ENGINEERING NOTE · DESIGN CHECKLIST

MIL-STD-1275, 810 and 461 for Battery Chargers: A Design Checklist for Rugged 24 V Vehicle Chargers

A rugged charger's specification can pull in some 1,400 pages of military standards, but fewer than 150 of them change the design. This checklist maps each requirement to the design decision it forces and the test that proves it, with the arithmetic behind the hard ones.

Tan Shuai · tanshuai.com · i@tanshuai.com

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Abstract

A rugged 24 V battery charger for vehicles and the field is, at heart, an ordinary switch-mode charger with four hard problems wrapped around it. MIL-STD-1275 puts a 100 V surge from a 0.5 Ω source on its input, which no clamp diode can absorb, so the front end needs a series surge stopper built from 150 V-class parts. MIL-STD-461 makes emissions, not immunity, the difficult side: every power input needs a two-stage filter at the connector wall, and the case has to seal electrically as well as mechanically. MIL-STD-810 asks for a sealed box that sheds heat at +55 °C in the sun, survives 26 drops and breathes at altitude without letting water in. A 40,000-hour MTTF leaves no room for a fan. Everything else, from humidity and salt fog to ESD, touch temperature and the reliability report, follows good practice and is verified by test or by document. Most specifications still cite revisions from the 1980s and 1990s; designing to the current ones and handing over a cross-reference table costs nothing and avoids rework. A credible qualification takes three samples and 8 to 16 weeks, and at published lab rates in mainland China it costs roughly $20,000 to $55,000.

Why I wrote this

Requests for rugged chargers arrive as a page of requirements and a list of standards: MIL-STD-810 for the environment, MIL-STD-461 for electromagnetic compatibility, MIL-STD-1275 for vehicle power, a safety standard, an MTTF figure and a few human-factors rules. The documents behind that list run to about 1,400 pages. Read literally, they turn a charger into a research project. Skimmed, they hide the three or four clauses that decide the block diagram, the enclosure and the price.

I recently worked through such a specification line by line, read the standards themselves rather than summaries of them, and sorted every clause by what it does to the design. This note is the result, written as a checklist for engineers who have to turn a specification like that into hardware, and for buyers who want to know what they are asking for. Every number below is as of November 2026, and money is in US dollars.

Results at a glance

Figure 1. Of about 1,400 pages of standards, fewer than 150 decide the design. The rest is good practice and paperwork.

The documents behind a typical rugged-charger specification, and what each part of them does to the work.



Tier 1 — Decides the architecture

Settle before the design freezes

- **MIL-STD-1275** — Front-end topology and part voltages
- **MIL-STD-461 emissions** — Filters at the wall, sealed seams, cable treatment
- **MIL-STD-810 heat, rain, dust, altitude** — No fan, finned wall, vent, wall thickness
- **MIL-STD-810 vibration and shock** — Structure, part retention, bumpers
- **Safety insulation** — Clearances, creepage; couples with the EMI filter
- **Two definitions** — Which 1275 revision; what "EMP protection" means

Tier 2 — Good practice, then test

Look up once, mark on the drawings

- **Low temperature** — Parts and display rated for −40 °C
- **Humidity and salt fog** — Coatings, sealing, no dissimilar metals
- **Sand and dust** — Abrasion of paint and display window
- **Immunity tests** — Usually passed by a sealed, bonded case
- **ESD** — 4 kV contact, 8 kV as margin
- **Human factors** — Gloved handle, knob detents, character size

Tier 3 — Documents or analysis

Written, not tested

- **MTTF** — Parts-stress prediction, MIL-HDBK-217F
- **Design review** — MIL-HDBK-454 checklist
- **Factory** — ESD control program, ISO 9001
- **Withdrawn standards** — Equivalence statements
- **By analysis, if accepted** — Low pressure, solar load, radiated EMP

Source: The author's reading of the standards cited; page counts are those of the published documents.

The checklist itself, from the requirement to the design decision it forces and the way to prove it:

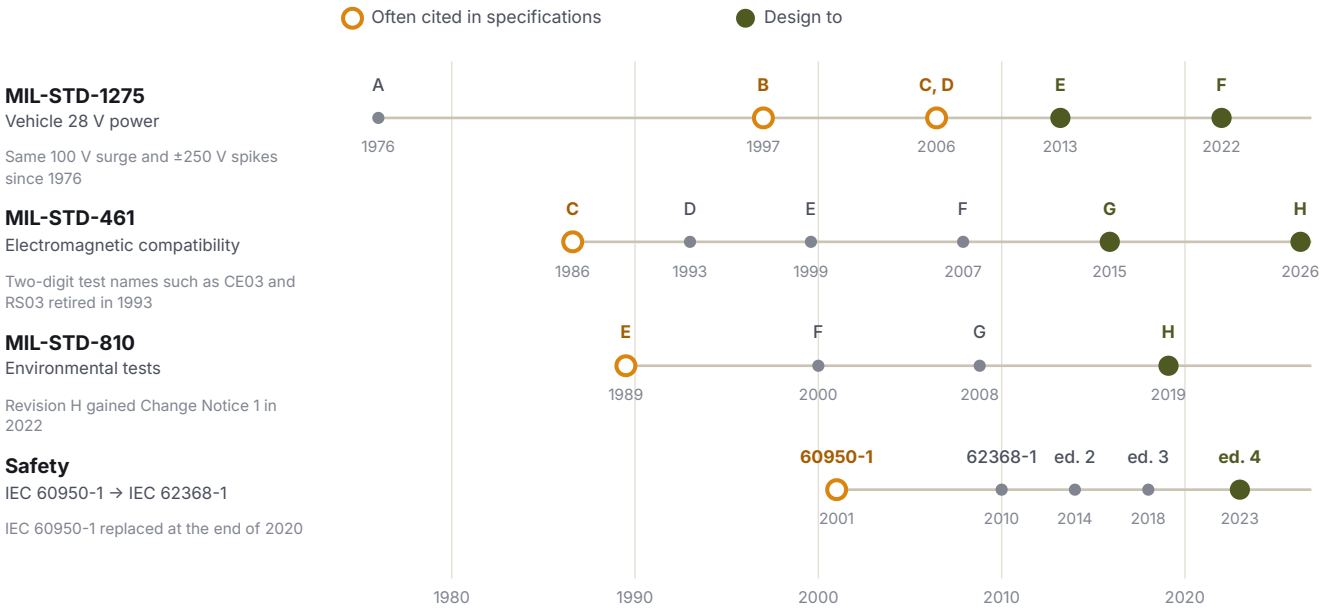
Requirement	What it does to the design	How it is verified
MIL-STD-1275, 24 V vehicle power	Series MOSFET surge stopper with 150 V-class parts, TVS for spikes, reverse-polarity blocking without a diode drop; charge from 16 to 33 V, pause and resume by itself during engine starts	Test with a transient generator built for the cited revision
MIL-STD-461, EMI	A two-stage LC filter on every power input, mounted at the connector wall; conductive gaskets on every seam; converters planned for frequency; pre-scans on the first prototype	Chamber test, after in-house pre-scans
MIL-STD-810, environment	Sealed, fanless electronics bay with heat leaving through fins; an ePTFE vent for altitude; corner bumpers and recessed connectors for drops; parts rated for −40 to +71 °C storage	One sample through the climatic chain, one through the mechanical chain
Li-ion charging temperature	Measure every battery and charge only inside its window, typically 0 to 45 °C; pause, show why, resume by itself; optional preheating	Test at the temperature extremes
Safety, IEC 62368-1	Clearances designed to the larger reading of the tables; a metal fire enclosure above 100 W; polymer handles and knobs for touch temperature	CB test report and inspection
ESD	4 kV contact discharge on everything a hand can reach, 8 kV as margin	Test, about half a day
MTTF of 40,000 hours	A budget of 25 failures per million hours for the whole charger: no fan, derated parts	MIL-HDBK-217F prediction, with the method agreed up front
Human factors, MIL-STD-1472	A handle sized for gloves, knob detents 15 to 40° apart, characters readable at arm's length	Inspection and a demonstration with gloves

Step zero: design to the current revisions

Specifications for rugged equipment are often older than they look. It is common to find MIL-STD-810E (1989) and MIL-STD-461C (1986) next to safety standards that have since been withdrawn, because procurement offices copy their templates forward. The two-letter, two-digit test names of 461C, such as CE03 and RS03, were retired in 1993. MIL-STD-810 is now at revision H (January 2019, with Change Notice 1 in 2022); MIL-STD-461 at G (December 2015), followed by H in April 2026; MIL-STD-1275 at E (March 2013) and F (2022). IEC 62368-1 replaced IEC 60950-1 at the end of 2020 and is in its fourth edition (2023). EN 50091-1, which still turns up in charger specifications, is a UPS standard that was withdrawn in 2005.

Figure 2. Specifications still cite revisions from the 1980s and 1990s. Design to the current ones and report against both.

Revisions of the four standard families a rugged charger meets. Design to the current revisions and report against the ones cited.



Source: Revision dates from the standards themselves and from a US test lab's revision list; IEC publication dates.

The default severities of MIL-STD-810 barely changed between 1989 and 2019, and the two stresses that shape a MIL-STD-1275 front end have been the same since 1976, so designing to the current revisions costs nothing. What it buys is a design that will still pass if the customer updates the specification, and test labs that still run the methods. My rule is to design to 810H, 461G or H, 1275E or F and IEC 62368-1:2023, to report results against the method numbers the customer cited, and to hand over a one-page table that maps old to new. Where an old method survives in only a few labs, such as 461C's CE03 conducted emissions, agree on the current equivalent before booking a chamber.

