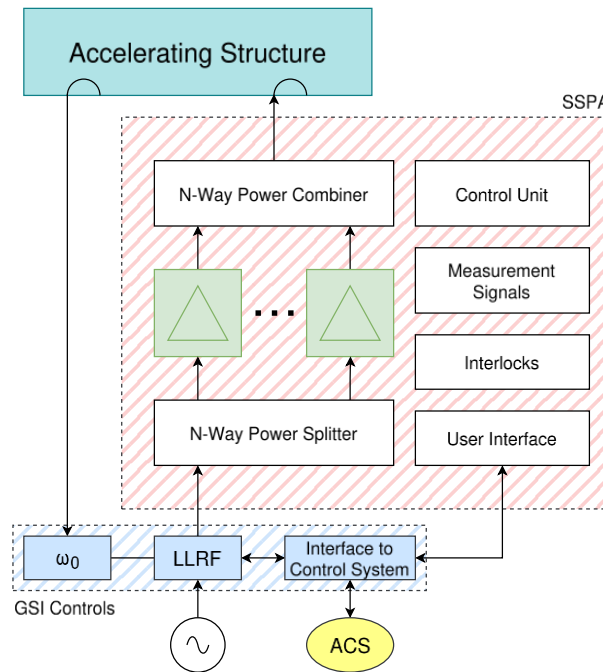


Figure 2: Amplifier System for the UNILAC

3.2. Technical Maturity

Owing to the very short target delivery time the offer shall demonstrate a high level of technological readiness of the proposed SSPA solution. The contractor shall provide verifiable evidence that the system will be delivered, commissioned and operated within the fixed project deadlines.

All components within the offer, especially key components like RF pallets, circulators and combiners shall be evaluated, simulated and in best case realized and tested before contract award. Special care shall be taken for bought-in components.

Any proposal shall include a comprehensive risk mitigation plan, detailing proof of concept, modular redundancy strategies and a proven track record in high-power RF applications to ensure long-term operational stability.

3.3. Technical Design

3.3.1. Radio Frequency Requirements

The following data shall be achieved:

Table 1: RF Requirements

Parameter	Value
RF transistor nominal output power	$\geq 3000 \text{ W}$
Operating frequency	108.4 MHz
Nominal RF output pulse power	$\geq 300 \text{ kW}$
Max. RF output average power	6 kW
Output power at 1 dB compression	$\geq 310 \text{ kW}$
Gain linearity	
15 % - 90 % of max. RF power	$\leq 1.5 \text{ dB}$
2 % - 15 % of max. RF power	$\leq 3 \text{ dB}$
Δ gain stability over cooling water temperature at 100 % nominal power	$\leq 3 \% / ^\circ\text{C}$
Max. intra pulse amplitude variation	$\leq 0.5 \text{ dB}$
Max. harmonic level at resistive load at nominal power	$\leq -24 \text{ dBc}$
Max. level of non-harmonic frequencies at resistive load at nominal power	$\leq -60 \text{ dBc}$
Bandwidth @1 dB	$\geq \pm 1.0 \text{ MHz}$
Power rise time	$< 5 \mu\text{s}$ (10 % to 90 %) $< 1 \mu\text{s}$ (50 % to 80 %)
Δ Phase over 0 % to 100% nominal power @ 23°C	$\leq 40^\circ$
Δ phase stability over cooling water temperature at 100 % nominal power	$\leq 2^\circ / ^\circ\text{C}$
Duty factor	$\leq 2 \%$
Pulse duration	$\leq 2 \text{ ms}$
Average pulse repetition rate	$\leq 10 \text{ pulses per second}$
Minimum time between pulses	70 ms
Input impedance	50 Ω
Input VSWR	≤ 1.2
Input power at nominal power	$\leq 7 \text{ dBm}$
Input power maximum	$\leq 10 \text{ dBm}$
RF input connector	N-type, female
Output impedance	50 Ω
Amplifier load	Resonant load with Q-factor of 23000
Reflected power	100 % of max. level, any phase
RF output connector	EIA 4 ½"

3.3.2. Pulse and Repetition Scheme

The high-power amplifier systems at GSI work in a pulse mode operation illustrated in Figure 3.

