HARDWARE DESIGN SPECIFICATION

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11. Revision History
    - Version | Date | Author | Description of Changes

1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

The purpose of this Hardware Design Specification (HDS) document is to define the detailed hardware architecture, design requirements, components, and interfaces for Aurora. This document serves as the authoritative reference for the design, development, verification, and manufacturing of the system hardware.

Specifically, this document aims to:

- Provide a comprehensive description of the hardware subsystems, including power supply, control electronics, ozone generation, sensors, actuators, and enclosure.
- Specify mechanical, electrical, and environmental design requirements to ensure compliance with safety, regulatory, and performance standards.
- Serve as a baseline for system integration, testing, validation, and certification.
- Facilitate communication between hardware engineers, manufacturing teams, quality assurance, and regulatory bodies.

This document is intended for engineers, designers, project managers, and other stakeholders involved in the development, assembly, maintenance, and certification of Aurora.

1.2 SCOPE OF THE HARDWARE DESIGN

The hardware design of Aurora encompasses all physical and electrical components required to generate and deliver controlled ozone concentrations for industrial sanitization purposes. The scope includes, but is not limited to:

1. Power Subsystem: AC/DC input, power conversion, backup systems, and protection circuits.
2. Control Subsystem: Microcontroller or embedded processor, digital and analog interfaces, communication ports, and control logic hardware.
3. Ozone Generation Subsystem: Ozone generators, high-voltage circuits, cooling mechanisms, and safety interlocks.
4. Sensor Subsystem: Ozone concentration sensors, temperature and humidity sensors, flow meters, and safety sensors.
5. Actuator Subsystem: Fans, valves, relays, and other devices required for ozone delivery and ventilation.
6. Mechanical Subsystem: Enclosure design, mounting, thermal management, materials selection, and assembly features.
7. Electrical Interfaces: PCB design, signal routing, connector pinouts, grounding, and EMI/EMC compliance.
8. Environmental and Safety Requirements: Operating conditions, environmental tolerances, protection against ozone leaks, and compliance with regulatory and safety standards (ISO, IEC, UL, CE).

The scope explicitly excludes software implementation details, user manuals, and operational procedures, which are covered in separate documentation. This ensures that the hardware design specification remains focused, precise, and actionable for hardware development, testing, and certification.

1.3 DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

This section provides the definitions of technical terms, acronyms, and abbreviations used throughout this document to ensure clarity and consistency.

Term / Acronym	**Definition**
HDS	Hardware Design Specification
PCB	Printed Circuit Board
EMI	Electromagnetic Interference
EMC	Electromagnetic Compatibility
IP Rating	Ingress Protection Rating (IEC 60529 standard)
AC	Alternating Current
DC	Direct Current
O3	Ozone, a triatomic oxygen molecule used for sanitization
HVAC	Heating, Ventilation, and Air Conditioning
ISO	International Organization for Standardization
IEC	International Electrotechnical Commission
UL	Underwriters Laboratories
CE	European Conformity

Notes:

- All technical terminology in this document follows the IEEE and IEC standards wherever applicable.
- Acronyms and abbreviations are defined on first occurrence in the text to maintain readability.
- Units of measurement follow the SI standard system unless otherwise specified.

2. SYSTEM OVERVIEW

2.1 HIGH-LEVEL SYSTEM DESCRIPTION

Aurora is an industrial-grade device designed to provide controlled ozone-based sterilization for air and surfaces in commercial and industrial environments. The system integrates multiple hardware subsystems including ozone generation, sensing, control electronics, power management, and actuation to deliver reliable, safe, and efficient sanitization.

The hardware architecture is modular, with distinct subsystems communicating through standardized interfaces, enabling ease of maintenance, upgrade, and scalability. The system is enclosed in a robust, thermally managed housing designed to comply with industrial safety standards while protecting sensitive electronic and mechanical components.

Key functional highlights:

- Industrial ozone generation using high-efficiency dielectric barrier discharge modules.
- Multiple environmental sensors (ozone, temperature, humidity) for closed-loop control.
- Central microcontroller unit (MCU) for monitoring, safety enforcement, and actuator control.
- Redundant safety mechanisms including overcurrent protection, emergency shutdown, and leak detection.
- Modular design for easy maintenance and replacement of critical components.

2.2 FUNCTIONAL OBJECTIVES

The hardware is designed to achieve the following primary objectives:

1. Safe and Controlled Ozone Generation
   - Deliver ozone concentrations within pre-defined safe operational limits.
   - Ensure rapid activation and deactivation of ozone output under software or manual control.
2. Environmental Monitoring and Feedback
   - Continuous real-time monitoring of ambient ozone, temperature, and humidity.
   - Provide sensor feedback to the control subsystem to maintain optimal sanitization conditions.
3. Reliable Power Management
   - Stable power supply to all subsystems with protections against voltage spikes, overcurrent, and short circuits.
   - Ability to operate from a standard industrial power source while maintaining efficiency.
4. User and Maintenance Safety
   - Emergency shutdown and fail-safe mechanisms to prevent accidental ozone exposure.
   - Mechanical and electrical safeguards for safe maintenance access.
5. Interoperability and Control
   - Standardized interfaces for communication with software control systems.
   - Compatibility with remote monitoring, logging, and reporting features.

2.3 SYSTEM BLOCK DIAGRAM

The following diagram represents the high-level hardware architecture of Aurora:

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Explanation of Flow:

Power Supply feeds the Control MCU.

MCU handles processing, safety logic, and communicates with both sensors and user interface.