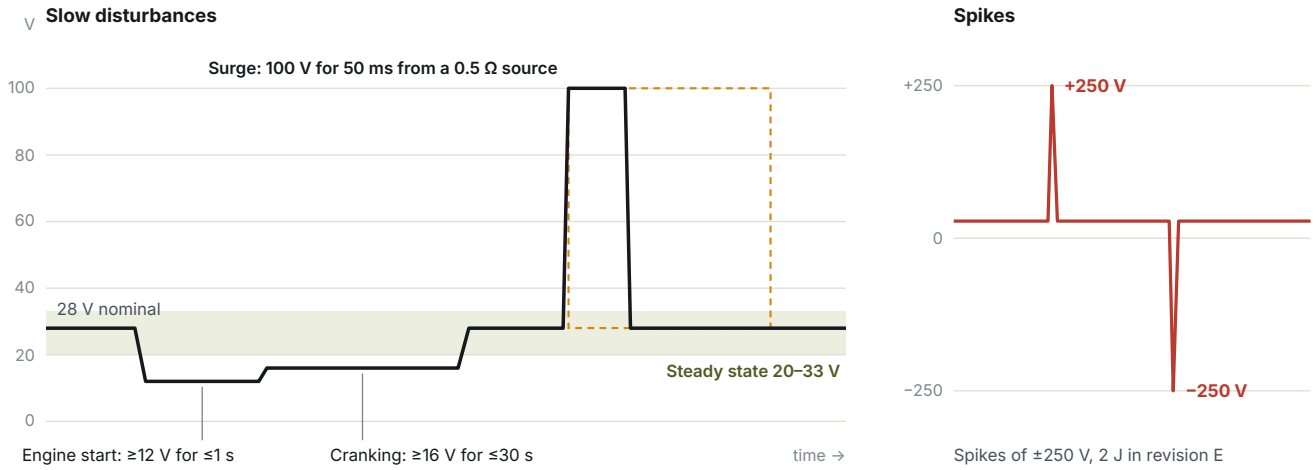
Two questions belong in the first email, because the answers change the cost: which revision of MIL-STD-1275 applies, with what pass criterion, and what "EMP protection" means. Cable injection of damped sine waves (CS116, or CS10 and CS11 in 461C) takes about one chamber day. A radiated pulse test (RS105, or RS05 in 461C) is a different budget, and 461H applies it only to equipment that carries an explicit EMP requirement.

MIL-STD-1275: the 24 V input decides the block diagram

Every revision of MIL-STD-1275, from A in 1976 to E in 2013, contains the same two stresses that define the design: a surge to +100 V lasting 50 ms from a 0.5 Ω source, and spikes of ±250 V. What changed between revisions is bookkeeping: operating modes, the spike energy (15 mJ in B and D, 2 J in E), the floor of the engine-start dip (no lower than 6 V for 1 s in the older revisions, 12 V in E, then no lower than 16 V for up to 30 s while cranking) and the steady-state window, 20 to 33 V in E. Revision F, judging by the documentation of the test generators built for it, stretches the surge to about 500 ms from a much stiffer source and cuts the spike energy to 250 mJ.

Figure 3. The MIL-STD-1275E envelope on a 28 V vehicle bus.

The envelope a charger's vehicle input must survive, and keep working through. Time is not to scale.



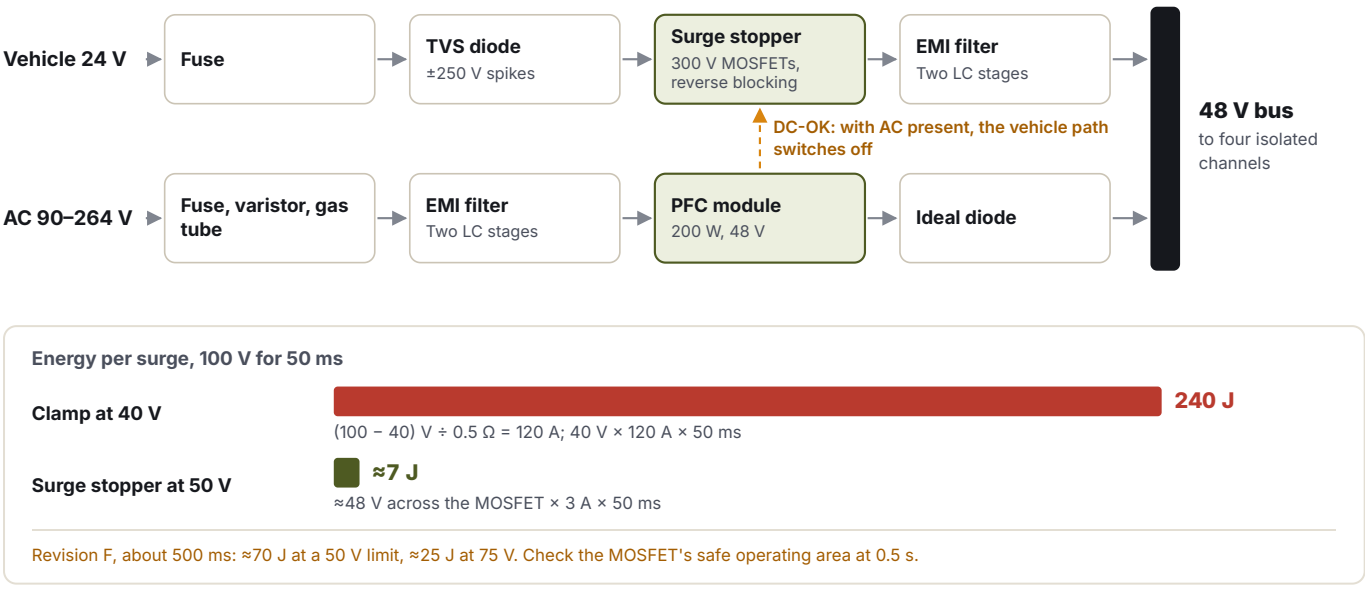
Revision F: the surge lasts about 500 ms, from a much stiffer source