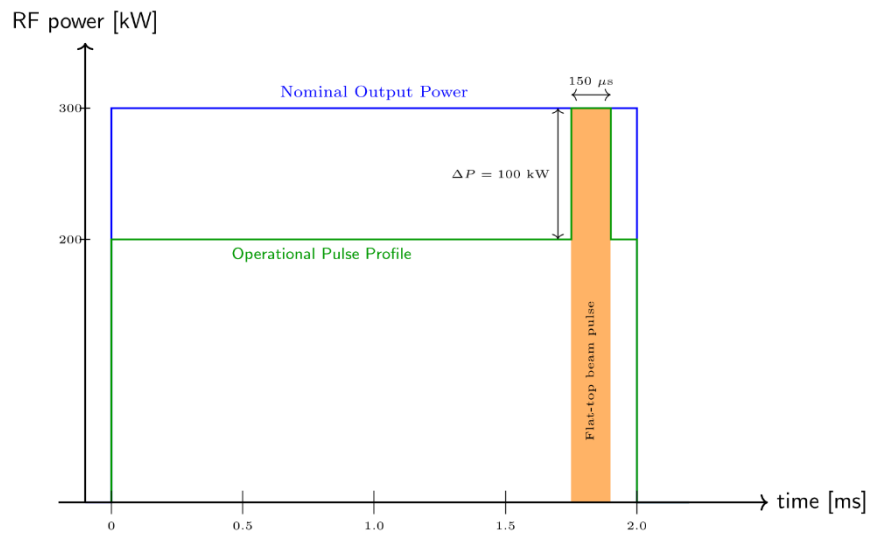


Figure 3: Example RF Pulse

The RF amplitude requirements can vary from time slot to time slot. The maximum RF output power of 300 kW shall be guaranteed at 10 Hz average repetition rate and 2 ms pulse duration. It shall be considered that the repetition scheme can be arbitrary chosen by the accelerator operators and ran from less than 0.1 Hz up to approximately 10 Hz. It shall also be considered that the ion beam within the RF active window depicted in Figure 3 requires a rapid power adaption. The length of a flat-top beam pulse can vary from 30 μ s to 1 ms. The additional power for the ion beam is up to 25 % of the operational RF power and shall be almost instantly provided. All parameters of the specified SSPAs are summarized in Table 1.

3.3.3. Reflected Power

The SSPA shall be able to resist fully reflected power at any phase and at any time, an adjustment of the length of the transmission line is not an option. The use of circulator technology in the RF path is mandatory.

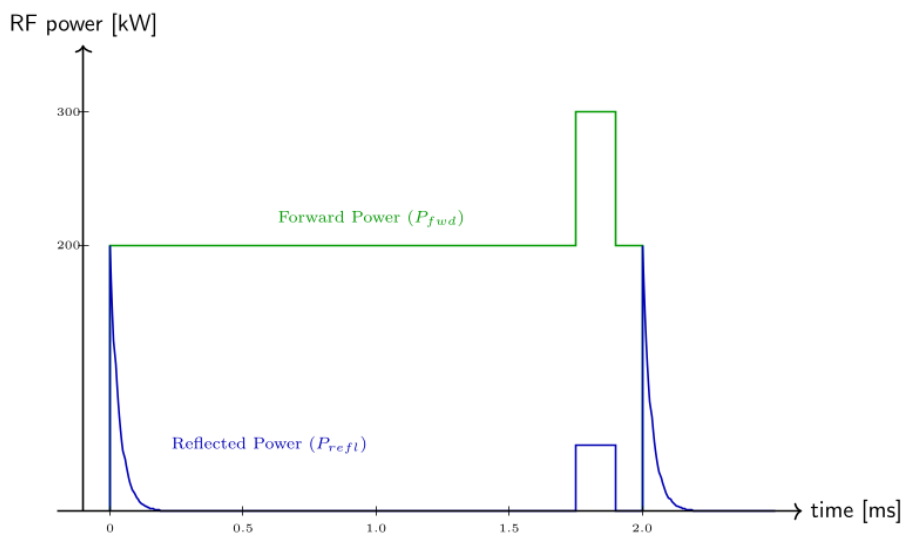


Figure 4: Reflected Power

The green line in Figure 4 depicts the forward power of the SSPA, the blue one shows the reverse power. At the beginning of the RF pulse most of the power is reflected by the non-steady state cavity. Due to mismatch during beam loading power reflection will occur and shall be tolerated for a certain amount. At the end of the RF pulse stored energy is transferred from the cavity to the SSPA.

