Compute Project

450W Power Supply Hardware v1.0

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1 Scope

This document defines the technical specifications for a 450W standalone, single voltage power supply, powered from an AC line, and used for IT systems for both online and backup power functions. This device works in conjunction with the Open Compute Project battery backup cabinet (see the *Open Compute Project Battery Cabinet Hardware v1.0* specification).

2 Contents

3 Overview

When data center design and hardware design move in concert, they can improve efficiency and reduce power consumption. To this end, the Open Compute Project is a set of technologies that reduces energy consumption and cost, increases reliability and choice in the marketplace, and simplifies operations and maintenance. One key objective is openness—the project is starting with the opening of the specifications and mechanical designs for the major components of a data center, and the efficiency results achieved at facilities using Open Compute technologies.

One component of this project is a custom server power supply. This document describes in detail the technical specifications for the 450W AC/DC power converter, single voltage 12.5VDC, closed frame, self-cooled power supply used in high efficiency IT applications. The power converter includes independent AC input and DC output connectors, plus a DC input connector for backup voltage. The power converter can locally provide temporary backup in case of AC outage; backup voltage needs to be applied to the DC input to enable this function. Both AC and DC inputs are hot swappable, and their respective connector counterparts are installed on cable assemblies (power cords). Current sharing and parallel operations are not required, while the main focus is a design with very high electrical efficiency.

The power converter throughout the specification is referred as a power supply.

3.1 Accessibility

The power supply must be physically installed in a restricted (controlled) area with service accessibility exclusively permitted to authorized personnel only; certified and trained personnel only can have access to the actual power supply and its interconnections.

3.2 License

4 Compliance Requirements

The power supply complies with the following standards as standalone unit, and is certified and labeled accordingly.

4.1 Safety Certifications, Applicable Documents

- UL60950-1 (Standard for Safety of IT Equipment)
- CAN/CSA-C22.2 No. 60950-1-03 (Standard for Safety of IT Equipment)
- EN60950-1:2006 / IEC60950-1 (Standard for Safety of IT Equipment)
- cCSAus Certification is allowed in place of the equivalent UL certification
- CE Mark, CB Report and Certificate
- EU Low Voltage Directive, EMC Directive
- UL94V-0 material flammability rating, with an oxygen index of at least 28%

4.2 Immunity Standards, EMC

- EN61000 / IEC61000 applicable standards for Emissions and Immunity Requirements
- EN61000-3-2 (AC Mains Harmonic Current Emissions)
- EN61000-3-3 (Voltage Flicker)
- EN61000-4-2, Level 4 (ESD)
- EN61000-4-3 (Radiated Immunity, 3V/m)
- EN61000-4-4, Level 4 (EFT/Burst)
- EN61000-4-5 (AC Mains Surge Immunity, see levels at section 5.9)
- EN61000-4-6 (Conducted Radio Frequency Immunity, 3V/m)
- EN61000-4-8 (Power Frequency Magnetic Fields)
- EN61000-4-9 (Pulse Magnetic Field)
- EN61000-4-11 (AC mains voltage dips and sags, fluctuations)
- Power supply always resumes operations after any fatal PLD
- Output Voltage never dips if backup voltage is applied to the power supply
- Backup functionality is not affected by substantial repetitive dips and sags
- GR-1089-CORE, Issue 4 (Power Line Disturbances)
- BS EN 55024:1998, CISPR 24:1997 - Information Technology Equipment

Note: Once the power supply is installed, the EUT powered by the power supply continues to operate without interruptions and/or reset occurrences during above tests under EN61000-4-(*).

4.3 Further Applicable Immunity Standards

The power supply meets the EN61000 standards for industrial immunity:

- EN61000-6-1 (Immunity / Light Industry)
- EN61000-6-2 (Immunity / Industry)

This section of BS EN61000 applies to electrical and electronic apparatus intended for use in industrial environments. This standard applies to an apparatus intended to be connected to a power network supplied from a high or medium voltage transformer dedicated to the supply of an installation feeding industrial plants, and intended to operate in (or in proximity to) industrial locations. This standard applies also to an apparatus that is battery operated and intended to be used in industrial locations. The environments encompassed by this standard are industrial, both indoor and outdoor, and where heavy inductive or capacitive loads are frequently switched, and/or with presence of high currents and associated magnetic fields.

4.4 EMI Compliance and Limits

- The AC mains tests are conducted as stand-alone unit, at both 200VAC and 277VAC, full load.
- FCC Part 15, EN55022, CISPR 22: Conducted Emission, Class B (peak-reading)
- FCC Part 15, EN55022, CISPR 22: Radiated Emission, Class B
- The DC backup converter meets Class A with 3 dB margin, at 48VDC input and full load
- At system level, the power supply complies with Class A limits for both conducted and radiated emissions, with at least 3 dB margin, and for both AC and DC inputs/converters.

4.5 Environmental Engineering Standards

- ETS 300 019-2-3, Class 3.2 (Operation)
- ETS 300 019-2-2, Class 2.3 (Transportation)
- ETS 300 019-2-1, Class 1.2 (Storage)

4.6 AC Mains Leakage Current

Leakage current is in compliance with applicable EN/IEC standards, and does not exceed 1.5mA RMS at 60Hz and 277VAC.

4.7 RoHS Compliance

The power supply is RoHS-6 compliant (BOM and Manufacturing Process).

5 AC Input Requirements (Main AC to DC Converter)

5.1 AC Input Voltage, AC LOSS Detection Time

The AC input voltage range is 180VAC to 305VAC RMS (auto ranging).

The nominal AC input voltage is 277VAC RMS (200 – 277 VAC).

The power supply complies with the specification up to 290VAC RMS, which corresponds to 277VAC (+5%).

All the components used in the AC input section have a voltage rating compatible with 300VAC operations, up to 305VAC, which is 277VAC (+10%). The power supply can withstand continuous exposure to 305VAC RMS input with no damage, while at this voltage level is not expected to meet the Power Factor and THD requirements. Input voltages higher than 310VAC RMS may damage the power supply.

The front-end circuitry can detect any AC loss within 5ms after the actual occurrence, at any AC Input level, and at any PHASE of the Input AC sinusoidal waveform (from 1 degree to 360 degrees, wherever the AC loss occurs).

5.2 Input AC Connector and Fuse, EMI filter

The input power inlet is a 3 position Tyco Mate-N-Lok p/n 643228-1, female socket AC connector. An equivalent connector rated 277VAC may be used.

The connector counterpart used in the AC power cord is a 3 position Tyco Mate-N-Lok "Plug" contacts, wire-terminated free-hanging type. A Tyco Mate-N-Lok "Strain Relief" is installed on the sheathed cable for a safe and reliable power cord assembly.

The AC input fuse is a non-replaceable leaded component soldered directly to the board, used for safety and for extreme protection in case of catastrophic failures. The AC input connector is polarized and so, the fuse, in the power supply layout, is connected in series to the hot conductor (Line). The fuse is rated 5A "slow blow" type and never trips during inrush or any AC input current transients the power supply is designed to stand in normal operations. The fuse is a safety-approved component with a rating of at least 305VAC RMS, and 5 x 20 [mm] of minimum size (may be bigger due to the high AC voltage involved). At system level, the power supply is powered by a custom AC power strip embedding its own protection fuse rated 15A: a proper I2T coordination is verified when the power supply is powered by the strip (for example, the AC input stage of the power supply fails in short → the power supply input AC fuse blows and the AC power strip fuse does not blow).

The EMI filter uses two cells, with low series DC resistance. The design uses bulky choke components in order to reduce the copper losses and so to maximize the efficiency. As already mentioned, all the components used in the AC input power section are rated at least 305VAC RMS (for example, AC input connector, protection fuse, X2 EMI caps, surge protection devices, bleeder resistors, and so forth). A rating of 300VAC may be used instead; this would be the maximum AC voltage allowed for the power supply.

5.3 Primary MOS and Bulk Capacitors (Ratings)

The bulk capacitors are rated 500V 105C, and are long life components. For each bulk cap, a single component rated 500V is required (compared to potential alternative of having two caps rated 250V each and connected in series). Use high quality capacitors only. Voltage stress, especially when positive peak of the low frequency ripple voltage at worst conditions is included, is not negligible, while at the same time a reliable design, fully working up to 290VAC RMS input, must be guaranteed (305VAC RMS peak).

The 500V rating gives enough margin for a nominal bulk voltage that likely is in the range of 430VDC - 440VDC.

All of the high-voltage power MOS used in the primary side must be rated 600V (minimum), 650V preferred.

5.4 AC Inrush Current

The inrush current never exceeds 8A peak at cold start, Vin = 290VAC RMS, Tamb = +35°C.