Source: MIL-STD-1275E (2013); the revision F note is inferred from the documentation of F-rated test generators.

The surge is what rules out the obvious answer. Clamp it at 40 V with a TVS diode or a varistor, and the source drives (100 − 40) / 0.5 = 120 A into the clamp for 50 ms, which puts 40 V × 120 A × 0.05 s = 240 J into one part. No clamp of sensible size takes that repeatedly. A series surge stopper does the job differently: a MOSFET in the supply path limits its output to a set voltage and drops the rest, so it dissipates only the difference between the surge and that voltage, times the load current. For a 150 W load held at 50 V, that is about 48 V × 3 A, or roughly 150 W for 50 ms: about 7 J, thirty times less than the clamp.

Figure 4. A clamp would have to absorb 240 J; a series surge stopper dissipates about 7 J.

The two input paths of a rugged charger, and the arithmetic that rules out clamping the MIL-STD-1275 surge.



Source: The author's design; energies calculated for a 150 W load.

The rest of the front end follows from that:

- **Parts rated for 150 V or more** in the surge path. I use a 300 V MOSFET, which buys margin against the spikes.
- **Revision F changes the numbers.** At 500 ms, the same 50 V limit would put about 70 J into the MOSFET. Raising the limit to about 75 V, which 18–75 V input DC-DC modules accept continuously, brings the current

down to 2 A and the voltage across the MOSFET to about 24 V, about 25 J in all; check the MOSFET's safe operating area at 0.5 s either way.