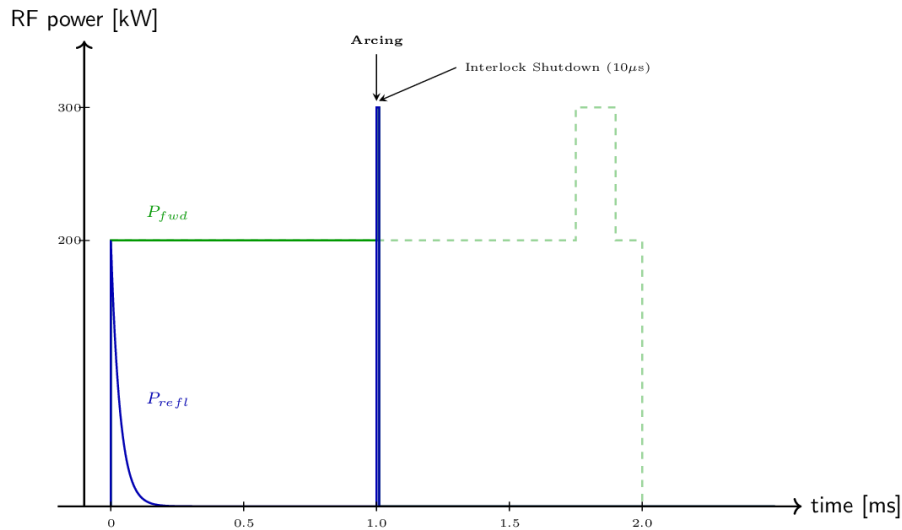


Figure 5: Arcing

In the event of arcing within the cavity (see Figure 5), a total reflection of the SSPA output power shall be anticipated at any time for the entire duration of the RF pulse. The SSPA shall withstand a fully reflected power of 300 kW at a pulse length of 2 ms and a repetition rate of 10 Hz indefinitely. Compliance with this criterion shall be verified during Factory Acceptance Testing (FAT) and Site Acceptance Testing (SAT).

Notwithstanding the amplifier's inherent ruggedness, a fast-shutdown feature with adjustable parameters for absolute reverse power and time delay shall be provided. The minimum achievable shutdown latency shall be $\leq 10 \mu\text{s}$. This function is intended solely for the protection of the transmission line and shall be distinct from the SSPA's internal hardware protection (e.g., circulators). Following a shutdown event, the subsequent RF pulse shall be available at full specified performance without any restrictions.

3.3.4. Fast-Shutdown Interlocks

Analogue to the fast-shutdown feature for reverse power described in section 3.3.3, an additional set of in-pulse-interlocks for absolute forward power and analogue vacuum signals (0 V to 10 V) shall be implemented. Following a shutdown event, the subsequent RF pulse shall be available at full specified performance without any restrictions.

3.3.5. Power Requirements

Each SSPA including all necessary auxiliary power supplies and systems shall be fed by exactly one 400 V three phase circuit. The rated maximum short circuit current of 200 kA at its main input terminals. This value may be relaxed during the design phase pending further information on the characteristics of the supplying network.

The first and only switching device connected to the input terminals shall be a main circuit breaker, followed by a main disconnect switch. The circuit up to and including the main disconnect switch's input terminals shall be especially separated from other parts of the system and well protected against direct contact with active parts, because it may remain energized during maintenance work when the subsequent circuitry is de-energized by means of opening the main disconnect switch (MCCB).

At the input and output terminals of the main disconnecter switch additional means of phase voltage indication and verification of absence of voltage for the purpose of de-energizing the system shall be foreseen, e.g. 3-phase indicator lights.

The output terminals of the main disconnecter switch shall be connected to a busbar from which all additional subcircuits are branched off.

Device-off buttons, door interlock contacts and similar functions for the purpose of device- and operator-protection shall only act on the main disconnecter switch or subsequent disconnecter switches by means of undervoltage relays, as appropriate for the desired function. Circuit breakers shall only act corresponding to their respective overcurrent or short circuit setting or due to an arc-flash interlock. Auxiliary supplies for undervoltage relays and control circuits which are to remain unaffected by device-off actions or similar, shall be derived from inside the system at an appropriate point after the main circuit breaker. No parallel supply from an external source shall be implemented.

For permanent monitoring capability an internal 230 V supply feeding the control unit shall be provided as depicted in Figure 6. This line shall be protected by a separate RCBO.

A minimum of one power outlet (230 V, 10 A) to connect external measurement equipment shall be installed.