5.5 Hold-up Time

The minimum hold-up time is 20ms.

Hold-up time is measured at full load, with no extra capacitance added to the output, at T=25°C, from when AC is lost at the sinusoidal 0V crossing, to when the output voltage falls below 12V.

5.6 AC Input Under Voltage Protection

The power supply will shut down for Vin < 170VAC and automatically restart when Vin > 180VAC (10VAC of hysteresis). No hiccups or ON/OFF oscillations are allowed under any conditions.

The power supply withstands without damage multiple input dropouts under all conditions, and:

- It resumes normal operations when no backup voltage is connected to the power supply.
- It resumes normal operations after multiple successful backup sequences, when backup voltage is connected to the power supply, without any output voltage dips.
- Input over voltage protection is not required.

5.7 Internal Bias Supply

The internal bias supply (auxiliary supply) is intended for housekeeping functions only (no stand-by voltage externally available is required). The implementation of an independent bias supply is preferred solution and it should work from a minimum of 100VAC RMS (correspondent to 140VDC on the bulk capacitors). Bias supply must be implemented with a high efficiency scheme.

5.8 Power Factor and THD

The power supply complies with EN61000-3-2 (see section 4.2) up to 290VAC RMS input.

See further requirements at section 6.9.3, Power Quality.

5.9 Input AC Surge

See section 4.2 (EN61000-4-5) with the following limits:

- 1KV DM (Differential Mode is Line to Neutral)
- 2KV CM (Common Mode is Line/Neutral to Ground)

The power supply is protected against surge events and it will not get damaged in such occurrences. The power supply can continue to operate without functional failures or hiccups during surge tests per the above limits, and the output voltage is not affected by the surge pulses under any conditions. Surge events cannot reset the system. In the server rack, the power supply is powered by a custom AC power strip embedding its own surge protection circuitry. Under these conditions, the power supply passes 2KV DM and 4KV CM, both standalone (with a passive load) and at system level (with actual server load).

5.9.1 Isolation Requirements

The power supply supports safety-reinforced insulation between high-voltage AC primary section and any secondary sections (3000VAC RMS of isolation).

Isolation between high-voltage AC primary section and chassis GND is 1500VAC RMS.

Both positive and negative 12.5VDC output terminals are floating with respect to the chassis GND, with a galvanic isolation of 100VDC.

The input of the DC backup converter is a safe voltage, and so its DC primary section needs to support reinforced insulation with the AC primary section.

The DC backup converter is isolated with at least 500VDC of insulation between its primary section and the secondary of the power supply (12.5VDC output). The isolation capability may be higher than 500VDC depending on the actual topology implemented for the backup function.

6 DC Output Requirements (Main Converter)

6.1 Output Voltage and Power

The power supply is a single-voltage power converter.

The nominal output voltage is set to 12.5VDC (±1% set point at 75% load, 25°C ambient). The reference voltage IC for the DC main converter is the same used for the DC backup converter. The SMT dividing resistors for output voltage reading are rated 0.1%.

The output voltage regulation is ±1% under any conditions of input voltage, load, temperature, aging, and so forth.

The power supply can withstand a no-load condition for indefinite time, without damage and with (or without) the maximum allowed capacitive load connected to the output terminals.

The nominal continuous output power is 450W. Peak power capability is 500W (maximum 5 seconds of duration up to one occurrence per minute, for the related thermal design).

Output OR-ing MOS, current share and parallel operations are not required.

6.2 Output Over Current Protection

Over current threshold is set to 44A (± 5%) and the protection mode, during short or overload, is "constant current" mode. Output voltage recovers automatically when the over current condition (or short) is removed. The power supply is sized (thermally and electrically) to stand indefinitely a short circuit, without damage, and under any conditions.

An over current condition lasting more than 5 seconds (± 0.1 second) latches OFF the power supply, and AC recycle (≥ 100ms) is needed to resume operations. The 5 second timer resets every time the power supply exits the over current condition even for a very short time (typically > 20ms).

The power supply can start under overload or short circuit conditions.

6.3 Output Over Voltage Protection

Over voltage threshold is set to 15VDC.

Protection mode is latch OFF type, so AC (≥ 100ms) recycle is needed to attempt to resume operations after an over voltage event.

The over voltage circuitry is independent, includes a separate voltage reference device, and does not make use of the microprocessor to implement the function. The microprocessor is notified in case of an over voltage event.

6.4 Over Temperature Protection (OT)

The power supply is protected against overheating to prevent damage or degradation. The power supply may overheat for many reasons, including (but not only) internal failing conditions, environmental factors, or because of improper use such as air obstruction, or similar. The power supply shuts down for OT protection and is able to automatically resume operations once the temperature falls back within the expected range (with some hysteresis). No components have been over stressed at the temperature shutdown threshold level.

All the thermal sensors are routed to the microprocessor (primary sensors are opto-isolated).

The air inlet temperature sensor is needed for the implementation of the fan automatic speed control.

Note: The microprocessor oversees all power supply functionality.

6.5 Capacitive Load

The maximum capacitive load at system level may be as high as 8000μF. The power supply is able to start up properly and, more importantly, is unconditionally stable when such a capacitance (or lesser value) is connected to the output (in parallel to any resistive loads, or just the capacitance).

6.6 Transient Response

The amplitude of the positive and negative output voltage peaks during transient-loads test are within ±2.5% of the nominal output voltage (±300mV), with a response time < 5ms, under the following test conditions:

- Electronic load set in "constant current" mode.
- Current steps cycling from 50% to 100% of the power supply maximum load (18A to 36A), 50Hz dynamic load frequency, 50% duty cycle, 1A/μS slew rate (minimum).
- Transient requirements are met with (or without) the maximum allowed capacitive load connected to the output terminals.

6.7 Output Voltage Ripple and Noise

The maximum ripple and noise never exceeds 200mV peak-peak at 20MHz bandwidth.

Measurement is performed at the connector at PCB level, with the board installed in the chassis, safety ground connected through AC power cord, 180VAC input, and full load. A digital oscilloscope is used for this measurement, with acquisition set to detect the peaks. The probe will be utilized without cap to minimize the length of the return connection, in order to achieve a reliable R&N reading (with this setup, the return is directly the metal body of the probe). A small 1μF X7R 0805 SMT ceramic capacitor may be connected locally to the probe tip during this measurement. The power supply output voltage circuitry may include a small CM choke added very near to the output connector, for common mode noise suppression.

6.8 Output Turn-ON/Turn-OFF

Under any conditions of dissipative load, capacitive load, temperature, and with or without backup voltage connected to the power supply:

- The power supply turns ON when a valid AC input is provided. Standby switch and/or ON/OFF signal are not required. The design of the PFC and DC-DC circuitry, soft starts, and so forth, is such that the total time, from when a valid AC input is applied and the DC output voltage reaches regulation, is maximum 2 seconds under any conditions and Vin > 200VAC RMS.
- The power supply starts properly under no load conditions or overload conditions.
- For any loads (from "no-load" to "max-load"), the output voltage will rise monotonically from 0V to 12.5VDC, without overshoot or ringing, at any turn ON following application of AC input voltage, and anytime when power supply resumes functioning after an automatic protection condition. The output voltage will fall monotonically from 12.5VDC to 0V, without undershoot or ringing, at any AC loss, and at any turn OFF caused by an automatic protection condition.

  Note: Backup voltage is not applied.

- Output voltage never reverses polarity at the turn OFF (all conditions, backup included).
- The power supply includes a soft-start (PFC, DC-DC) that promptly resets at any input AC loss > 20ms, or after any automatic protection conditions.
- See section 9.2 for power supply behavior on AC loss, when a valid backup voltage is connected to the power supply.

Output Voltage Rise-Time (all conditions, and for both main and backup converters)

- After the bulk voltage is in regulation, the rise time of the individual DC main converter is always < 50ms, and is always < 1ms when the output capacitance is already pre-charged to 12.5V.
- After the DC input (range between 42VDC to 58VDC) is applied, the rise time of the individual DC backup converter is always < 50ms, and is always < 1ms when the output capacitance is already pre-charged to 12.5V.

  Note: The reason for the < 1ms above is to guarantee a rapid startup at AC outage and recover, for optimum backup performances and "DEAD-BUS event" compliance.

6.8.1 Power Supply Turn-ON Sequence

Under normal conditions, after a valid AC input is applied, the internal bias supply turns ON, the whole circuitry gets powered, the power supply turns ON, and the output voltage reaches regulation.

There is a turn-ON sequence requirement when AC restores during a backup phase lasting more than 6 seconds: the DC main converter turns ON with a random delay between 0 and 5 seconds. Note that the PFC always starts promptly when a valid AC input is applied.