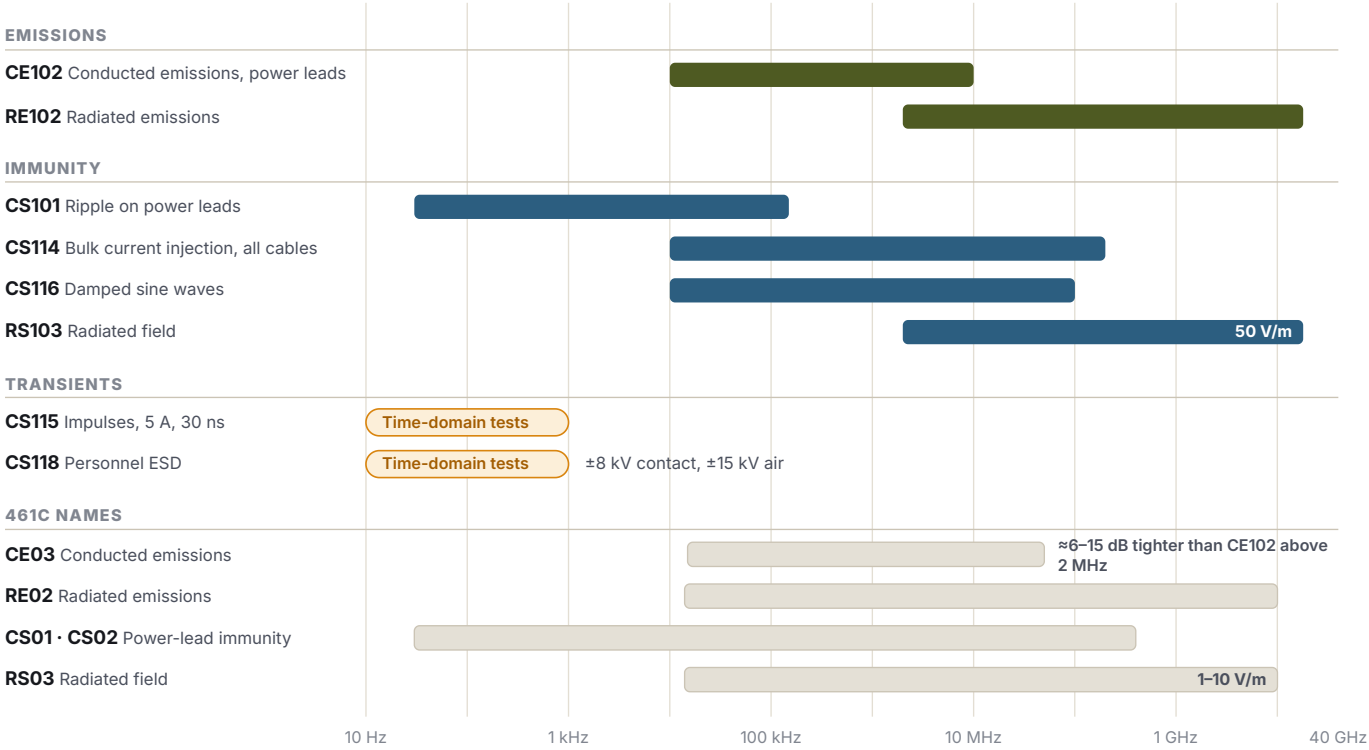
- **A TVS still catches the spikes.** At 2 J (or 250 mJ in F), that is a job it can do.
- **Reverse polarity is blocked by back-to-back MOSFETs** under an ideal-diode controller, not by a series diode, which would waste several watts.
- **Engine starts are a mode, not a fault.** Keep charging down to 16 V where possible. Below that, pause, keep the display and the logs alive, and resume without anyone touching the unit. Say so in the reply to the specification.
- **Modules with 18–75 V input help.** They typically tolerate 100 V for 1 s, so one stage of surge protection in front of them is enough.
- **Ripple counts too.** 1275D allows 7 V peak of ripple up to 200 kHz, which the input filter has to handle without resonating.

MIL-STD-461: emissions are the hard side

For Army ground equipment, MIL-STD-461G applies eight tests: CE102 conducted emissions on power leads (10 kHz to 10 MHz), RE102 radiated emissions (2 MHz to 18 GHz for ground equipment), CS101 audio-frequency ripple on power leads (30 Hz to 150 kHz), CS114 bulk current injection on every cable (10 kHz to 200 MHz), CS115 fast impulses, CS116 damped sine waves (10 kHz to 100 MHz), CS118 personnel ESD (±8 kV contact, ±15 kV air) and RS103 radiated immunity, 50 V/m from 2 MHz to 18 GHz. The 461H revision of April 2026 keeps the Army ground limits and tightens the procedures.

Figure 5. The MIL-STD-461G tests for Army ground equipment, and the 461C tests that older specifications still name.

Frequency ranges on a logarithmic axis, with the MIL-STD-461C tests that older specifications still name.



Source: MIL-STD-461G (2015), Table V and test sections; MIL-STD-461C (1986), Part 4.

A battery charger is a difficult case for emissions. It contains several switching converters: a power factor corrector, an isolated converter per channel and a buck-boost charge stage per channel. Four channels running at slightly different frequencies produce beat products, and the battery leads and vehicle cables make good antennas. Immunity is usually the easier side, though 50 V/m in RS103 deserves respect. An older specification shifts the

balance further: 461C's CE03 limit above 2 MHz is about 6 dB tighter than CE102 on a 28 V input and about 15 dB tighter on a 230 V input, and it runs to 50 MHz instead of 10 MHz, while its radiated immunity requirement is only 1 to 10 V/m.

What works:

- **A two-stage LC filter on every power input,** built on the connector wall so that filtered and unfiltered wiring never share a compartment. By my estimate, a charger needs 40 to 60 dB of attenuation at its switching frequencies and 50 to 70 dB from 2 to 50 MHz to meet CE03 with margin.
- **The sealed electronics bay doubles as the shield.** Conductive gaskets and a continuous bond on every seam turn the case into a Faraday cage at no extra cost.
- **Plan the converters' frequencies.** Synchronize the channel converters or spread their spectrum, and slow the switching edges where efficiency allows.
- **Choke the battery leads.** A common-mode choke at each output keeps the battery cables from radiating.
- **Measure early.** A conducted-emissions pre-scan on the first prototype costs a day with a LISN and a spectrum analyzer; finding a problem in the formal chamber costs weeks.

MIL-STD-810: a sealed box that sheds heat, breathes and survives drops

The ten environments a charger specification typically names map one-to-one onto 810E methods 500.3, 501.3, 502.3, 505.3, 506.3, 507.3, 509.3, 510.3, 514.4 and 516.4, which became 500.6, 501.7, 502.7, 505.7, 506.6, 507.6, 509.7, 510.7, 514.8 and 516.8 in 810H. Their default severities barely changed in thirty years. None of them is hard on its own; together they describe a sealed box, and a sealed box has three problems: heat, pressure and impact.