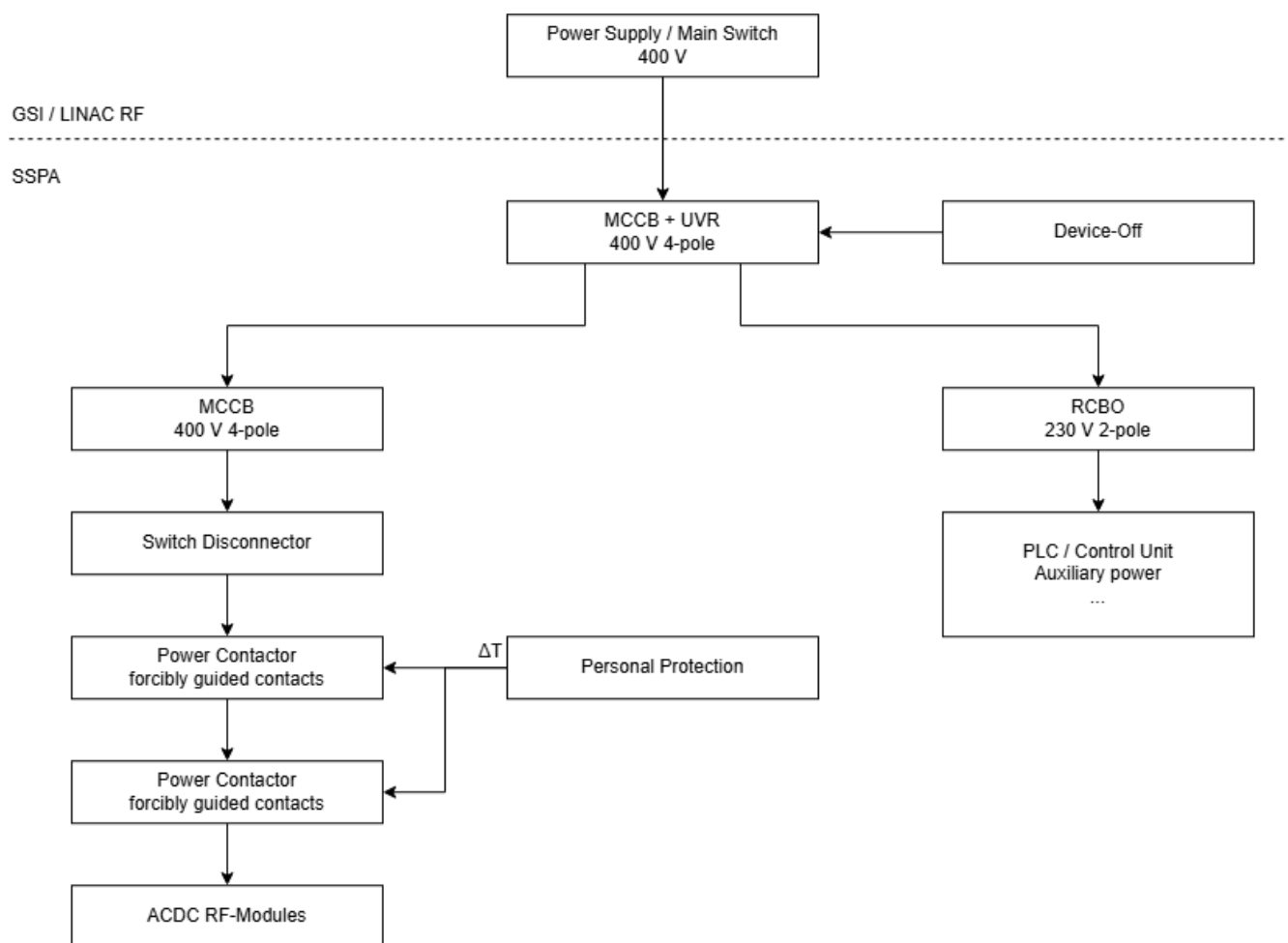


Figure 6: Proposed block diagram of the AC distribution

Figure 6 shows a block diagram of the proposed AC distribution. Regarding safety relay see section 3.4.6.

The used insulating materials shall be halogen-free and self-extinguishing. In case of fire, they must not release toxic or corrosive substances.

The contractor shall provide calculations for the maximum inrush current during power-up and recommendations for the upstream AC circuit protection.

For further requirements and general information see also “Technical Guideline – Electrical Design Rules and Regulations” and “Technical Guideline – Quality of switch cabinets and wiring” in section 6.1.

3.3.6. Cooling Requirements

The water-cooling of the SSPA shall be directly connected to the water-cooling system provided by GSI. The implementation of any separate water-chiller system in the required amplifier system shall be strictly avoided.

Allowed materials for the cooling water circuit are stainless steel, copper, and suitable plastic materials. The use of water cooling is mandatory, forced-air cooling is not an option.

Air-cooling for low energy components is permitted below a total sum threshold, see Table 2.

Table 2: Cooling and Environmental Requirements

Parameter	Value
Cooling	Deionized water (down to 1 μ S/cm)
Cooling water temperature	23 °C +/- 3 °C
Cooling water forward pressure	< 8 bar
Cooling water return pressure	$\approx$ 1.5 – 2.0 bar
Nominal flow rate cooling water	1 m/s (copper), 2 m/s (stainless steel)
Ambient temperature	15 – 45°C
Maximum heat loss to ambient air	< 1 kW
Acoustic noise level @ 1 m	< 65 dB(A)

3.3.7. Operational Requirements

The planned annual operation of the SSPA is at least 300 days (24/7) for the next 25+ years. Maintenance is only possible during short breaks once or twice a year. Unscheduled downtime for repair shall be minimised by design.

To guarantee these requirements redundancy is demanded (see section 3.7).

3.3.8. Personal Safety Requirements

Personal safety comprises user safety as well as RF interlock.