1. After AC power restores, the PFC starts normally, and the microprocessor keeps the DC main converter shut down (the DC-DC converter after the bulk).
2. It generates a random number "N" between 0 and 5000.
3. It turns-ON the DC main converter with a delay equal to N milliseconds.

See also section 9.2, point 4. The random number is dynamically generated right after each start of the DC backup converter (at each backup phase).

Note: During random startup, the DC input voltage (battery voltage providing backup power to many power supplies) will increase rapidly because the battery load will quickly decrease in the subsequent 5 seconds.

When a backup voltage IS NOT applied to the DC input, the random startup sequence will never occur (no startup delay).

When a valid backup voltage IS applied to the DC input, the random startup will repeat every time a valid AC voltage is re-applied to the input during a backup phase after continuous interruption of AC voltage exceeding 6 seconds.

6.8.2 DEAD-BUS Event

As described above, when AC power gets restored during a backup phase after an AC outage lasting more than 6 seconds, the power supply will randomly restart in the 5 second window. Would the DC input (battery voltage) fail during that 5 second window (in which the AC mains is actually back available) or within the 1 second filter always present before any main converter startup (see backup sequence, interval D), then the power supply would turn ON instantly (full load conditions), in attempting to avoid any output voltage dips and/or loss of regulation. As stated, this requirement should also be met during the "1 sec" filter timeslot prior to each turn-ON of the DC main converter, with or without random startup. See the complete backup sequence in Figure 3 and Figure 4.

The target is for the power supply to start fast enough to meet the above DEAD-BUS requirement when battery voltage Vin(DC) ≥ 42.5VDC. Achievable DEAD-BUS performance may be discussed during the design phase.

The battery pack includes a low voltage detector (LVD) device that isolates the batteries when the voltage level falls below 42VDC, but the power supply does not detect the 42V LVD input voltage level for to switch back to the AC input. In fact, if the backup converter is still running when the battery voltage approaches the 42V LVD level, this means that the whole "system shut-down" event is imminent (the standby emergency power generator **did not** turn ON: AC power is not available).

6.9 Microprocessor Control

All the logic and housekeeping functions (excluding over voltage) are implemented and driven by a low-power consumption microprocessor and low-power consumption circuitry. The microprocessor oversees all power supply functionality. If a DSP is used to drive the PWM(s), then it may (or may not) include the microprocessor functions.

The firmware of the microprocessor and/or DSP is upgradable for the life of the power supply. The power supply chassis cover has a small opening to reach a connector placed at the top of the logic board (edge pads on the PCB itself or their equivalent) for the easy download of updated compiled firmware codes without needing to open the chassis. A small indentation on the metal chassis or a mark provides reference for "pin 1" of the programming connector. A small panel (secured with a flathead screw) is added for protection, and can be removed easily to reach the connector for programming. Location on top cover is free.

6.9.1 Internal Cooling Fan

The power supply is self-cooled by an internal power-efficient fan that pulls fresh air inside the power supply (airflow is front to back). The power supply front (faceplate) is the air intake side where input connectors and LEDs are installed. The fan's mechanical mounting limits the propagation of vibrations to the power supply chassis caused by fan rotation: damping soft rubber sheet material is used between the fan housing and sheet metal. The fan may be installed using four flathead screws or other methods, and is located in such a way as to avoid any potential air short-circuits.

The fan is a 12V component, size 60 x 60 x 25 [mm], 30 CFM (minimum), and is a 4-wire, double ball bearing type.

The fan speed is driven by the microprocessor, with automatic speed control based on the intake air temperature. The fan cools the power supply and provides some extra airflow through the system. The minimum duty cycle of the PWM signal, used as the base speed of the fan, is 30% -- regardless of the power supply cooling conditions. A base speed is needed because the power supply must provide some minimum degree of CFM air to the system.

An air temperature sensor for the automatic speed control is located near the air intake in the front panel (see also section 6.4).

The fan speed does not directly change with the output current level. At the power supply turn ON, the fan starts at full speed and then settles down to the self-regulated speed value.

Because the fan is a 12V component, it is powered directly by the output voltage. A C-L-C filter is used to power the fan in order to reduce injection of spikes to the main 12.5VDC supply output. In fact brushless fans generate a lot of ripple and noise to their DC supply. The electrolytic capacitor connected directly in parallel to the fan can endure the low frequency ripple current with extra margin (low ESR and long life component).

Layout rule: At board level, the fan's positive and negative terminals connect directly to the main output capacitors before any further power supply output filters, using independent dedicated copper traces routed away from any noise-sensitive circuitry (like the main feedback loop circuitry).

The microprocessor monitors the fan speed using the tachometer signal, and will not shut down the power supply in case of fan failure, blocked fan, or inconsistent fan-speed readings. Under any fan failure conditions, the "FAIL" red LED will blink while the power supply is running (see also section 13).

The fan always runs at full speed during the backup phase.

The fan's L10 lifespan is at least 50,000 hours at 45°C inlet air temperature and full speed.

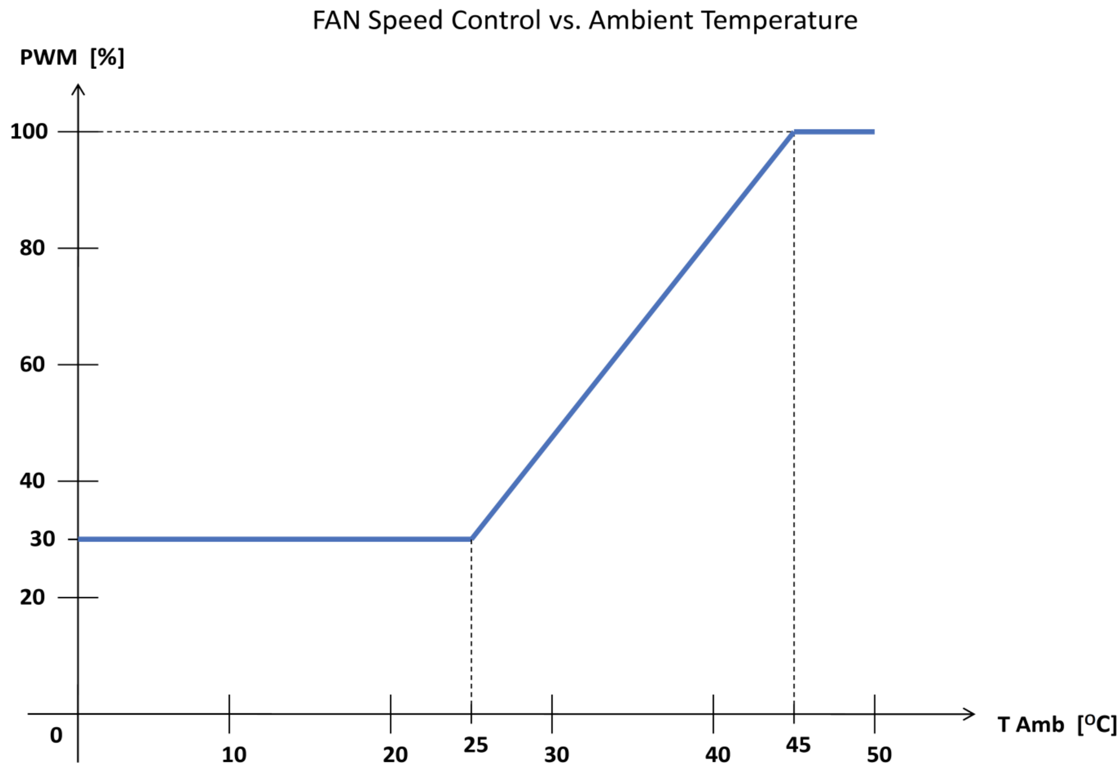


Figure 1 Fan Speed Control vs. Ambient Temperature

6.9.2 Power Supply Efficiency (AC Main Converter)

Efficiency exceeds the Climate Savers Computing Initiative PLATINUM rating. Those limits are:

- Efficiency > 90% at 20% load
- Efficiency > 94% at 50% load
- Efficiency > 91% at full load

Methodology for the measurement follows the CSCI directive, but at 200VAC RMS input.

Further target efficiency requirement:

- Efficiency > 95% (between 50% and 90% of maximum load).
- Wider than above load range is recommended, but not required.

Measurements are performed under the following conditions:

- Input AC voltage is 277VAC RMS (50Hz or 60Hz).
- AC and DC voltage are measured directly at the respective PCB pads.
- The power supply board is correctly installed in the chassis, with the cover, and with safety chassis GND connected through AC power cord.
- The cooling fan is powered using an external generator but with the speed controlled by the power supply logic, as happens during normal operations.
- Ambient temperature of +25°C.
- Measurements are taken after 30 minutes under initial 75% load, over five samples (they all need to pass). Efficiency measurements are provided in a table, in 5% load steps, with added power factor (PF) and total harmonic distortion (THD) values for each step.

