Enhanced Grade Fuses – Bridging the Gap Between Industrial and Space-Grade Circuit Protection for New-Space Applications

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INTRODUCTION

The rapid growth of the commercial (New-Space) sector is changing the way electronic components are selected for space programmes. Constellations, small satellites and commercial platforms are designed with shorter development cycles, lower unit cost targets and mission durations that are often measured in a few years rather than in decades. At the same time, these programmes cannot afford a systematic loss of reliability: a single failed protection device can disable a payload or a power bus and may ultimately limit the operational lifetime of the space system.

In the field of circuit protection, system developers today are largely limited to two options. They can use industrial fuses, which are produced in high volume and are commercially attractive but come with limited reliability assurance. Or they can use fully space-qualified fuses, such as the ESCC (European Space Components Coordination) qualified SCHURTER MGA-S [1, 2], which provide the highest level of assurance but at a cost and lead-time that many New-Space projects consider disproportionate to their mission profile. Between these two options lies the need for clearly specified qualification and screening measures tailored to New-Space mission requirements, without implying equivalence to full space-grade qualification.

Automotive-grade fuses qualified in accordance with AEC-Q200 [3], the stress test qualification of the Automotive Electronics Council, may represent a viable alternative to both industrial and fully space-qualified fuses for selected applications. On this basis, SCHURTER has initiated the development of the MGA-X, an enhanced grade fuse derived from its established MGA thin-film fuse technology. AEC-Q200 was selected as the qualification baseline and is supplemented by measures addressing the intended application and the identified gap to ESCC 4008 Chart F4, among them an ongoing high-temperature operating life test using samples from each production lot.

This paper presents the motivation, the requirement-definition process, the planned validation approach and the roadmap for the MGA-X. Since the project is currently moving from concept definition into the development and validation phase, the paper concentrates on the requirement definition, the gap analysis between AEC-Q200 and the ESCC 4008 periodic test programme, and the planned qualification approach.

THE ASSURANCE GAP IN CIRCUIT PROTECTION

Commercial Grade: the MGA Solid State, Thin Film, SMD Fuse

The SCHURTER MGA is a surface-mount thin-film fuse in a hermetically sealed 1206 package. It has been produced in high volume for more than two decades and its exceptional performance was the basis for the later development of the ESCC qualified version MGA-S [4]. The commercial MGA is manufactured under an industrial quality management system (ISO 9001) and holds UL 248-14 [5] approval.

Production testing includes 100 % measurement of cold resistance and 100 % verification of hermetic sealing, while dimensional characteristics are verified by sampling. The component has no individual marking. The MGA does not include screening tests such as 100 % burn-in or lot-based accelerated-life testing from which a quantified failure rate could be derived. This level is adequate for industrial applications, but it provides limited evidence for a spacecraft integrator who must document component selection for a specific mission.

Space Grade: the ESCC Qualified MGA-S

The MGA-S is qualified according to the ESCC Generic Specification No. 4008 [1] and the Detail Specification No. 4008/001 [2], covering twelve rated currents from 0.14 A to 3.5 A at a DC rated voltage of 125 V. The DC interrupt current is 300 A at 125 Vdc for rated currents up to 2.1 A; for the 2.8 A and 3.5 A variants it is 50 A at 125 Vdc and 300 A at 32 Vdc [2, 6]. The MGA-S applies a rated-current safety factor of √2 relative to the commercial MGA. Its formal assurance results from the ESCC qualification, screening and control framework: every ESCC-qualified lot undergoes the screening sequence of ESCC 4008 Chart F3, including a 168-hour burn-in at +80 °C and 95.7 % of rated current, and qualification is maintained by periodic testing of the Chart F4 subgroups every 24 months [1, 2]. Screening data from 2008 to 2024 show a basic failure rate below 1 FIT (0.44 FIT at room temperature; 1 FIT = one failure in 10^9 device hours).

This level of assurance is obtained through 100 % screening, lot-based and periodic testing, controlled changes under ESCC rules and a supply chain sized for institutional rather than commercial volumes, all of which are reflected in lead-time and unit cost.

Where the Gap Lies

The gap is not primarily a difference in the fuse technology. It is a difference in the level of quality control, qualification assurance and evidence generated around the component. The relevant dimensions include stress-test qualification, lot-level checks, continuing reliability monitoring, marking, documentation, material selection and change control. The MGA-X is therefore defined by the specific measures applied, not by a general claim of being equivalent to a space-qualified product. Table 1 summarises the two existing grades.