Sensor data informs the control loop, which adjusts actuators to maintain safe and effective ozone output.

Actuator system drives ozone valves, fans, and relays to execute commands from the MCU.

2.4 KEY PERFORMANCE INDICATORS

To ensure that the hardware meets industrial and operational requirements, the following KPIs are defined:

KPI	**Target**	**Measurement Method**
Ozone Concentration Range	050 ppm (adjustable)	Calibrated ozone sensor output
Response Time	< 5 seconds from command to ozone output change	Time-stamped control logs
Sensor Accuracy	±2% for ozone, ±1°C temperature, ±3% RH	Calibration verification
Power Efficiency	>= 85% overall system efficiency	Power analyzer measurements
Operational Reliability	MTBF >= 20,000 hours	Historical testing and accelerated aging
Safety Compliance	IEC/UL certified	Compliance testing and documentation
Environmental Tolerance	040°C, 1090% RH	Environmental chamber tests
Noise Level	<= 60 dB at 1 m	Sound level meter measurements

These KPIs serve as both design targets and verification benchmarks during testing, calibration, and operational validation.

3. HARDWARE ARCHITECTURE

The hardware architecture of Aurora is designed to ensure reliability, modularity, and safety while meeting performance requirements. The system is divided into five primary subsystems: Power, Control, Ozone Generation, Sensors, and Actuators. Each subsystem is engineered to function independently yet interact seamlessly through defined interfaces.

3.1 SUBSYSTEM BREAKDOWN

3.1.1 POWER SUBSYSTEM

The power subsystem provides stable and reliable electrical energy to all components of Aurora.

- Input Power: 100240 VAC, 50/60 Hz, single-phase.
- Power Conversion: Step-down transformers and DC-DC converters generate regulated 12 V DC rails.
- Protection Features:

- Overcurrent protection via fast-blow fuses.

- Surge protection and transient voltage suppression.

- Ground fault detection circuits.

- Power Monitoring: Integrated voltage and current sensors provide real-time monitoring for fault detection and energy management.
- Redundancy: Critical components, such as the microcontroller and ozone generator driver, have secondary backup power rails to ensure safe operation in case of main power failure.

3.1.2 CONTROL SUBSYSTEM

The control subsystem serves as the "brain" of Aurora, managing operations, monitoring safety, and executing user commands.

- Core Controller: Industrial-grade microcontroller (ESP32 or equivalent) with sufficient I/O pins and memory for real-time processing.
- Interfaces:

- Digital I/O for actuator control.

- Analog inputs for sensor readings.

- Communication interfaces: I2C, UART, SPI, optional Ethernet or Modbus TCP/IP for external monitoring.

- Software Integration: Runs embedded firmware implementing control logic, safety checks, scheduling, and logging.
- Fault Handling: Watchdog timers, system reset circuits, and error reporting mechanisms ensure safe shutdown during anomalies.

3.1.3 OZONE GENERATION SUBSYSTEM

This subsystem produces and delivers controlled ozone concentrations for sanitization.

- Ozone Generator Type: Corona discharge.
- Driver Circuit: High-voltage DC or AC driver with regulated output to control ozone production rate.
- Safety Features:

- Current and voltage limiting.

- Interlock circuits to prevent operation when the enclosure is open.

- Flow Management: Integrated fans or blowers to direct ozone through the treatment area uniformly.

3.1.4 SENSOR SUBSYSTEM

The sensor subsystem monitors environmental conditions, system health, and ozone levels to ensure safe and effective operation.

- Ozone Sensors: Electrochemical sensors to measure ozone concentration in real time.
- Environmental Sensors: Temperature, humidity, and airflow sensors for system performance and safety monitoring.
- Electrical Interface: Analog-to-digital conversion or digital protocols (I2C/SPI) for microcontroller integration.
- Safety Monitoring: Redundant sensors in critical zones to detect leaks or abnormal ozone levels.

3.1.5 ACTUATOR SUBSYSTEM

The actuator subsystem physically executes control commands to regulate ozone delivery, airflow, and safety mechanisms.

- Valves: Solenoid or motor-driven valves controlling ozone output.
- Fans/Blowers: Variable-speed fans to distribute ozone effectively.
- Relays and Switches: Electrically isolated relays to switch high-power circuits safely.
- Emergency Actuators: Fail-safe relays and shutdown mechanisms triggered by the control subsystem during fault conditions.

3.2 COMPONENT SELECTION RATIONALE

Component selection is guided by reliability, availability, safety, and performance criteria:

- Reliability: All components are rated for continuous operation within the expected temperature and humidity range.
- Safety Compliance: Components meet IEC, UL, or CE safety standards where applicable.
- Electrical Specifications: Voltage, current, and tolerance ratings exceed peak system demands with at least 20% margin.
- Environmental Tolerance: Components selected to withstand thermal cycling, vibration, and potential ozone exposure.
- Supplier Considerations: Preference for reputable suppliers with long-term availability to

ensure maintainability.

- Cost vs. Performance: Balanced to achieve optimal system performance while keeping overall costs reasonable.

3.3 SUBSYSTEM INTERCONNECTIONS

Subsystems are interconnected using well-defined electrical and mechanical interfaces to ensure modularity, maintainability, and safety:

- Power Distribution: Central power rail feeds all subsystems with proper isolation and filtering.
- Control Signals: Digital and analog lines connect sensors and actuators to the main controller, with isolation where required.
- Communication Buses: I2C/SPI/UART lines interconnect sensors, controllers, and optional external interfaces.
- Mechanical Integration: Subsystems are mounted within a single enclosure with vibration damping and secure cable routing.
- Safety Interlocks: Subsystem interfaces include interlocks to prevent unsafe operation (e.g., ozone generator disabled if enclosure door is open).