6.9.3 Power Quality

Efficiency is the first priority. Power Factor and THD of AC input current, with order of the harmonics up to and including 40:

- PF > 0.95 (> 20% of maximum load)
- THD < 10% (> 20% of maximum load)

Measurements are performed under the following conditions:

- Input AC voltage of 277VAC RMS (50Hz or 60Hz).
- A power analyzer with reading accuracy better than 0.1% will be used for the measurements.
- A precise low distortion AC source supplies the voltage during the measurements.
- The power supply board is correctly installed in the chassis, with the cover and with the safety chassis GND connected through AC power cord.
- Ambient temperature of +25°C.
- Measurements are taken after 30 minutes under initial 75% load, over five samples (they all need to pass).

6.9.4 Stability

The power supply is unconditionally stable, under any conditions and combinations of resistive and capacitive loading, constant power loading, temperature, aging, and so forth.

Bode graph shows a phase margin better the 45 degrees at worst conditions (or 60 degrees at nominal conditions), and the dynamic step-load plots (see section 6.6) show no ringing.

The stability criteria is met with and without the maximum allowed capacitive load.

6.9.5 Output Connector

The DC output connector is a power blade FCI, part number 51773-006LF. The configuration of the contacts is 2Power - No_Power - 2Power. The two negative contacts are pre-mating. Refer to Figure 7 for the exact location and pin layout. The connector counterpart at system level is power blade FCI, part number 51733-009LF (right-angle press-fit header). The power supply makes a direct interconnection with the motherboard.

7 Battery Backup Section (Backup Converter)

The power supply provides short-term backup power in the event of AC outage. To enable this function, a DC backup converter (an independent isolated DC-DC converter capable of at least 450W of power) is included within the power supply, with dedicated logic driving all functionality for the backup sequence. It provides seamless backup power, enabling smooth operations under any conditions during transitions of AC input, and is equivalent at the system level to an independent UPS. This functionality is enabled only when a valid DC voltage (called *backup voltage*) is applied to the input DC connector located on the power supply faceplate.

7.1 Summary of Whole Backup Section Requirements

For the backup converter, all the input and output requirements, performance, compliance requirements, and so forth, are *equivalent* to what is specified for the DC main converter powered by the high-voltage bulk. Depending on the topology used, the output of the backup converter may (or may not) supply power directly to the power supply output. The output requirements in section 9 (see also Figure 3 and Figure 4) are intended when the power supply output voltage is supported by the backup converter. All the exceptions to the requirements are listed in section 8 where they supersede (or re-phrase) certain specific requirements and/or parameters.

8 DC Input Requirements (Backup Converter)

8.1 DC Input Voltage, Max Startup Current at AC Outage

The nominal DC input voltage is 48VDC.

The DC input voltage range is 39VDC to 59VDC. The backup converter works over this whole range without any deratings. The converter can work down to 38V for short periods of time (peak capability only), specified as "for 5 seconds every 1 minute" for the related thermal design, with maximum 0.5V of regulation loss at 500W peak.

The maximum peak of the startup current at AC outage, while the power supply is switching to backup mode, never exceeds +20% of the related steady-state current, tested at any voltages from 44V to 56V (with 2V step increments), and for any loads. The maximum peak of the startup current never lasts more than 5ms.

Example with full load and 48V input voltage:

- Pout = 450W
- Pin = (450W / 0.9) = 500W (minimum efficiency is 90%, as specified in section 9.3)
- Iin (steady-state) = (500W / 48V) = 10.4A
- IinPK (peak startup current while switching to backup mode) = (1.2 x 10.4A) = 12.5A (for 5ms maximum)

8.2 Input DC Connector and Fuse, EMI filter

The DC input power inlet is a 2 position Tyco Mate-N-Lok, part number 643226-1.

The connector counterpart used in the DC power cord is a 2 position Tyco Mate-N-Lok "Plug" contacts, wire-terminated free-hanging type. A Tyco Mate-N-Lok "Strain Relief" is installed on the sheathed cable for a safe and reliable power cord assembly.

The DC input fuse is an inexpensive, replaceable, blade-type component with a holder directly soldered on board. It is used for safety and for extreme protection in case of catastrophic failures. The DC input connector is polarized so the fuse, in the power supply layout, is connected in series to the positive conductor. The fuse is a safety-approved component, rated 20A and 60VDC (minimum), automotive "slow blow" type, and never trips during inrush or any DC input current transients the power supply is designed to withstand in normal operations.

The EMI filter circuitry is simple enough to meet EMI requirements that are less demanding in the DC backup converter (compared to the DC main converter). The requirements are set to meet "Class A" limits (see section 4.4).

8.3 Input DC Reverse Polarity Protection

The DC input is protected against reversal of polarity, with or without a valid AC voltage applied to the AC input. The implementation makes use of a simple scheme (see Figure 2) with a MOS in series to the negative terminal, self-biased using the DC input voltage, with a very low-consumption circuitry. In case of reversal of the DC input polarity, the "FAIL" LED does not light red (see section 13). The LEDs are able to light only when a valid AC input is present, and during a backup phase following an AC outage.

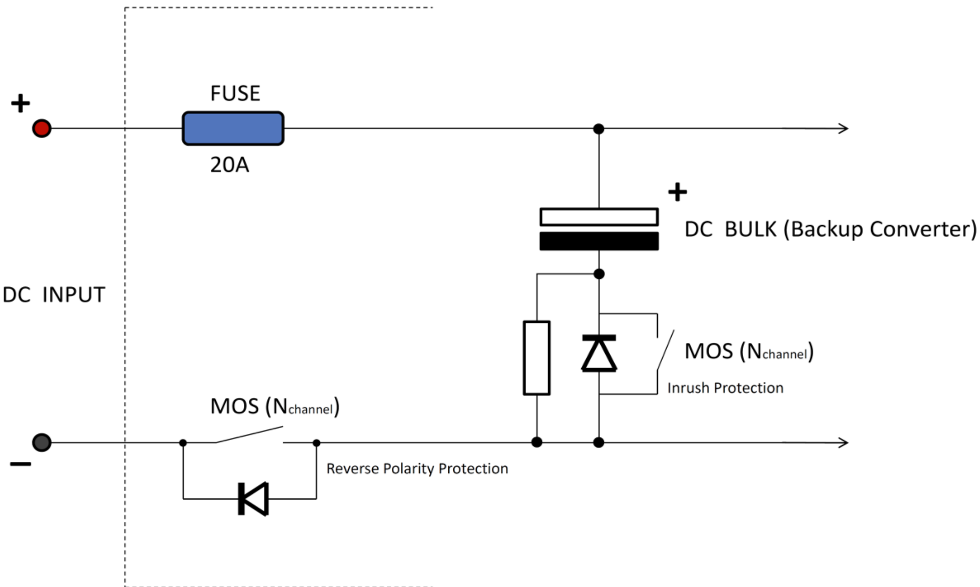


Figure 2 Reverse Polarity Protection

8.4 DC Inrush Current

The DC inrush never exceeds 5A peak under any conditions. The circuitry may use a dedicated hot swap IC for DC applications, or equivalent circuitry (there is no online auxiliary supply powered by the input DC). Basic functions are shown in Figure 2 with a MOS self-biased by using the input DC voltage with very low-consumption circuitry. Limiting inrush current on input DC is always active, with or without the presence of a valid AC input. Any alternative methods are accepted provided they make use of MOS devices (Inrush Relay not allowed). The inrush current spikes due to charging of any EMI ceramic caps are not considered.

The inrush sequence repeats after any DC interruption of enough duration to cause the bulk caps to discharge below 40V, under any conditions.

8.5 Hold-up Time, Bulk Caps

There is no minimum hold-up time for the DC backup converter. However, enough bulk capacitance is used to guarantee smooth backup operations, stand with margin the primary ripple of the backup converter, and for noise and EMI suppression. For these reasons, the minimum DC capacitance is set to 2500uF. Use high-quality capacitors rated 105C only. The bulk caps must always be charged to 54VDC minimum.

8.6 DC Input Under Voltage Protection, Backup Voltage

The backup converter circuitry includes an input under voltage protection set to 37V with 2V hysteresis; the converter on its own shuts down for Vin < 37VDC (±0.5VDC) and automatically restarts when Vin > 39VDC (±0.5VDC). When a valid AC input is present, the LED turns from yellow to green when an applied input DC voltage exceeds 39V, so the green activation threshold is driven by the same signal (see also section 13). No hiccups or ON/OFF oscillations occur under any conditions. During a backup-phase following an AC outage, after a UV shutdown, event the backup converter would not be able to restart because at this point the power supply is completely latched OFF until the AC comes back. Still, the UV protection is included in the backup converter circuitry.