Method (810E / 810H)	Default severity	Design response
Low pressure (500.3 / 500.6)	4,570 m, 57 kPa	A sealed box sees about 44 kPa across its walls; on a 340 × 240 mm lid that is about 3.6 kN. An ePTFE vent equalizes the pressure and keeps water out.
High temperature (501.3 / 501.7)	Hot-dry cycle: 32 to 49 °C ambient, 33 to 71 °C induced inside vehicles and enclosures	Fanless natural convection through a finned wall; every hot part conducts into it; firmware derates charge power above 50 °C.
Solar radiation (505.3 / 505.7)	1,120 W/m², 24-hour cycles	A lighter color reduces solar gain; agree whether analysis may replace the test.
Low temperature (502.3 / 502.7)	Basic cold to about −32 °C; colder categories by agreement	Parts and display rated for −40 °C; batteries are not charged below 0 °C (see below).
Rain (506.3 / 506.6)	10 cm/h, wind 18 m/s, 30 minutes per face	IP67 electronics bay, a continuous lid gasket, drain valves in the battery wells.
Humidity (507.3 / 507.6)	10-day cycles	Sealed bay and conformal coating.
Salt fog (509.3 / 509.7)	5% NaCl at 35 °C, 48 h wet and 48 h dry	Conversion coating under powder or CARC paint, stainless hardware, no dissimilar metals in contact.
Sand and dust (510.3 / 510.7)	Dust 10.6 g/m³ at 8.9 m/s; sand 1.1 g/m³ at 18 to 29 m/s	Sealed bay; abrasion-resistant coating and display window.
Vibration (514.4 / 514.8)	Wheeled or tracked vehicle profile: ask which	Stake heavy parts; a foam pad in the lid holds the batteries; charge real batteries during the test to prove operation on the move.
Shock and transit drop (516.4 / 516.8)	26 drops from 122 cm	About 10 mm of controlled deformation in corner bumpers; recessed connectors; nothing lands on a connector.

The combination that catches people is heat with sealing. At +55 °C in full sun, a sealed box cannot use outside air, so all of the loss has to leave by conduction and natural convection. At 120 W of output, a charger with 79 to 83% efficiency loses 25 to 32 W, which a finned aluminium wall can shed, but an AC-DC module that derates 2 to 3% per degree above 50 °C has to be sized for it. If the full output must be available at +55 °C, either the module grows a size or the firmware trims the charge current and says so.

No fan, because of the MTTF

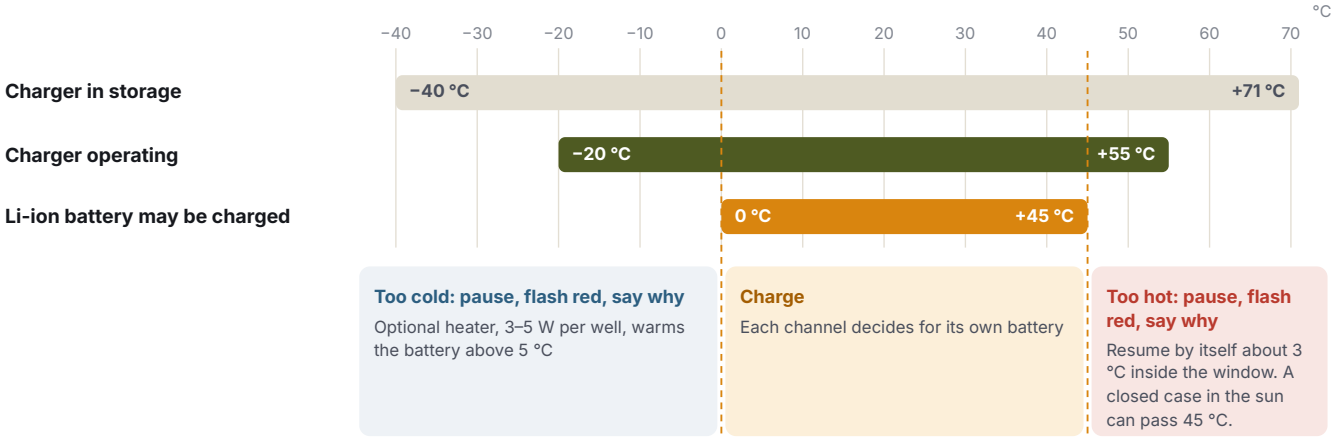
A required MTTF of 40,000 hours is a budget of 25 failures per million hours for the entire charger. The usual way to show it is a parts-stress prediction under MIL-HDBK-217F Notice 2 in the ground mobile environment, where capacitors carry an environment factor 20 times that of a benign one. A fan bearing has a characteristic life of about 35,000 hours at 60 °C and 22,000 at 70 °C; in that prediction, one fan contributes about 43 failures per million hours, more than the whole budget. That settles it: no fan inside, derated parts, and the prediction method, environment and temperature agreed with the customer before anyone runs the numbers. Demonstrating the figure by test is impractical: standard demonstration plans need tens of thousands of failure-free unit-hours.