The rack doors shall be monitored and locked for protection against electrical hazard. Personal safety shall be guaranteed at any time. In particular, the following safety features shall be implemented:

- Rack doors with live parts shall be locked as long as internal AC voltages are over 25 V, DC voltages are over 60 V and stored energy is over a threshold of 350 mJ.
- Door switches are required for safety and monitoring. An open rack door shall prevent the system to transit to a potentially dangerous state.
- Rack doors with no live parts shall be monitored, but not be part of the personal safety interlock. The state shall be displayed on the HMI.
- The use of a safety relay is mandatory. The performance level of the used safety devices shall be PLc or higher.

An additional personal safety requirement is the TVS Personal Safety Interlock of the UNILAC which prohibits any RF power while access to the accelerator is granted.

- In this case, the production of any RF power shall be impossible. Therefore, at least one RF relay at the input of the SSPA shall be foreseen.
- Both RF signals and DC power supplies shall be shut down. The RF signal shall be shut down in a time span of $t_{off,rf} = 1 \mu s$ or less. Eventually the AC contactors shall open in a time $t_{off,ac}$ which will be specified during the conceptual design phase.
- The shutdown shall be made in a controlled, load-less way for device protection. A staggered shutdown is permitted, as long the critical time requirements are met. Figure 7 illustrates an exemplary shut down sequence.
- The use of a safety relay is mandatory. The performance level of the used safety devices shall be PLd or higher.
- The safety state of the SSPA shall be provided to the external interlock system TVS.

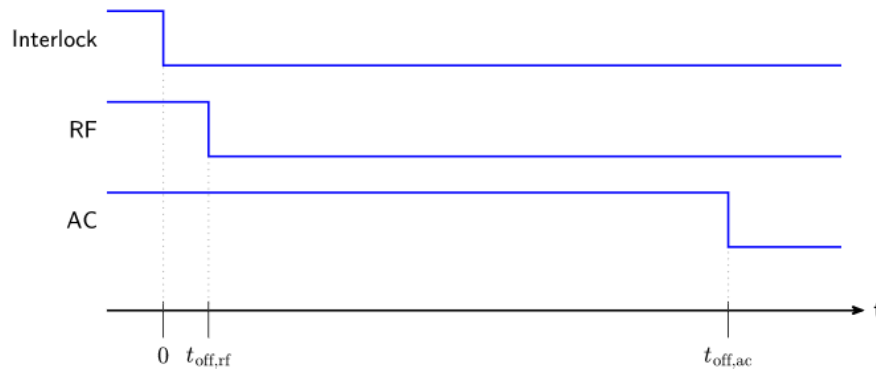


Figure 7: Example for a TVS RF Interlock

For further information see technical guideline “Electrical Design Rules and Regulations” (F-TG-ET-01e).

The SSPA shall be designed to be arc-fault-proof in accordance with IEC 61641 and shall meet the following requirements:

Table 3: Arc-fault-proof Parameters

Parameter	Value
Rated voltage	400 VAC
Rated frequency	50 Hz
Rated short-circuit withstand current ($I_{cw} = I_{p,arc}$)	50 kA (rms)
Arcing class	B (the arc fault shall be confined to a single rack)

3.3.9. Machine Safety

Two keyless black device-off buttons shall be installed at the SSPA front and back side respectively. In case of a device-off event the 400 V mains supply shall be disconnected by opening the main circuit breaker. The SSPA system shall transition to a safe state. This includes the internal 230 V voltage supply of the control unit as well.

In case of permanent loss of one or multiple phase voltages or in case of transient voltage dips beyond its hold-up capabilities, the SSPA system shall transition to the same safe state.

The SSPA shall monitor all relevant signals concerning its safety. In the case of an error, it shall protect itself by taking appropriate measures e.g., turning off the RF or shutting down the amplifier. All critical errors shall be acknowledged by a reset before returning into operational state.

At least the following features are required:

- Water-cooling circuits shall be monitored. Factors like flow, pressure and temperature shall be considered. Additional leakage detection by sensors placed at the bottom of the racks is required. In case of leakage, they shall notify the control unit and open the main circuit breaker. The exact behaviour will be discussed during the design phase.
- The installation of smoke detectors is mandatory. In case of fire, they shall notify the control unit and open the main circuit breaker. The exact behaviour will be discussed during the design phase.
- RF power i.e., forward as well as reflected power, shall be monitored on global and modular level. If thresholds are reached the SSPA shall react in such a way that no component gets damaged.
- Comprehensive monitoring of all critical voltages, currents and temperatures is mandatory at the modular level. This applies to the power supply units and RF power modules, extending down to the individual RF pallets, combiners, circulators and loads. Malfunctioning components shall be reliably identified.

3.4. Signals and Interfaces

3.4.1. RF Measurement Signals and Connectors

To connect the LLRF to the SSPA a panel with the signals listed in Table 4 is required. The connectors shall be of N-type.