Figure 3.1 Hardware Architecture Block Diagram: (Placeholder for visual block diagram showing all five subsystems and interconnections.)

4. MECHANICAL DESIGN

The mechanical design of Aurora encompasses the enclosure, structural components, mounting mechanisms, thermal management solutions, materials, tolerances, and assembly methods. The design ensures structural integrity, safety, serviceability, and compliance with environmental and operational requirements.

4.1 ENCLOSURE DESIGN AND DIMENSIONS

- Overall Form Factor: The enclosure is designed as a rectangular cabinet with dimensions of [Width × Depth × Height] mm to accommodate all subsystems, allow adequate airflow, and provide easy access for maintenance.
- Internal Layout: Components are arranged to minimize wiring length, reduce electromagnetic interference (EMI), and optimize airflow for thermal management. Subsystems (power, control, ozone generator, sensors) are grouped logically.
- Access Points: Front and rear panels include removable covers for maintenance, service ports, and user interfaces. Side panels include cable entry points with grommets.
- Sealing and Protection: Gaskets and seals provide IP54 protection, preventing dust and water ingress while allowing ventilation where required.
- Mounting Provisions: The enclosure includes internal rails, brackets, and standoffs to secure PCBs, sensors, actuators, and auxiliary modules.

4.2 MOUNTING AND INSTALLATION CONSIDERATIONS

- Installation Method: The system can be wall-mounted, floor-mounted, or rack-mounted depending on the facility layout.
- Mounting Hardware: Includes reinforced mounting points with M6 threaded inserts for secure attachment.
- Vibration and Shock Isolation: Rubber or silicone pads are included to reduce vibration transfer from motors, fans, or external sources.
- Accessibility: All panels are removable without specialized tools, allowing maintenance without disassembling the entire enclosure.
- Weight Distribution: Components are placed to maintain center of gravity near the base for stability during handling and operation.

4.3 THERMAL MANAGEMENT

Efficient thermal management ensures reliability and extends component lifespan by maintaining operational temperatures within manufacturer-specified limits.

4.3.1 VENTILATION

- Passive Ventilation: Strategically placed vents on top and bottom of the enclosure allow natural convection to remove heat from low-power components.
- Active Ventilation: High-power components (e.g., ozone generator and power supply) use forced airflow with low-noise axial fans.
- Airflow Path: Internal baffles guide air across heat-generating components, ensuring uniform cooling and minimizing hotspots.
- Filters: Removable dust filters protect fans and sensitive electronics from particulate

accumulation.

4.3.2 HEAT SINKS

- Material: Aluminum heat sinks with high thermal conductivity (>= 200 W/m·K) are used on power electronics.
- Mounting: Heat sinks are mechanically secured with thermal interface material (TIM) to ensure efficient heat transfer.
- Design: Finned structures maximize surface area while minimizing airflow resistance.

4.3.3 COOLING FANS

- Fan Selection: Industrial-grade, brushless DC fans with rated life >= 50,000 hours.
- Control: Fan speed is controlled via temperature sensors on critical components for dynamic thermal regulation.
- Noise and Vibration: Fans are mounted with anti-vibration grommets; noise levels kept below [specified dB limit].

4.4 MATERIAL SELECTION AND FINISH

- Enclosure: Powder-coated steel or aluminum alloy for rigidity, corrosion resistance, and electromagnetic shielding.
- Internal Mounts: ABS or polycarbonate brackets for lightweight support and electrical insulation.
- Surface Finish: Smooth, matte finish for aesthetic consistency and ease of cleaning.
- Corrosion Protection: Components exposed to high ozone concentrations are anodized or coated to prevent oxidation.
- Fire Safety: Materials meet UL94 V-0 flammability rating.

4.5 MECHANICAL TOLERANCES

- Dimensional Accuracy: ±0.5 mm on critical mounting points, ±1 mm on overall enclosure dimensions.
- Flatness and Parallelism: Panels maintain flatness within ±0.3 mm to ensure proper sealing and gasket performance.
- Hole Locations: ±0.2 mm tolerance for PCB standoffs, fan mounts, and fastener holes.
- Assembly Repeatability: Designed for consistent assembly without the need for adjustment tools.

4.6 ASSEMBLY CONSIDERATIONS

- Modular Design: Subsystems are designed as modules for ease of assembly and replacement.
- Fasteners: Use standardized fasteners (M3, M4, M6) with torque specifications indicated in the assembly instructions.
- Cable Management: Integrated channels and clips reduce strain and prevent interference with moving components.
- Ease of Maintenance: Front-access panels, quick-release latches, and labeled connectors reduce downtime.

- Documentation: All assembly steps, torque specifications, and alignment instructions are detailed in the Assembly Instructions document.

5. ELECTRICAL DESIGN

The electrical design of Aurora ensures reliable, safe, and efficient operation of all subsystems, including power delivery, control, sensing, actuation, and communication. This section covers power requirements, safety features, sensor and actuator interfaces, and PCB design considerations.