Input over voltage protection is not required.

At system level, the backup voltage is provided by an external battery pack charged at 54VDC floating voltage. During AC mains outage the batteries will provide power to the DC backup converter (discharge phase). Batteries have their own independent charger, controller, and LVD (see the *Open Compute Project Battery Cabinet Hardware v1.0* specification). After the backup phase begins, the battery voltage starts to lower almost immediately, heading towards LVD disengagement (the LVD threshold is set to 42V in the separated battery cabinet unit).

8.7 Internal Bias Supply, Battery Leakage

The backup converter never activates without the prior presence of a valid AC input.

The DC input leakage current is less than 10mA at 54VDC (battery leakage at system level) under any conditions, and with (or without) the presence of a valid AC input.

9 DC Output Requirements (Backup Converter)

9.1 Output Voltage and Power

The nominal output voltage is set to 12.5VDC (±1% set point at 75% load, 25°C ambient). The DC backup converter uses the same IC reference voltage that is used for the DC main converter.

The SMT dividing resistors for the output voltage reading, for both main and backup converters, are rated 0.1%, in case only one output voltage divider is used to read the output voltage for both converters.

Note that the two converters share current easily during overlapping working mode (transitioning from AC mode to DC backup mode, and vice versa) when the respective output voltages are nominally identical.

The output power, like all the major requirements, is the same as what is specified for the DC main converter. However, the backup converter may start to lose regulation with 500W of output power at 39VDC input (and at lower levels) but with output voltage still above 12V: Vout ≥ 12.0V @ 38VDC input and 500W peak power.

9.2 Power Backup Sequence

1. The backup converter does not turn ON when a valid DC voltage is applied to the DC input, with or without the presence of a valid AC input.

During the backup phase, if the DC input is removed for a long enough duration to cause the output voltage to fall below the PWR_OK minimum threshold, and the DC input is reapplied, then the backup converter does not resume backup mode (it does not turn ON again).

2. When a valid DC voltage is applied to the DC input, the backup converter turns ON when both signals below are reset (position changes from "1" to "0"; see the backup sequence):

   AC LOSS: AC input drops below the minimum threshold (Vin < 170VAC RMS).

   AC_BULK OK: Bulk voltage drops below the minimum threshold.

   As per section 5.1, any sinusoidal AC LOSS must be detected within 5ms after the actual loss. Any fast AC cycles not causing the bulk voltage to drop below its minimum threshold will be covered by the AC hold-up time (20ms).

   There is a 100ms timeout for backup engagement: If BULK_OK does not change 100ms after the AC LOSS resets and stays low, then the backup sequence starts anyway.

   The transition from AC mode to DC mode lasts 10ms maximum (typically), during which the two converters will operate in parallel. During the transition from the main converter (AC mode) to the backup converter (DC mode), and vice versa, the output voltage dips (or spikes) stay within ±2% of the output voltage to which it is set, at full load conditions. This provides a seamless change from AC input mode to DC input mode (battery backup mode), and vice versa.

   The DC backup converter is switched ON typically not earlier than 10ms after an actual AC LOSS event, but it will vary. During transitions between the AC input converter and the DC input converter (and vice versa), both converters (AC input and DC input) operate in parallel (see Figure 3 and Figure 4), balancing the load at best.

   Note: Both converters use the same reference voltage and 0.1% resistors in the voltage divider for Vout reading, so good load sharing should naturally occur. It is important to note that load sharing helps for a smooth startup of the DC backup converter at AC outage: this limits the DC input current overshoot (startup current), as specified in section 8.1.

3. In normal conditions, when valid AC power is present and the main converter is delivering power to the output, the backup converter is kept OFF to enhance the overall power supply efficiency, but ready to kick in at any AC loss. See section 6.8 for details on the power supply turn ON and turn OFF sequences.
4. If during a backup phase the AC comes back, the DC main converter turns ON only after a valid bulk voltage, in conjunction with a continuous valid AC input, is continuously present for at least 1 second, and works in parallel with the DC backup converter during the following 0.25 seconds, sharing the load at best. If "AC LOSS" or "AC_BULK OK" signals toggle during these timing intervals, the counters ("1 sec", or "0.25 sec") reset and start over. At the end of the 0.25 second portion, the DC backup converter phases away in a (< 20ms) time window, releasing back the full load to the DC main converter (see Figure 4). This generates a backup sequence mode that guarantees the highest rejection against input AC disturbances/random dips, on top of guaranteed UPS grade performances during AC outage.
5. At system level, the backup phase will not last for more than 60 seconds total due to rapid discharge of the batteries and so, from a thermal prospective, the backup

converter is sized to guarantee 90 seconds at full load 450W, at 40VDC input and 45C of temperature, without degradation of performance and reliability. There cannot be more than one 90 second backup event within a 10-minute period.

Backup Phase Time-Out: The power supply shuts down after a continuous 90 seconds of backup operations. This functionality is built into the power supply logic.

6. The fan runs at full speed during backup phase.
7. The DC backup converter does not engage (it does not turn ON) if the DC main converter shuts down due to any protection conditions (for example, output over voltage, over temperature, any failures, and so forth).
8. **DEAD-BUS sequence:** See section 6.8.2, DEAD-BUS Event.

9.2.1 AC_BULK OK

This is an internal to the power supply signal reporting the "status of health" of the bulk voltage:

- AC_BULK OK = good (logic status "1") if Bulk Voltage > 90% of its nominal value.
- AC_BULK = not good (logic status "0") if Bulk Voltage < 85% of its nominal value.
- Hysteresis = 5%

9.2.2 AC LOSS

This is an internal to the power supply signal reporting the status of the AC input voltage. As already previously stated, this signal changes status within 5ms after actual AC loss (at any angles of the input AC sinusoidal waveform).

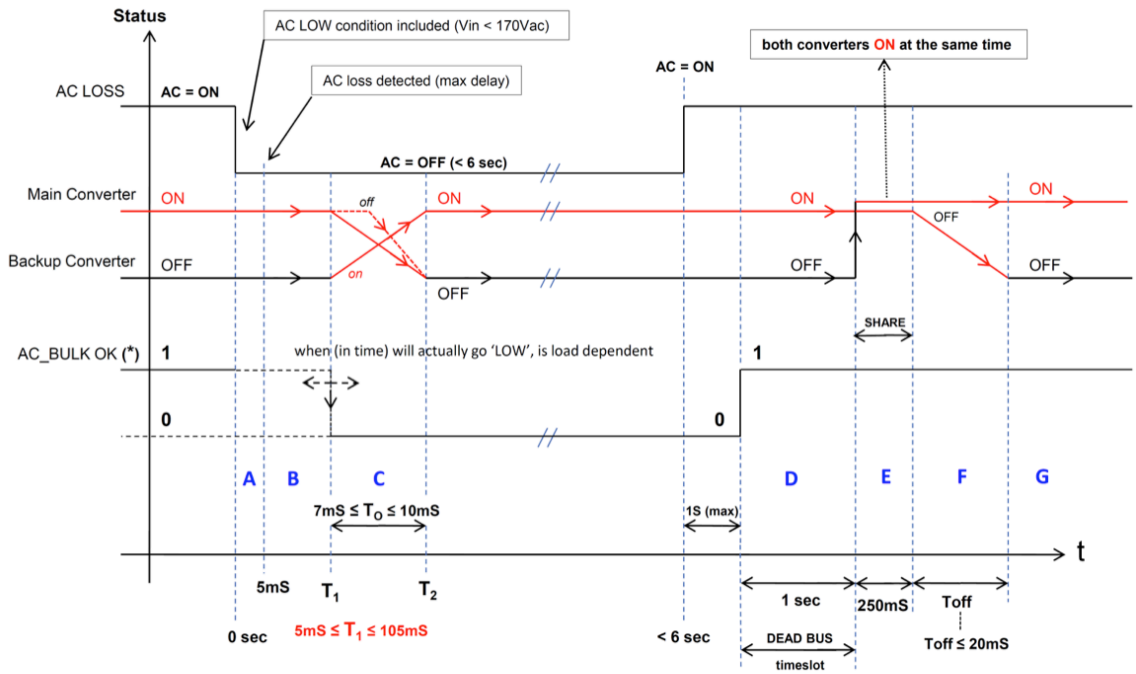
9.2.3 Front-End PFC Section

The PFC always promptly starts up after a valid AC input is available (maximum 1 second start-up time after 200VAC is applied to the power supply), after AC inrush completes.

9.2.4 Backup Power Sequence Charts

Refer to Figure 3 and Figure 4 for the backup power sequencing.