Table 4: LLRF RF connection points

Source	Type	Label	Quantity	Level
Input RF power	input	LLRF_RF_In	1	≤ 10 dBm
SSPA RF power fwd	output	LLRF_SSPA_fwd	1	≤ 20 dBm
SSPA RF power refl	output	LLRF_SSPA_refl	1	≤ 20 dBm

It is mandatory to monitor the RF power at different stages of the SSPA. The appropriate signals are summarized in Table 5. Therefore, another panel with N-type connectors is required.

Table 5: RF measurement output

Source	Direction	Label	Quantity
Input RF power	forward	RF_In	1
SSPA RF power	forward	SSPA_fwd	2
SSPA RF power	reflected	SSPA_refl	2

To ensure an unaffected RF operation the amplifier shall be equipped with independent 2-way directional coupler for those measurements. The required parameters of the coupler at the output of the SSPA (P1, P2) is given in the following table.

Table 6: Parameters RF coupler

Parameter	Value
Coupling factor	-50 dB
Accuracy	$\pm 0,1$ dB
Directivity	>30 dB
Impedance	50 Ω

3.4.2. Digital LLRF Interface

The digital communication between the LLRF and the SSPA shall run over Ethernet (1000BASE-T or 100BASE-T) via OPC-UA. An appropriate RJ45 connector shall be provided. A detailed list of signals and commands will be defined during the design phase.

3.4.3. LAN Interface

An additional LAN interface (isolated port) is required that provides all available status and measurement signals. Furthermore, the warning / error list of the amplifier system and each amplifier module shall be available via the LAN interface. A DHCP client shall be implemented to connect easily to the amplifier. The interface shall be platform independent, a browser-based solution for remote access is preferred. The additional provision of internal data of the SSPA via OPC-UA server will be positively assessed. A detailed concept will be discussed during the design phase.

3.4.4. Gating Signal

A gating signal is provided that represents the RF pulse cycle. For this reason, a BNC connector is required. A signal level of 0 V indicates RF operation and 5 V indicates that there is no RF operation. The RF operation starts with a delay with respect to the rising edge of the gating signal which shall be defined during the design phase.

3.4.5. Cavity Water and Vacuum Interlocks

A connector for the cavity water-cooling and vacuum interlock signal is required:

Table 7: Interlock Signals Connector Vacuum/Water

Signal name	Unit	Level at pin	Pin #	Signal direction	Comment
Vacuum interlock supply	V	24V	1	Amp out	Power supply for vacuum interlock
Water interlock supply	V	24V	2	Amp out	Power supply for water interlock
Vacuum interlock	V	alarm = open OK = closed	3	Amp in	Global safety interlock signal
Water interlock	V	alarm = open OK = closed	4	Amp in	Global safety interlock signal

3.4.6. TVS Personal Safety Interlock

To accommodate the site's Personnel Safety System (PSS), the amplifier's safety interface shall be designed as a universal, fail-safe interface compliant with ISO 13849-1 (Min. PL d).

- Input (Command): The contractor shall provide a dual-channel, redundant input circuit. This interface shall be compatible with both potential-free safety contacts and electronic safety outputs. The system shall detect cross-circuits and external voltage injection as a fault state.
- Output (Feedback/Status): To enable external device monitoring, the amplifier shall provide a dual-channel, potential-free feedback signal (utilizing forced-guided relays or equivalent safety-rated electronics). This feedback shall directly represent the safe state (e.g., high voltage off and RF drive inhibited).
- Connector: The physical interface shall use a standardized, ruggedized industrial connector (e.g., M12 or Han-Series) with the pinout to be finalized during the design review phase.

Table 8: Safety Interlock Signals Connector PSS

Signal name	Level at pin	Pin #	Signal direction	Comment
PSS supply	24V	1	Amp out	
PSS interlock A		2	Amp in	Global safety interlock signal
PSS interlock B		3	Amp in	Global safety interlock signal
PSS interlock reference	0V / GND	4	Amp out	
PSS status reference A	Potential-free	5	Amp in	
PSS status A	Potential-free	6	Amp out	Safe state = closed operational = open
PSS status reference B	Potential-free	7	Amp in	
PSS status B	Potential-free	8	Amp out	Safe state = open operational = closed

3.5. Internal Controls and Graphical User Interface

For the implementation of control and state machine of the SSPA, GSI permits only the use of a Siemens S7-1500 series PLC. In addition, each SSPA shall provide an HMI / GUI for the user. It shall comprise at least the following features:

- Control buttons for the state machine,
- Visualisation of the state machine,
- Display of current errors,
- Display of current warnings,
- Archives for errors and warnings with sub-second precise timestamps,
- Each archive shall be capable of saving at least the last 1000 entries,
- Synchronisation over time server,
- Implementation of an OPC-UA server.

Furthermore, an expert user interface which enables the trained user to adjust settings like thresholds within reasonable limits is mandatory.