5.1 POWER REQUIREMENTS

5.1.1 INPUT VOLTAGE AND CURRENT

- Input Voltage: The system accepts a nominal AC mains input of 100240 VAC, 50/60 Hz.
- Operating Current: Maximum steady-state current is 4.2 A at 230 VAC.
- Startup Surge: Inrush current limited to 10 A using NTC thermistor and soft-start circuitry.
- DC Subsystems: The system converts AC mains to regulated DC rails:

- +12 V DC: Logic, sensors, controllers, actuators and relays

- Voltage Tolerances: ±5% for all DC rails under full load
- Input Protection: MOVs for transient suppression and surge protection.

5.1.2 POWER CONVERSION

- AC/DC Conversion: Switch-mode power supply (SMPS) with efficiency >= 90%
- DC/DC Regulation: High-efficiency synchronous buck converters for each DC rail
- Isolation: Transformers provide galvanic isolation between AC mains and low-voltage circuits
- Power Sequencing: Soft-start for sensitive components; sequence controlled via microcontroller

5.1.3 REDUNDANCY AND BACKUP

- Redundant Power Supply: Optional secondary SMPS can be added for critical installations
- Battery Backup: 12 V 7 Ah sealed lead-acid or Li-ion battery for emergency shutdown and safe ozone module deactivation
- Automatic Failover: Microcontroller monitors primary supply and switches to backup within 10 ms if undervoltage is detected

5.2 SAFETY FEATURES

5.2.1 FUSES AND CIRCUIT BREAKERS

- Fuses: Fast-acting fuses on all DC rails, rated 125% of maximum operating current
- Circuit Breakers: Thermal-magnetic breakers on AC mains input, rated for 110% of nominal load
- Overcurrent Detection: Microcontroller-based current monitoring on critical rails; triggers shutdown if thresholds exceeded

5.2.2 GROUNDING AND ISOLATION

- Protective Earth (PE): Chassis connected to earth to prevent electric shock

- Isolated Digital Ground: Separate analog and digital ground planes to minimize noise
- Isolation Barriers: Opto-isolators for high-voltage to low-voltage communication signals
- Leakage Current: Compliant with IEC 60950-1 limits (< 3.5 mA)

5.3 SENSOR AND ACTUATOR INTERFACES

5.3.1 COMMUNICATION PROTOCOLS

- Internal: I2C and SPI buses for sensor data acquisition and actuator control
- External: UART and RS-485 for system integration and remote monitoring
- Protocol Standards: Modbus RTU for industrial compatibility, 8N1 data format
- Signal Integrity: Differential signaling for long lines (> 1 m) to reduce noise

5.3.2 SIGNAL CONDITIONING

- Sensors: Low-noise amplifiers and filtering circuits for ozone, temperature, and humidity sensors
- Actuators: PWM control for fans and valves, relay drivers with flyback diodes for inductive loads
- Analog-to-Digital Conversion: 12-16 bit ADCs with programmable gain for high accuracy
- Protection: ESD diodes on all sensor and actuator lines

5.4 PCB OVERVIEW

5.4.1 BOARD LAYOUT GUIDELINES

- Component Placement: Grouped by subsystem (power, control, sensor interface) to minimize trace length and EMI
- Thermal Management: High-power components placed near heat sinks; thermal vias for heat dissipation
- Connector Placement: Edge connectors for modular assembly and maintenance

5.4.2 SIGNAL ROUTING AND LAYER STACKUP

- Layer Stackup: 4-layer PCB:

1. Top: Signal + Components

2. Bottom: Ground plane

- Trace Widths: Calculated per IPC-2221 standards for current carrying capacity
- High-Speed Signals: Controlled impedance routing for communication lines

5.4.3 EMI/EMC CONSIDERATIONS

- Shielding: Metal enclosure with conductive gaskets to contain radiated EMI
- Filtering: LC filters on input power lines and sensitive signals
- Decoupling: 0.1 uF and 10 uF ceramic capacitors near each IC power pin
- Compliance: Designed to meet CISPR 32 and IEC 61000-6-3 standards

6. COMPONENTS AND MATERIALS

This section provides a comprehensive overview of all hardware components used in Aurora, including summaries, specifications, recommended suppliers, and packaging considerations. It is intended to guide procurement, assembly, and maintenance teams, ensuring compatibility, safety, and reliability across the system.

6.1 BILL OF MATERIALS (SUMMARY)

The Bill of Materials (BOM) provides a high-level summary of all primary components used in the hardware. A detailed BOM with part numbers, manufacturers, and specifications is maintained in a separate document.

Item No.	Component Type	Description	Quantity	Reference Designator	Notes
1	Power Supply	24V DC, 150W switching supply	1	PSU1	Includes overcurrent protection
2	Microcontroller	ARM Cortex-M7, 1MB Flash, 512KB RAM	1	MCU1	Controls sensors and actuators
3	Ozone Generator	Corona discharge type, 0100 mg/h output	1	OZ1	Requires dedicated ventilation
4	Temperature Sensor	Digital, ±0.5°C accuracy, I2C interface	2	TEMP1, TEMP2	For ambient and internal monitoring
5	Humidity Sensor	±3% RH accuracy, I2C interface	1	HUM1	Integrated with Temp sensor optional
6	Fan	12V DC, 2000 RPM, 60mm	2	FAN1, FAN2	Cooling and ozone dispersion
7	Relay Module	24V coil, SPDT, 10A contacts	2	REL1, REL2	Controls high-voltage loads
8	PCB	Multi-layer, FR4, 2mm thickness	1	MAIN	Main control board

Item No.	Component Type	Description	Quantity	Reference Designator	Notes
9	Connectors	Various, JST and Molex	10	CON1CON10	Power and signal connections

> Note: Detailed BOM includes manufacturer part numbers, RoHS compliance, and alternative suppliers for redundancy.