Backup Sequence in case of AC loss event lasting less than 6 seconds



(*) 'AC_BULK OK' signal will go 'LOW' after any AC loss, but it is load-dependent **when**

T_1 (max) = 105mS: there is 100mS time-out for backup engagement after a detected 'AC LOSS' signal, regardless the load

The start of a Backup Sequence is primarily driven by 'AC LOSS' signal, in conjunction with 'AC_BULK OK' signal

Figure 3 Backup Sequence in Case of AC Loss Event Lasting Less Than 6 Seconds

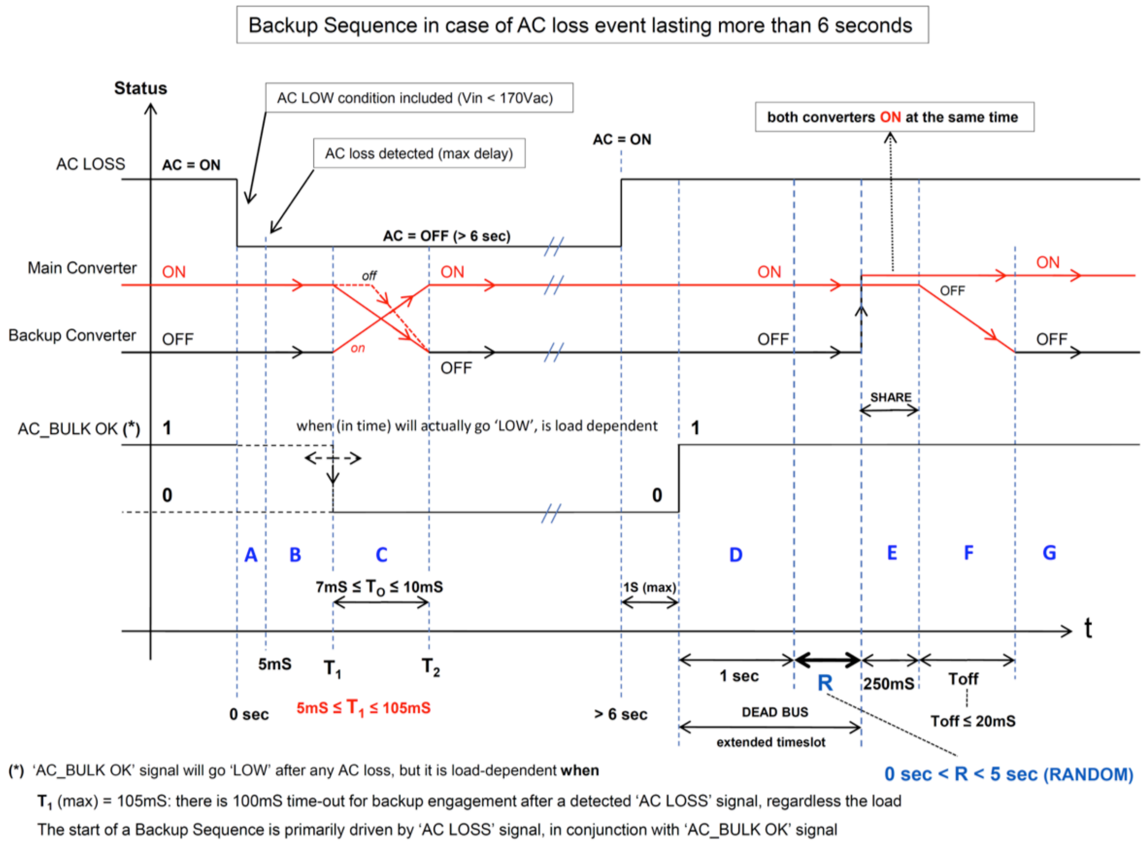


Figure 4 Backup Sequence in Case of AC Loss Event Lasting More Than 6 Seconds

9.3 Power Supply Efficiency (DC Backup Converter)

The efficiency of the backup converter is as follows:

- Efficiency > 90% (> 40% of maximum load)

This efficiency is intended as a ratio of the power supply output power and DC input power, during the backup phase.

Measurements are performed as follows:

- Input DC voltage is 48VDC
- DC voltages are measured directly at the respective mating connectors
- The power supply board is completely assembled in the chassis, with the cover
- The cooling fan is running at full speed during the backup phase (fan is not powered using an external generator, but self-powered by the power supply)
- Ambient temperature of +25°C
- Measurements are taken over five samples (they all need to pass), after 30 minutes under initial 75% load with AC present

9.4 Isolation Requirements

The backup converter supports galvanic insulation between DC input and power supply output, and supports reinforced safety insulation with the main AC input. Detailed isolation requirements are included in Figure 5.

10 Power Supply Block Diagram

This is a high-level block diagram. Isolation voltage levels are also listed.

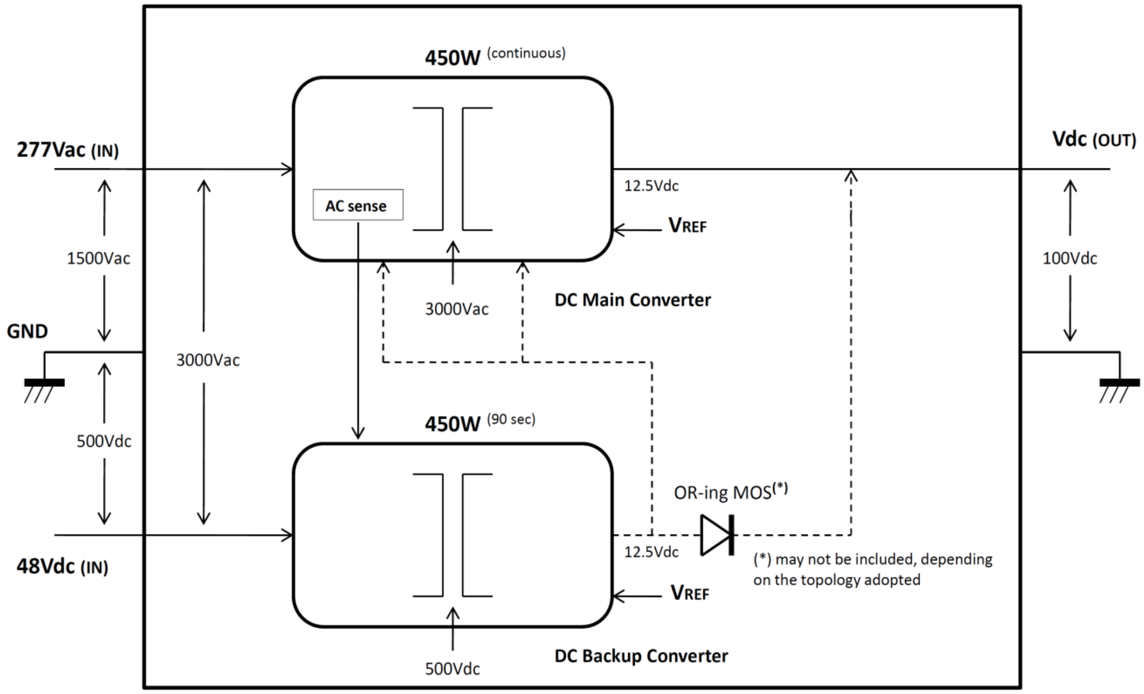


Figure 5 Power Supply Block Diagram

11 Environmental Requirements

- Gaseous contamination: Severity level G1 per ANSI/ISA 71.04-1985
- Ambient operating temperature range: -5°C to +45°C
- Power supply can start at -15°C of ambient temperature
- Operating and storage relative humidity: 10% to 90% (non-condensing)
- Storage temperature range: -40°C to +70°C
- Transportation temperature range: -55°C to +85°C (short-term storage)
- Operating altitude with no deratings: 3000m (10000 feet)

11.1 Vibration and Shock

The power supply meets shock and vibration tests per IEC78-2-(*) and IEC721-3-(*) Standard and Levels, with the specifications listed in Figure 6.

	Operating	**Non-Operating**
Vibration	0.5g acceleration, 1.5mm amplitude, 5 to 500 Hz, 10 sweeps at 1 octave/minute for each of the three axes (one sweep is 5 to 500 to 5 Hz)	1g acceleration, 3mm amplitude, 5 to 500 Hz, 10 sweeps at 1 octave/minute for each of the three axes (one sweep is 5 to 500 to 5 Hz)
Shock	6g, half-sine 11mS, 5 shocks for each of the three axes	12g, half-sine 11mS, 10 shocks for each of the three axes

Figure 6 Vibration and Shock Requirements

12 Mechanical Requirements

12.1 Physical Dimensions

The power supply dimensions are:

- Length: 220mm (8.66")
- Width: 120mm (4.72")
- Height: 64mm (2.52")

The sheet metal material is steel, pre-plated hot-dip zinc-coated, 1mm thick.