With respect to sustainable operation notifications of upcoming maintenance are desirable for all critical components.

3.5.1. Control: Hand / Remote

A rotary switch is required which determines if the SSPA is controlled locally by the GUI or by remote control via commands from GSI's side. It shall be located close to the HMI.

3.5.2. Reset

A reset button close the HMI is mandatory. It shall work both in local mode and during remote control. An additional depiction of a received reset at the GUI is requested.

3.6. Mechanical Design

The SSPA shall be arranged in two racks. The first comprises the control units, HMI, the AC feeding and, if necessary, low level RF components like RF driver or RF splitter. The second rack exclusively contains all RFPM and RF combiners as well as PSU.

3.6.1. Maximum Dimensions

The maximum mechanical rack dimensions of a single SSPA are restricted to 2000 mm x 2300 mm x 1400 mm (width x height x depth). The RF power rack shall not exceed a width of 1000 mm.

The final mechanical design of the amplifier system shall be submitted in the FDD and will be approved by GSI in the FDR. Each cabinet shall be equipped with height-adjustable feet for levelling.

3.6.2. Connector Arrangement

All global connectors for mains supply, cooling-water, RF input, RF output and signal ports as well as communication ports shall be arranged at the top of the amplifier system. The side rack walls shall remain clear for side-by-side installation. Installation on a raised floor is not an option.

Appropriate connectors will be specified during the conceptual design phase and finalised in the CDD.

3.6.3. Enclosure Rating

The enclosure rating shall be at least IP51.

3.6.4. Transportation and Delivery

The racks of the SSPA shall be separable for transportation. Final assembly is done at the installation location. The separate SSPA racks shall be liftable by crane. Therefore, appropriate transport lugs are required.

For further requirements and general information see also "Technical Guideline – Transport" in section 6.1.

3.7. Redundancy

The SSPA architecture shall be designed for high availability and fault tolerance. It is understood that the failure of a single RF component (e.g., transistor or circulator) may lead to disproportionate power losses due to resulting mismatches and dissipation within the combining structures. Consequently, the contractor is required to provide comprehensive simulations and a failure mode analysis for the entire RF chain.

The simulations shall demonstrate the impact on total output power, phase stability and the 1dB compression point for the following scenarios:

- Transistor failure: Failure of one individual RF transistor,
- Pallet failure: Failure of one individual RF pallet,
- Module failure: Complete loss of one RF Power Module,
- Passive component failure: Malfunction of circulators or isolation resistors within the combiner tree,
- Power supply failure: Loss of one or more DC power units.

Minimum demands concerning redundancy are given in Table 9.

Table 9: Redundancy Requirements

Device	Minimum redundancy
DC supply for control unit	100 %
DC supply for RF power modules	Minimum 20 %

4. Project Organization and Production Release

This call for tender implies a customizing process of the RF amplifier system in close interaction with the LINAC RF department at GSI. The participants of this tender shall submit a conceptual design of the amplifier system, which convinces GSI.

After the application process, a kick-off meeting will take place with the contractor to discuss technical details and issues regarding project management. Following up the kick-off meeting, the contractor shall submit a conceptual design document (CDD) that summarizes the discussed issues and presents feasible solutions. This document shall pass the conceptual design review (CDR) by GSI. The final design document (FDD) will complete the planning phase. This document shall include:

- System design overview,
- BOM of the amplifier system,
- Design document of each module (RF modules and power supply modules),
- BOM of each module,
- Schematics, board layouts and assembly drawings of each PCB,
- Wiring diagrams,
- Mechanical drawings including a 3D model of the SSPA,
- Technical report including simulation and measurements of the thermal modelling regarding the RF modules (especially transistor cooling),
- Manufacturing time, as progress diagram (time schedule) including the expected dates for FAT and delivery,
- A list of recommended spare parts including prices and quantities.

GSI will schedule a review period of up to 20 workdays to approve the FDD with its technical details and drawings. The review includes a quality assurance that verifies all submitted documents. As a result of the successful final design review (FDR) GSI will grant a production release and the contractor shall build the amplifier systems according to this specification and the FDD.

In the following customizing process, an effective collaboration between the contractor and GSI shall be ensured. This collaboration shall be enabled by monthly progress reports of the contractor to GSI. Upcoming technical and organizational issues of the amplifier system during this project phase shall be discussed and solved in strong cooperation. Furthermore, GSI shall release each customized unit of the SSPA based on the documentation provided by the contractor before the module production starts. These acceptance tests are a mandatory prerequisite for continuing the project. Inspections by GSI staff members during manufacturing time shall be possible after announcement.