6.2 KEY COMPONENT SPECIFICATIONS

6.2.1 POWER COMPONENTS

- Power Supply (PSU1):

- Input: 100240VAC, 50/60Hz

- Output: 12VDC, 150W max

- Efficiency: >90%

- Protections: Overvoltage, overcurrent, short-circuit

- Cooling: Convection, 40°C max ambient

- Fuses and Circuit Breakers:

- Fast-acting fuses for PCB protection

- Rated for 2x maximum expected current

6.2.2 SENSORS

- Temperature Sensor (TEMP1, TEMP2):

- Type: Digital, I2C interface

- Accuracy: ±0.5°C

- Operating range: -20°C to +85°C

- Response time: 5s

- Humidity Sensor (HUM1):

- Type: Capacitive, digital I2C output

- Accuracy: ±3% RH

- Operating range: 0100% RH

- Drift: <0.5% per year

- Ozone Output Sensor:

- Electrochemical type

- Detection range: 010 ppm

- Accuracy: ±0.2 ppm

- Response time: <30s

6.2.3 ACTUATORS

- Fans (FAN1, FAN2):

- Voltage: 12VDC

- Speed: 2000 RPM

- Airflow: 25 CFM

- Noise level: <35 dBA

- Bearing type: Sleeve / Ball bearing

- Relays (REL1, REL2):

- Coil voltage: 12VDC

- Contact rating: 10A @ 250VAC

- SPDT configuration

- Dielectric strength: 1.5kV

- Solenoid or Valves (if applicable):

- Rated for ozone exposure

- Response time <200ms

- Operating voltage: 12VDC

6.2.4 CONTROLLERS AND MICROPROCESSORS

- Microcontroller (MCU1):

- Core: ESP32

- Flash: 1MB

- RAM: 512KB

- Operating voltage: 3.3V

- Interfaces: I2C, SPI, UART, PWM, GPIO

- Temperature range: -40°C to +85°C

- Embedded safety features: Brownout detection, watchdog timer

  - Optional Co-processors / ADC Modules:

- 16-bit resolution for sensor readings

- Low noise design

- Fast sampling rate (<1ms)

6.3 SUPPLIER RECOMMENDATIONS

Component Type	Preferred Supplier	Part Number / Series	Notes
Power Supply	Meanwell	LRS-150-24	High reliability, global availability
Microcontroller	STMicroelectronics	STM32F767	Robust, widely supported, long lifecycle
Ozone Generator	Ozotech / Wedeco	OZG-100	Tested for industrial ozone output
Sensors	Sensirion	SHT31 / SHT85	High accuracy, I2C digital output
Fans	Delta Electronics	AFB0612H	Low noise, long lifespan
Relays	Omron	G2R-1-S	Industrial grade, high switching cycles
PCB Manufacturer	JLCPCB / PCBWay	Custom	Multi-layer, lead-free, FR4

> Note: Multiple suppliers per component are recommended to mitigate supply chain risks.

6.4 COMPONENT FOOTPRINTS AND PACKAGING

  - PCB Footprints:

- Standardized footprints following IPC guidelines

- SMD for most components, through-hole for high-current parts

  - Mechanical Components:

- Fans, generators, and relays mounted with vibration-resistant screws or mounts

- Clearance for thermal expansion and ozone corrosion

  - Packaging and Handling:

- Components shipped in anti-static bags or reels

- Storage temperature: 530°C

- Relative humidity: <60% non-condensing

- Ozone-sensitive components protected with airtight packaging

  - Labeling:

- All critical components labeled with part number, revision, and lot code

- QR codes for traceability (optional)

7. ENVIRONMENTAL REQUIREMENTS

This section defines the environmental conditions under which Aurora is designed to operate reliably and safely. Adherence to these requirements is critical for maintaining performance, longevity, and safety of both hardware and electronics. All specified limits are based on industrial standards for electronic and ozone-generating equipment.

7.1 OPERATING TEMPERATURE AND HUMIDITY

- Operating Temperature Range: 0°C to 45°C (32°F to 113°F)

The system must maintain full functional performance within this temperature range without degradation of components, sensors, or control electronics.

- Relative Humidity: 20% to 80% non-condensing

Condensation inside the enclosure can damage PCBs, sensors, and actuators. Humidity beyond this range requires dehumidification or environmental control.

- Temperature Gradient Tolerance: Maximum 5°C/hour

Rapid temperature changes should not induce thermal stress on mechanical or electronic components.

- Derating Requirements:

- At temperatures above 40°C, ozone generation efficiency may decrease; system software will adjust output accordingly.

- Active cooling or forced ventilation is recommended for sustained operation near the upper temperature limit.

7.2 STORAGE CONDITIONS

- Storage Temperature Range: -20°C to 60°C (-4°F to 140°F)

Protects electronics, sensors, and ozone-generating components from thermal stress during transport and storage.

- Storage Humidity: 10% to 90% non-condensing

Moisture exposure during storage can degrade sensor calibration and promote corrosion of metallic components.

- Packaging Considerations:

- Storage in anti-static bags for PCB assemblies.

- Enclosures should be sealed to prevent dust ingress and moisture condensation.

- Shelf Life: 12 months recommended before recalibration and pre-use verification.

7.3 SHOCK AND VIBRATION

- Shock Tolerance:

- 10g peak, 11ms half-sine pulse in all axes for transport and handling.

- Internal components should be secured with fasteners, padding, or vibration-damping mounts.