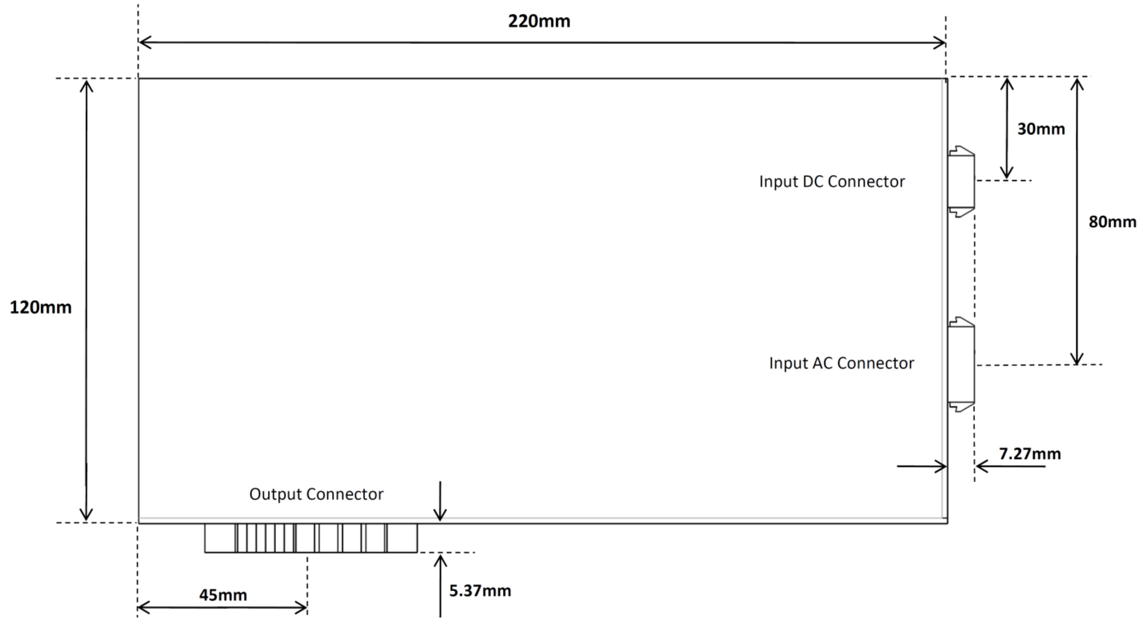
The power supply mechanical chassis is composed of a base and a cover assembled using flathead screws; there are no rivets so the power supply can be opened with a screwdriver. The cover has a small opening for a microprocessor/DSP firmware upgrade (see section 6.9), with a small plate (held together with a flat-head screw) that can be easily uninstalled to reach the connector. The unit uses a hard-tooled chassis.

The power supply is installed in a metal tray with a direct interface from the output connector to the board-mount counterpart installed on the motherboard.

A simple mechanical interlock with mounting holes, mounting plunger pins, and a thumbscrew secures the power supply to the tray. This allows the quick installation of the power supply in the tray without the needing a screwdriver.

Important: The whole power supply assembly, including the mechanical enclosure and the chassis itself, meets certain environmental contamination requirements (see section 11).

12.2 Power Supply Top View (Cover), Connectors Layout



Notes:
- Connectors are installed at the edge of the PCB main board, flat on top without any vertical gap
- The distance from the top of the PCB main board and the bottom of the chassis base is 9.4mm
- Sheet metal thickness is 1mm, PCB main board thickness is 1.6mm

See mechanical drawing in appendix for all the details

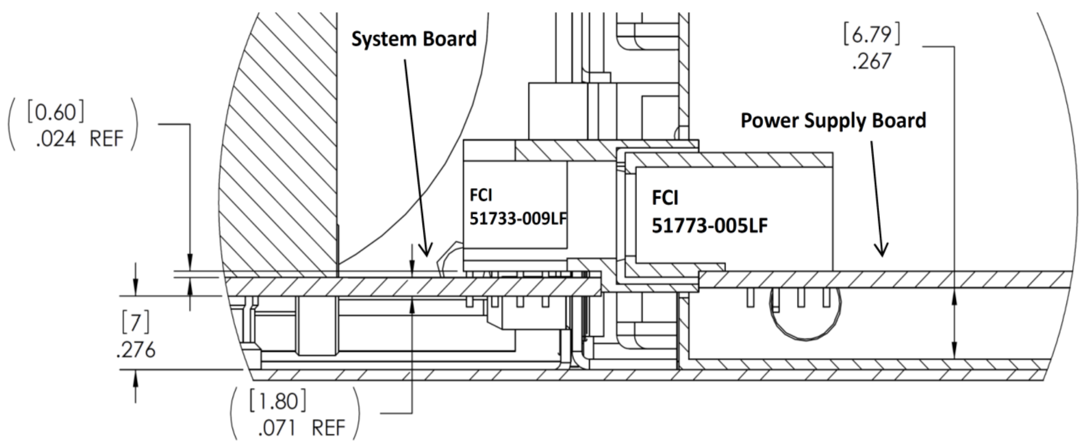


Figure 7 Power Supply Top View (top); Power Supply Direct Interconnection to Motherboard (bottom)

12.3 Power Supply View (Front and Back)

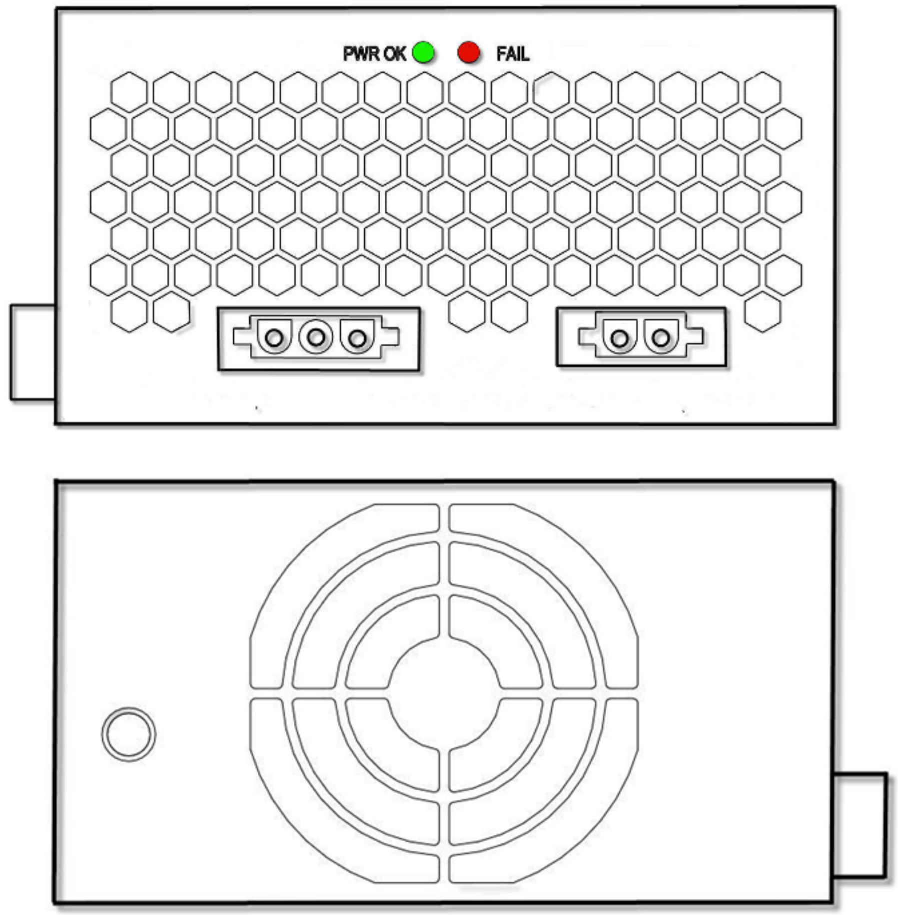


Figure 8 Power Supply Front Panel/Air Intake (top), Back Panel/Air Outlet (bottom)

13 LEDs, Silkscreen

Two LEDs on the front panel of the power supply indicate its status (see Figure 8).

The LEDs don't light unless valid AC input is available, but LEDs will light during a backup phase following an AC outage.

- "Valid" AC Input: VAC(in) > 180VAC RMS
- "Valid" DC input: Vin > 39VDC (with correct polarity)
- "Valid" DC output: 11.3VDC < Vout < 13VDC

13.1 PWR OK LED (Bi-color Green/Yellow)

- The PWR OK LED turns yellow when the output voltage is "Valid" **and** the DC input is not present or "Not Valid", or it is applied with reversed polarity.