5. Documentation

The following documents shall be supplied at delivery (one set in paper form and digital version):

- User manual including detailed descriptions of all interfaces,
- General description, maintenance and calibration instructions,
- Overview drawing of the amplifier system,
- BOM of the amplifier system,
- Source code and associated source code files,
- Design document of each module (e.g., RFPM and PSU),
- BOM of each module,
- Complete circuit diagram of the amplifier system and each module,
- Wiring diagrams and terminal connection table of each module,
- Layouts of electric and electronic schemes including circuit board arrangements,
- Description of analogue and digital circuits, as well as service and adjustment (calibration) instructions,
- Mechanical drawings (PDF, STEP and DWG files or similar CAD files),
- Test and acceptance certifications,
- CE-compatibility statement, declaration of incorporation (“Einbauerklärung”),
- List of recommended spare parts, including recommended quantities and costs,
- Risk assessment (“Gefährdungsbeurteilung”, etc.).

Schematics created by a CAD system, also text based on Microsoft Word®, shall be delivered on an adequate data medium. Documentation language is to be stipulated by order.

6. Standards and Technical Guidelines

6.1. GSI Documents

Table 10 shows the Technical Guidelines provided by GSI.

Table 10: Technical Guidelines

Technical guideline	File name
Electrical design rules and regulations	F-TG-ET-01e Electrical Design Rules and Regulations v3
Quality of switch cabinets and wiring	C-TG-GAT-en-Quality-of-switch-cabinets-and-wiring-V002
Transport	F-TG-T-01e Transport V002

6.2. EMC Compatibility and Requirements

The compliance with the EMC standards shall be verified by an accredited EMC laboratory. RF radiation shielding shall fulfil all related standards, in particular:

- EN IEC 61000-6-4:2020-09,
- EN IEC 55011:2026-05,
- EN IEC 61326-1:2022-11.

The required SSPA system will be treated as a Class A, Group 1 equipment according to EN 55011. At the operating frequency of 108.4 MHz the radiated emission limit is relaxed from 50 dB μ V/m to 60 dB μ V/m at 3 m measurement distance.

It is not mandatory to perform the surge test according IEC 61000-4-5 in an accredited EMC laboratory. Nevertheless, the contractor shall show that the required SSPA system has the ability to withstand the defined surge test parameters defined in IEC 61000-4-5. Furthermore, the amplifier system shall fulfil the attached GSI/FAIR technical guideline “Electrical Design Rules and Regulations”.

6.3. Safety Requirements

The device shall match all CE requirements and a statement of CE-compatibility (declaration of incorporation). A risk assessment document shall be submitted at delivery.

6.4. Quality Management

The contractor shall be certified by an accredited certification body according to ISO 9001.

7. Acceptance

7.1. Factory Acceptance Test (FAT)

Precondition for the FAT is an operation of the amplifier system at design parameters shown and documented in the stipulated monthly progress reports. Furthermore, all RF equipment used for the FAT shall be calibrated. The contractor shall set up the technical equipment to perform the factory acceptance tests at full peak and average power as required by this specification to a 50 Ω dummy load. GSI shall be informed at least 20 days before start of the FAT. GSI may also request test data in advance. A written test report containing all tests shall be provided by the contractor to GSI after the test. A 24-hour test at the maximum output level shall be demonstrated on a dummy load.

The contractor shall present a draft of an acceptance test template latest two weeks before acceptance test.

The FAT shall include at least following items:

- Verification of correct amplifier system start up and all defined interlock functions,
- Control panel check and verification of all control functions and status indications, respectively,
- RF measurements with a signal generator as source and a 50 Ω load at the amplifier output:
 - All specified parameters of Table 1 can be tested.
 - Demonstration of the maximum output power and check of the internal power measurements by the amplifier system. This test also includes the verification of the integrated monitoring.
 - Evaluation of the harmonic and non-harmonic distortions at maximum output power measured with an external coupler and spectral analyser.
 - Verification of the input/output characteristics especially according to the required linearity.
 - Test of external triggering with a pulsed signal generator (AM mode) and an independent TTL-trigger.
- System test with different RF pulses according to section 3.3.2. The pulse durations, repetition rates and RF pulse power are arbitrary and will be defined at the FAT according to specified parameter range:
 - The specified rise time of RF output pulses,
 - The distortion/droop of the pulse shape during the RF pulse,
 - Test with adequate load and short at the output port of the amplifier system at any given phase (details to be discussed),
 - Test with different rising edges and times,
 - All tests can be executed with arbitrary RF phase and RF power level.

7.2. Site Acceptance Test (SAT)

The SAT includes the installation and commissioning of the SSPA at GSI. The date of the SAT has to be scheduled according to the operating conditions at GSI. All tests of the FAT can be requested by GSI. The SAT will contain two test scenarios: In the first scenario the amplifier shall operate on a 50 Ω dummy load and in the second scenario on a resonant load (accelerator cavity). For this reason, the SAT might be divided in two appointments. Both scenarios will include a 2-hour test at the maximum output level.