The battery has its own temperature window

A Li-ion battery may only be charged inside the temperature window its maker allows, typically 0 to 45 °C, while the charger is usually asked to work from −10 or −20 °C up to +55 °C. Charging a cold cell plates lithium and destroys it; charging a hot one shortens its life. The charger therefore has to know each battery's temperature, from the pack's thermistor or its smart-battery data, and decide for each channel separately.

Figure 6. The charger has to work over a wider range than the battery may be charged in.

Temperature ranges for a rugged charger and a typical Li-ion battery, and what each channel does at the edges.



Source: Typical Li-ion charging window from battery datasheets; charger ranges and behavior from the author's design.

The behavior I specify: outside the window, that channel stops charging while display, data reading and built-in test keep working; its LED flashes red and the display says why, in the operator's language; when the battery returns to the window, with about 3 °C of hysteresis, charging resumes without anyone touching it. If a customer needs charging at −10 °C, a 3 to 5 W heater pad in each well brings the battery above 5 °C first. And because the wells of a closed case in the sun can pass 45 °C, a promised charge time only holds at moderate temperature, which belongs in the written assumptions.

Safety, touch temperature, ESD and human factors

Safety. IEC 62368-1 replaced IEC and UL 60950-1 at the end of 2020, and its 2023 edition revised the battery-charging clauses. Published readings of its clearance table disagree (1.5 and 3.0 mm in one test report, 1.8 and 3.6 mm in a semiconductor maker's reading), so I design to the larger values: at least 1.8 mm basic and 3.6 mm

reinforced up to 2,000 m, multiplied by 1.48 at 5,000 m. A charger delivering more than 100 W is a PS3 circuit and needs a fire enclosure; a metal case is one. A CB test report covering the battery-charging annex is the efficient way to show all of it.

Touch temperature. MIL-HDBK-454 allows 49 °C on controls, 60 °C on other parts a hand can reach and 70 °C elsewhere, at 25 °C ambient. At +55 °C ambient, bare metal already exceeds 49 °C, so handles, knobs and corner bumpers are polymer or elastomer, and hot surfaces are marked. The same guideline asks for leakage current of at most 3.5 mA, bonding resistance of at most 0.1 Ω and capacitors that discharge below 30 V within 2 s.

ESD. The usual requirement is 4 kV human-body-model contact discharge on every control an operator can touch and at the center of every surface, with 2 kV on unpowered interface pins. Testing at the 8 kV of 461G's CS118 as well adds margin at almost no cost. The factory needs its own ESD control program, under ANSI/ESD S20.20 or IEC 61340-5-1.

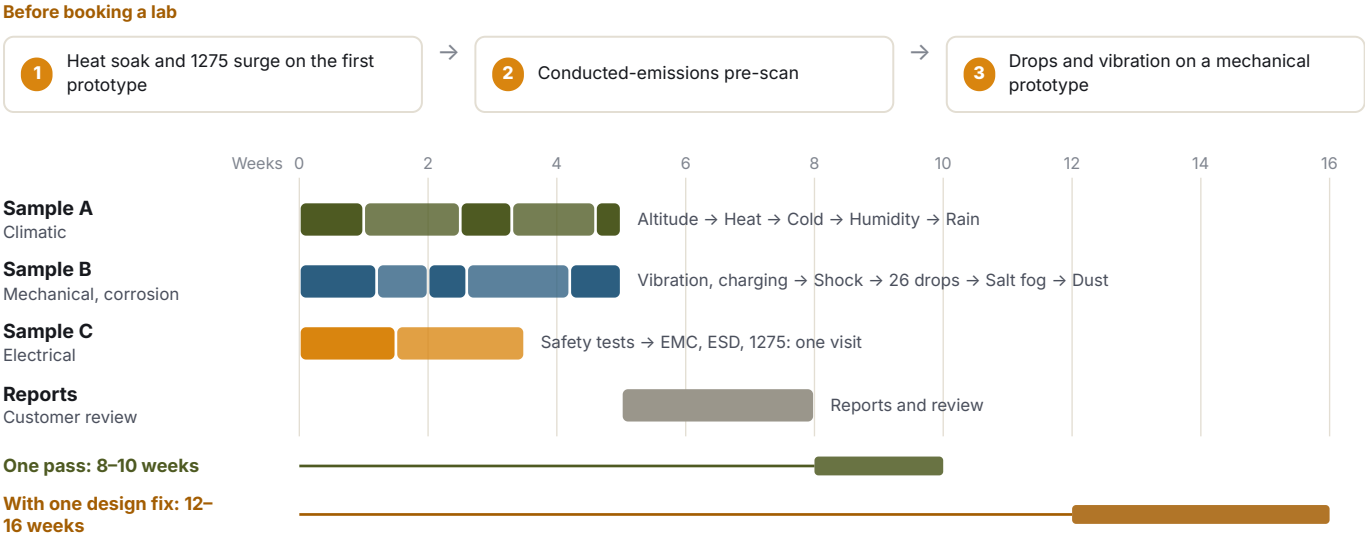
Human factors. MIL-STD-1472 sizes a one-hand handle for a gloved hand at 125 mm inside width, 50 mm finger clearance and 100 mm depth (111, 48 and 75 mm bare-handed; 135, 75 and 150 mm in mittens), knob torque at 115 to 680 mN·m with detents 15 to 40° apart, and characters 2.5 to 5 mm high at a 710 mm viewing distance. All of it is verified by inspection and a demonstration with gloves, at no lab cost.