- The PWR OK LED turns green when the output voltage is "Valid" **and** the DC input is "Valid". Note that with 54VDC input level, at DC removal the green light turns yellow within 3 seconds after DC disconnection.
- The PWR OK LED blinks yellow (1 Hz, 50% duty-cycle) during a backup phase following an AC outage (every time the output power is supported by a valid DC input source).
- The PWR OK LED is OFF when the DC output is "Not Valid" under all cases (output short-circuit/overload and all protections included, and failure). So, simple output voltage reading is sufficient to determine the OFF status of this LED.

13.2 FAIL LED (Red)

- The FAIL LED lights in case of any power supply failure (excluding fan failure), and when the power supply is under any latching-OFF or temporary-OFF protection conditions (like over voltage, over temperature, over current latched-OFF conditions).
- The FAIL LED does not light in case of output short circuit/overload condition, but it lights when the power supply gets latched OFF after the time delay for an output short circuit/overload condition (AC mode only; in DC backup mode, the LED stays OFF).
- The FAIL LED blinks (1 Hz, 50% duty-cycle) in case of fan failure, which is defined as a tachometer fan speed reading < 750RPM. In this case, other than the actual fan failure with the correspondent blinking LED indication, the power supply keeps working normally until a potential over temperature condition occurs.
- The FAIL LED is OFF otherwise.

Note: "**AND**" is intended as a logical operator.

The size of the LEDs is 3mm. A simple black silkscreen for the LEDs is on the power supply faceplate.

14 Not Allowed Components

Avoiding the following components ensures a more reliable power supply.

- Trimmers and/or potentiometers
- Tantalum capacitors
- Dip switches
- High-side driver ICs
- Paralleled power MOS are allowed provided that design prevents parasitic oscillations
- Phase-shift topology is not allowed
- SMT ceramic capacitors are allowed when the case size < 1206. The size 1206 can still be used when SMT capacitors are placed far from the PCBs edge, and with a correct orientation that minimizes risks of cracks
- Allowed ceramics materials for SMT capacitors are: X7R or better material

The COG or NPO types should be used in critical portions of the design, such as feedback loop, PWM clock settings, and so forth.

The use of any electro-mechanical relays should be discussed up front before any approval is given to include them in the design.

14.1 Capacitors

All the electrolytic capacitors are made by high quality manufacturers and are rated 105°C.

All capacitors have a predicted life of at least 50,000 hours at 45°C inlet air temperature, under worst conditions.

15 Complete BOM for the AC and DC Power Cords

15.1 BOM for a Complete AC Power Cord (Symmetrical Cable)

- Housing of wire-terminated MALE contacts (2x): TYCO p/n 350766-1
- MALE contacts (pin1 "N", pin3 "L") for AWG 14/20 (4x): TYCO p/n 350218-1

Note: The external diameter of the wires, including insulation, is between 1.52mm and 3.30mm.

- Pre-mating MALE contact (pin2 "GND") for AWG 14/20 (2x): TYCO p/n 350654-1

Note: The external diameter of the wires, included insulation, is between 1.52mm and 3.30mm.

- Strain relief for 3 positions Mate-N-Lok (4x): TYCO p/n 641945-1
- Cable size is AWG 18, 600V, UL1015; system level power cord length is 4.5"
- The cable is sheathed, with the sheath grabbed by the strain reliefs at both endings of the cable

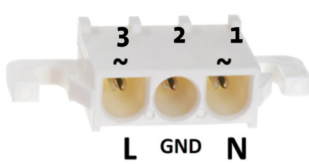


Figure 9 AC Input Connector

- Counterpart connector polarity at both AC power cord sides.
    - Pin 1: NEUTRAL
    - Pin 2: GROUND
    - Pin 3: LINE

15.2 BOM for a Complete DC Power Cord (Symmetrical Cable)

- Housing of wire-terminated MALE contacts (2x): TYCO p/n 350777-1
- MALE contacts (pin2, positive) for AWG 10/12 (2x): TYCO p/n 350922-3
- Pre-mating MALE contacts (pin 1, negative) for AWG 10/12 (2x): TYCO p/n 770234-3
- Strain relief for 2 positions Mate-N-Lok (4x): TYCO p/n 640713-2
- Cable size is AWG 14, 300V, UL1015; system power cord length is 5.5 inches
- The cable is sheathed, with the sheath grabbed by the strain reliefs at both endings of the cable

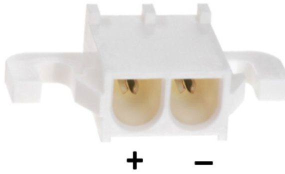


Figure 10 DC Input Connector

- Counterpart connector polarity at both DC power cord sides
  - Pin 1: NEGATIVE (-48V)
  - Pin 2: POSITIVE (+48V)

16 Power Supply Mechanical Drawing

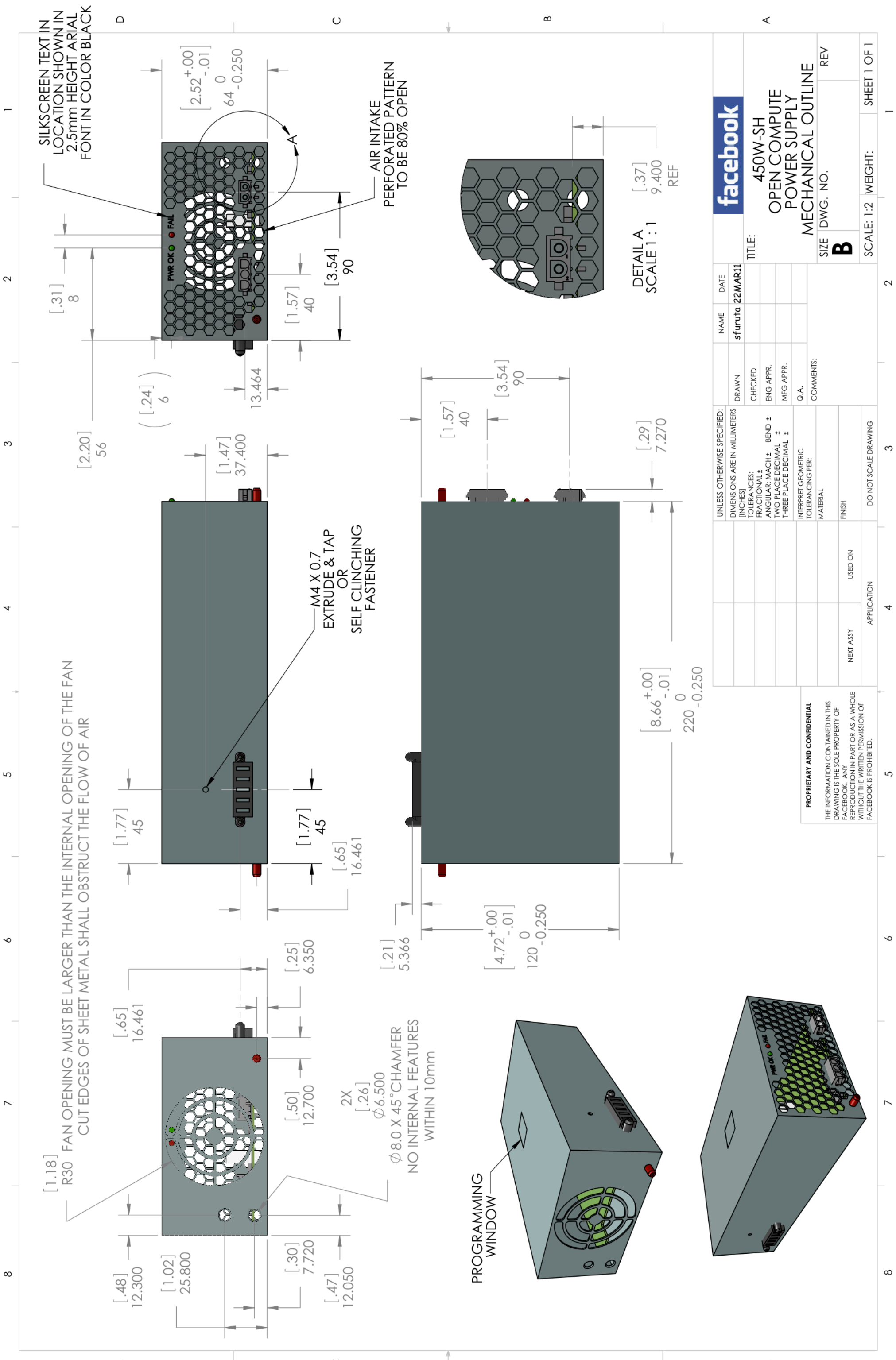


Figure 11 Power Supply Mechanical Drawing