- Vibration Tolerance:

- 5500 Hz, 1.0g RMS sinusoidal or random vibration for operational use.

- PCB and actuator mounts must incorporate vibration damping to prevent connector loosening or mechanical fatigue.

- Testing Recommendations:

- Perform pre-shipment vibration testing to confirm mechanical integrity and sensor stability.

7.4 INGRESS PROTECTION (IP RATING)

- Target IP Rating: IP54 (dust protected, splash-proof)

- Protects electronics and ozone generator from dust accumulation and water splashes in typical industrial environments.

- Enclosure Requirements:

- Sealed gaskets at all access panels.

- Cable entry points must use IP-rated glands or seals.

- Periodic Inspection:

- Check seals and gaskets for wear or damage every 612 months.

- Clean ventilation filters to maintain airflow without compromising IP rating.

7.5 ALTITUDE AND ATMOSPHERIC CONSIDERATIONS

- Operating Altitude: 02000 meters (06560 feet) above sea level

- Above 2000 meters, ozone generation efficiency may decrease due to reduced air density; software adjustments or flow modifications may be required.

- Storage Altitude: 03000 meters (09840 feet)
- Atmospheric Pressure Tolerance: 80110 kPa (0.81.1 atm)

- Equipment must maintain safe electrical insulation and ozone generation within this pressure range.

- Air Quality Considerations:

- Avoid environments with excessive dust, corrosive gases, or chemical vapors that could degrade sensors, electronics, or ozone generation components.

Notes: All environmental parameters should be verified during the hardware qualification phase. Deviations from these requirements may affect system safety, ozone output, and electronic reliability.

8. RELIABILITY AND SAFETY CONSIDERATIONS

Aurora is designed with high reliability and stringent safety requirements due to the inherent risks associated with ozone generation and exposure. This section outlines the hardware strategies, protective mechanisms, and compliance considerations integrated into the system to ensure safe and continuous operation.

8.1 FAULT TOLERANCE AND REDUNDANCY

- Redundant Critical Components:

- Dual power supplies to maintain operation in case of single supply failure.

- Parallel ozone sensors (primary + backup) to prevent false readings from sensor drift or failure.

- Fail-Safe Design Philosophy:

- Default-to-safe states (e.g., ozone generator de-energizes if control signal is lost).

- Watchdog timers on control electronics to reset in case of microcontroller malfunction.

- Error Detection and Correction:

- Built-in self-test routines for sensors and actuators during startup.

- Continuous diagnostic monitoring with fault logging.

- Isolation of Subsystems:

- Segregation of high-voltage ozone generation circuits from low-voltage control logic to prevent cascading failures.

8.2 OZONE LEAK PROTECTION

- Integrated Leak Detection:

- Multiple ozone sensors placed inside the enclosure and near exhaust vents.

- Sensors calibrated to trigger alarms when concentrations exceed 0.1 ppm (aligned with OSHA permissible exposure limits).

- Automated Protective Responses:

- Immediate shutdown of the ozone generator when leaks are detected.

- Automatic activation of ventilation fans to dilute ozone concentrations.

- Hardware Safeguards:

- Sealed enclosures with ozone-resistant gaskets and fittings.

- One-way valves on gas outlets to prevent backflow.

- Preventive Maintenance Design:

- Sensor calibration intervals defined in Calibration Procedures.

- Replaceable seals and filters with recommended service schedule.

8.3 EMERGENCY SHUTDOWN PROCEDURES

- Hardware Kill-Switches:

- Emergency Stop (E-Stop) button directly wired to cut power to ozone generation circuits.

- Independent of software control to ensure immediate response.

- Power Isolation:

- Dedicated circuit breakers and fuses accessible externally.

- Lockout/Tagout (LOTO) compatibility for maintenance personnel.

- Automatic Shutdown Triggers:

- Over-temperature sensors trip the system if internal enclosure temperature exceeds safe limits.

- Overcurrent detection circuits disable the ozone generator in case of electrical fault.

- Recovery Protocol:

- Manual reset required after emergency shutdown to prevent unintentional restart.

- Logged shutdown events for root cause analysis.

8.4 COMPLIANCE WITH SAFETY STANDARDS

- Electrical Safety:

- IEC 61010-1: Safety requirements for electrical equipment for measurement, control, and laboratory use.

- UL/CSA 61010 compliance for North American markets.

- Electromagnetic Compatibility (EMC):

- IEC 61326 compliance for industrial, scientific, and medical (ISM) equipment.

- EMI shielding integrated into PCB and enclosure design.

- Ozone Safety Standards:

- OSHA 29 CFR 1910.1000 (0.1 ppm permissible exposure limit).

- EPA regulations for ozone-generating devices in industrial environments.

- Environmental Safety:

- RoHS (Restriction of Hazardous Substances) compliance for all components.

- WEEE (Waste Electrical and Electronic Equipment) considerations for end-of-life disposal.

8.5 LIFECYCLE AND DURABILITY CONSIDERATIONS

- Design Lifetime:

- System designed for >=10 years of service life under industrial operating conditions.

- Critical components (ozone cells, sensors, fans) selected with MTBF ratings >50,000 hours.

- Maintenance and Replaceability:

- Modular design allows replacement of ozone cells, sensors, and PCBs without full system disassembly.

- Preventive maintenance schedule defined for filters, seals, and fans.

- Environmental Durability:

- Corrosion-resistant materials (stainless steel, anodized aluminum, PTFE seals) for ozone exposure.

- IP54-rated enclosure for dust and splash protection (upgradeable to IP65 for harsher environments).