Qualification: three samples, two parallel chains, one EMC visit

Three samples are the comfortable number for qualification, two the minimum. Sample A runs the climatic chain: low pressure, high-temperature storage and operation, low temperature, solar radiation if it is tested, humidity and rain. Sample B runs the mechanical and corrosion chain: vibration while charging, transport, functional shock and bench handling, the 26 drops, salt fog and dust. Sample C runs the electrical chain: safety type tests, MIL-STD-461, ESD and MIL-STD-1275. Run in parallel, the first two chains take four to five weeks; EMC and power transients take one and a half to two; reports and the customer's review add two to three. That makes 8 to 10 weeks if everything passes, and 12 to 16 weeks with one design correction.

Figure 7. A qualification plan for three samples: 8–10 weeks if everything passes, 12–16 with one design fix.

A qualification plan in weeks from the first test, after the risks have been burned down on prototypes.



Lab cost at published rates

Mainland China	US or Europe
$18,000–45,000	**≈$70,000–115,000**
$22,000–54,000 with a 20% retest allowance	estimate

Source: The author's plan; lab rates from a Jiangsu provincial institute (2025), Taiwan's standards bureau and two US labs.

The order matters more than the lab. Before booking anything, run the heat soak and the 1275 surge on the first prototype, then an EMC pre-scan, then the drops and vibration on a mechanical prototype. Then several savings come almost free: hot and cold operation in one chamber booking; batteries charging during vibration, which also proves operation on the move; temperature-rise data for the safety report collected during the +55 °C soak; ESD and 1275 in the same visit as EMC; one test plan covering 810, 461 and 1275, approved once by the customer, who then witnesses only EMC, drop and vibration. Low pressure, solar radiation and a radiated EMP pulse can often be shown by analysis instead of test.

No lab publishes prices for military testing, so the costs have to be built up from public fee schedules. A provincial test institute in Jiangsu lists climatic chambers at $4.50 to $37 an hour and an EMC chamber at $119 to $149 an hour; Taiwan's standards bureau lists vibration at about $121, a drop test at about $73, ESD at about $364 and a full EMC set at about $2,610; in the United States, one lab advertises MIL-STD-461 testing from $3,999 and another bills engineering time at $157 to $377 an hour. Built up from those rates, a full set (461, 1275, ESD, ten 810 methods and a safety report) costs roughly $18,000 to $45,000 in mainland China, or $22,000 to $54,000 with a 20% allowance for a retest, and I estimate $70,000 to $115,000 in the United States or Europe. Taiwan's public labs are not dearer than the mainland's at their published rates. Whether a buyer accepts a given lab's reports is a commercial question best settled before the first booking.

Need a charger built to this checklist?

This checklist comes from designing one: a sealed, fanless four-bay charger with AC and 24 V vehicle inputs, built as a platform that scales from two to eight bays. How it is built, how the gaps in a specification get filled and how it gets from a specification to engineering samples in 16 weeks are in Custom Rugged Multi-Bay Battery Chargers in 2026, and what such chargers cost is in Multi-Bay Military Battery Charger Prices in 2026.

If you have a battery that needs a rugged charger, send its model or datasheet, the number of bays, the input power, the standards you need and the quantity to i@tanshuai.com. I reply with the questions that decide the design.

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About the author

Tan Shuai is a technologist and founder with more than twenty years of work across chips, hardware and system software, and 20 granted patents. His work has taken him through Silicon Valley, New York, Chicago, Taiwan, the Greater Bay Area (Shenzhen and Hong Kong), Vietnam and Malaysia, with a long focus on advanced manufacturing and supply chains. Today he works as an AI researcher and developer, and builds custom rugged electronics with manufacturing partners in Shenzhen.

Rugged charger projects and technical discussion: i@tanshuai.com.