- Stress and Fatigue Testing:

- Thermal cycling and vibration tests performed to validate mechanical robustness.

- Electrical stress testing to simulate prolonged ozone generation operation.

- End-of-Life Considerations:

- Components designed for safe decommissioning and recycling.

- Clear labeling of ozone-generating modules and hazardous parts for safe disposal.

9. DESIGN CONSTRAINTS

The hardware design of Aurora must adhere to a set of design constraints to ensure functionality, safety, regulatory compliance, and long-term maintainability. These constraints are critical in shaping design decisions across mechanical, electrical, and software-hardware integration aspects.

9.1 SPACE AND WEIGHT LIMITATIONS

- Footprint Requirements:

Aurora is intended for deployment in industrial environments such as food processing plants, warehouses, and medical sterilization rooms. The maximum system footprint shall not exceed 1200 mm (L) × 800 mm (W) × 1800 mm (H) to allow passage through standard industrial doorways and integration into existing process lines.

- Clearance Requirements:

A minimum of 300 mm clearance on all serviceable sides must be maintained for ventilation, service access, and safe ozone dissipation.

- Weight Limitation:

The system shall not exceed a total weight of 150 kg, enabling relocation with a two-person lift and compatibility with standard pallet jacks and trolleys. Sub-assemblies should be designed in modules not exceeding 30 kg each to comply with ergonomic handling guidelines.

9.2 COST CONSTRAINTS

- Target Manufacturing Cost (TMC):

The system shall be designed to achieve a TMC not exceeding USD $4,500 per unit (for volumes of 100 units/year), including mechanical fabrication, electronics, sensors, and assembly.

- Cost Drivers:

Primary cost drivers include the ozone generation unit, high-precision ozone sensors, and safety-rated power electronics. Cost optimization must be pursued through:

- Selection of readily available, non-custom components where possible.

- Modular design to share subassemblies across multiple Aurora product variants.

- Supplier agreements for bulk purchasing of electronic and mechanical components.

- Lifecycle Cost Consideration:

Design decisions must minimize operational expenses (e.g., low energy consumption, long-life ozone cells) and reduce the need for frequent component replacement.

9.3 REGULATORY CONSTRAINTS

Aurora must comply with international, regional, and industry-specific regulations governing ozone sanitization systems, electrical safety, and emissions.

- Ozone Exposure Standards:

- Compliance with OSHA 29 CFR 1910.1000: permissible exposure limit (PEL) of 0.1 ppm (8-hour TWA).

- Compliance with EPA and EU guidelines for indoor air ozone concentrations.

- Automatic shutdown and purge functions must activate when ozone concentration exceeds safe thresholds.

- Electrical and Safety Regulations:

- IEC 61010 / UL 61010 for safety of electrical equipment.

- IEC 60204-1 for industrial machine safety.

- EMC compliance with EN 55011 / FCC Part 15.

- Environmental and Chemical Regulations:

- Restriction of Hazardous Substances (RoHS) compliance.

- Waste Electrical and Electronic Equipment (WEEE) directives.

- Safe material disposal guidelines for ozone-producing components.

9.4 MAINTAINABILITY AND SERVICEABILITY

The system shall be designed to minimize downtime, simplify servicing, and ensure operator safety during maintenance.

- Service Access:

- Front-facing access panels with tool-less latches for routine filter replacement and calibration.

- Rear access for power electronics and ozone generator replacement.

- Clear labeling of serviceable components with QR code links to manuals.

- Modular Replacement:

Critical components such as ozone cells, sensors, and fans shall be replaceable in under 15 minutes using standard tools.

- Diagnostics and Troubleshooting:

- Built-in self-test (BIST) functionality at startup.

- Error code display with plain-language fault descriptions.

- Data logging to assist service engineers in remote diagnostics.

- Downtime Requirements:

Routine maintenance (filter changes, sensor recalibration) must not exceed 30 minutes per session.

9.5 UPGRADABILITY AND MODULAR DESIGN CONSIDERATIONS

Aurora shall be designed with a modular hardware architecture to support future upgrades and product variants without significant redesign.

- Modular Subsystems:

- Ozone generation modules interchangeable for different output capacities (e.g., 10 g/h, 20 g/h, 50 g/h).

- Sensor cartridges replaceable with upgraded detection technology.

- Communication boards upgradeable to support future industrial protocols (EtherCAT, OPC-UA).

- Scalability:

The hardware must support scaling from small-room sanitization systems to large industrial units by stacking or linking multiple Aurora modules.

- Backward Compatibility:

New hardware revisions must remain compatible with existing enclosures and software interfaces to protect customer investment.

- Expansion Interfaces:

Reserved ports and mounting points must be included for integration of optional accessories (e.g., wireless modules, external sensors, AI-based monitoring systems).

10. REFERENCES

The references section provides all standards, technical references, and supporting documents that have been consulted or are applicable for the design, development, testing, and certification of the Aurora Ozone Sanitization System. This ensures compliance, traceability, and reproducibility of the hardware design.

10.1 APPLICABLE STANDARDS (ISO, IEC, UL, CE)

The hardware design adheres to the following international and regional standards to ensure safety, reliability, and regulatory compliance:

1. ISO 9001:2015 Quality Management Systems

Framework for quality assurance in design, development, and production.

2. ISO 13485:2016 Medical Devices Quality Management System (if applicable)

Applicable for ozone sanitization devices used in healthcare or sterilization contexts.

3. IEC 61010-1:2010 Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Covers electrical safety of the Aurora control system and ozone generator.

4. IEC 61326-1:2020 Electrical Equipment for Measurement, Control, and Laboratory Use EMC Requirements

Defines electromagnetic compatibility requirements for industrial devices.

5. UL 61010-1 Standard for Safety Requirements for Electrical Equipment for Measurement, Control, and Laboratory Use

Recognized certification for North American markets.

6. CE Marking Directives (Low Voltage Directive 2014/35/EU, EMC Directive 2014/30/EU, Machinery Directive 2006/42/EC)

Ensures compliance with European Union regulations on electrical safety, EMC, and machinery safety.

7. ISO 11979 / ISO 7197 (Optional) Safety standards for ozone-generating devices or similar environmental sanitation equipment

Applies if Aurora is used in commercial sanitization environments.

8. OSHA / NFPA Guidelines (USA) Occupational safety standards regarding ozone exposure limits and industrial safety

Relevant for workplace compliance and operator safety.

10.2 REFERENCE DESIGNS AND WHITE PAPERS

Design decisions and system architecture were guided by peer-reviewed white papers, industrial reference designs, and technical guides:

1. Ozone Generation in Industrial Systems White Paper, XYZ Research Lab, 2021

Provides performance benchmarks, safe ozone generation practices, and material compatibility considerations.

2. Industrial Air Sanitization System Design Reference TechDesign Inc., 2020

Used as a reference for modular design, control architecture, and actuator integration.

3. Thermal Management of Electrical Enclosures IEEE Transactions on Components and Packaging, 2019

Guided thermal modeling, heat sink sizing, and airflow management in the enclosure.

4. Sensor Integration in Environmental Monitoring Systems Journal of Instrumentation, 2020

Served as a reference for ozone, humidity, and temperature sensor placement, calibration, and interface design.

5. PCB Design Guidelines for EMC Compliance IPC-2221 Standards

Ensured proper layout, grounding, and shielding for electromagnetic compatibility.

10.3 SUPPORTING DOCUMENTATION (DATASHEETS, MANUALS)

All hardware components were selected, integrated, and validated based on manufacturer documentation and technical manuals:

1. Ozone Generator Module Datasheet Manufacturer ABC, Rev 3.2

Electrical ratings, safety instructions, and expected output specifications.

2. Microcontroller Unit Datasheet MCU Model XYZ, Rev 5.1

Pin configuration, electrical characteristics, communication protocols.

3. Power Supply Module Datasheet Model PS-1200, Manufacturer DEF

Voltage/current ratings, protection features, and efficiency curves.

4. Sensors Documentation:

- Ozone Sensor: Manufacturer GHI, Datasheet Rev 2.0

- Temperature/Humidity Sensor: Manufacturer JKL, Datasheet Rev 4.3

- Pressure Sensor: Manufacturer MNO, Datasheet Rev 1.5

5. Mechanical Components Manuals:

- Enclosure Assembly Guide, Manufacturer PQR

- Mounting Bracket Specifications, Manufacturer STU

6. Software-Firmware Integration Guides:

- MCU Peripheral Interface Reference

- Communication Protocol Reference Manual (UART/I2C/SPI)

7. Testing and Calibration References:

- Ozone Calibration Gas Certificates

- Test Bench Operation Manuals for Electrical Safety and Performance Testing

Note: All datasheets, manuals, and references are archived in the project documentation repository and are traceable by version, publication date, and author to ensure full reproducibility and audit compliance.

11. REVISION HISTORY

The Revision History records all changes made to this Hardware Design Specification document, including updates to hardware design, corrections, and version increments. Maintaining a detailed revision history ensures traceability, accountability, and compliance with engineering and quality standards.

GUIDELINES FOR REVISION ENTRIES

- Version: Use a clear versioning scheme (e.g., Major.Minor.Patch).

- Major: Significant design changes or architecture updates.

- Minor: Modifications, optimizations, or small feature additions.

- Patch: Typographical corrections, formatting fixes, or minor clarifications.

- Date: Record the date the revision was finalized (YYYY-MM-DD).
- Author: Include the full name and role of the person responsible for the revision.
- Description of Changes: Provide a concise but detailed summary of what was changed, added, removed, or corrected. Include references to sections, diagrams, or appendices affected.

REVISION HISTORY TABLE

Version	**Date**	**Author**	**Description of Changes**
1.0	2025-08-21	Jane Doe, Hardware Lead	Initial release of Aurora Hardware Design Specification. Included full hardware architecture, mechanical and electrical design, BOM, and system overview.
1.1	2025-09-05	John Smith, Electrical Engineer	Updated PCB layout details and signal routing diagrams; added EMI/EMC considerations in Section 5.4.
1.2	2025-09-20	Emily Zhang, Mechanical Engineer	Revised enclosure design dimensions and thermal management specifications (Section 4.14.3).

Version	**Date**	**Author**	**Description of Changes**
1.3	2025-10-02	Jane Doe, Hardware Lead	Added sensor calibration notes in Section 6.2 and updated supplier recommendations.
1.4	2025-10-18	Alex Johnson, QA Engineer	Corrected typographical errors; added references to safety standards (Section 8.4).
2.0	2025-11-01	Jane Doe, Hardware Lead	Major revision: integrated actuator interface changes, updated functional objectives, and expanded environmental requirements (Sections 2.2, 5.3, 7).

> Tip: For each new version, ensure that the "Description of Changes" is precise enough for engineers and auditors to understand the rationale behind the update without needing to compare entire sections manually. Always date and sign off revisions before distribution.