Table 1. Comparison of the existing commercial and space grade fuses

Criterion	Commercial grade (MGA)	Space grade (MGA-S)
Fuse technology	Solid-state thin-film, SMD 1206	Solid-state thin-film, SMD 1206
Governing standard / specification	UL 248-14 / manufacturer datasheet	ESCC 4008 and 4008/001 [1, 2]
Rated current range	0.2 A – 5 A	0.14 A – 3.5 A (same elements, rated with safety factor √2)
Marking on component	No	Yes
Lot-level tests	Cold resistance 100 %, hermetic seal 100 %, dimensions on samples	Same as MGA, plus 100 % screening per ESCC 4008 Chart F3 incl. 168 h burn-in at +80 °C
Periodic testing	None	Per ESCC 4008 Chart F4, every 24 months
Reliability data	None	< 1 FIT basic failure rate, based on burn-in data [4]
Documentation delivered	None	Certificate of conformance, test report
Material and process control	Industrial change control	ESCC controlled, change notification

DEFINING THE MGA-X

Objectives and Boundary Conditions

The following objectives were defined for the MGA-X:

- Provide a documented increase in assurance compared with the commercial MGA, with a positioning clearly below ESCC qualification.
- Retain the commercial MGA design and manufacturing process as the technical baseline.
- Plan qualification against AEC-Q200 and add selected measures justified by the intended application.
- Provide component marking, a certificate of conformance and defined lot-acceptance documentation.
- Address terminal-finish, solderability and tin-whisker considerations with measures specific to the MGA-X.

Two boundary conditions were applied. First, the MGA-X and the MGA-S address different assurance needs. Second, each additional measure must be linked to a risk or a documentation need; requirements were not included solely because a similar activity appears in an ESCC flow.

Definition Process

The requirements were derived by comparing three reference points: the commercial MGA production flow, the AEC-Q200 stress-test qualification and ESCC 4008 Chart F4. The comparison identified measures that are absent from the commercial flow, measures covered by the automotive qualification baseline and measures that remain specific to the ESCC-qualified product. Candidate measures were then assessed for risk reduction, manufacturability, documentation value, cost and lead-time impact.

Customer and application input was used to refine the concept. It was collected through direct technical and commercial discussions with New-Space integrators and subsystem suppliers, using their application requirements and their feedback on reliability, qualification, lead-time and cost as inputs to define the MGA-X positioning. The recurring requests were a lot-level reliability test, a certificate of conformance, a recognised qualification and a component marking.

The outcome of this process was the decision to qualify the MGA-X to AEC-Q200 and to add a small set of space-specific measures on top of that qualification. Fig. 1 illustrates the resulting positioning of the MGA-X between the commercial and the ESCC qualified product.

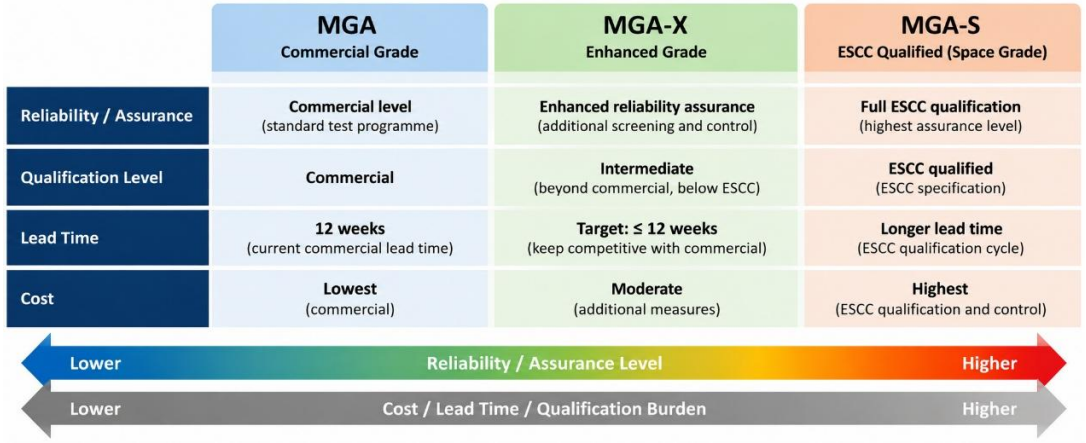


Fig. 1. Positioning of the MGA-X between commercial and space grade

AEC-Q200 as the Foundation

AEC-Q200 defines a stress test qualification for passive components [3]. For a given component family it prescribes a fixed set of environmental, mechanical and electrical stress tests, each with a defined sample size, duration and acceptance criterion, and it requires the tests to be repeated when the design, materials or manufacturing process change. The standard is widely used, its test methods are largely based on established MIL and JEDEC methods, and its results are readily understood by component engineers outside the automotive industry. For a component manufacturer that already operates AEC-Q200 qualification flows, extending them to a further product is a well-controlled, moderate effort. These properties make AEC-Q200 an attractive foundation for an enhanced grade fuse: it delivers a recognised, third-party-defined level of environmental robustness at a cost that remains compatible with commercial volumes.

AEC-Q200 was, however, written for the automotive environment, not for space. Fuses were added to the standard only with Revision E in 2023 (Table 15 of [3]); earlier revisions did not cover them. Table 2 compares the AEC-Q200 fuse test set with the screening and periodic test programme of ESCC 4008 (Charts F3 and F4, with the detail conditions of ESCC 4008/001) that applies to the MGA-S, and shows how each difference is treated for the MGA-X.

Table 2. Gap analysis between AEC-Q200 (Table 15, fuses) and ESCC 4008 / 4008/001, and resulting MGA-X approach (IR = rated current)

Test / requirement	**AEC-Q200 Rev E, Table 15 [3]**	**ESCC 4008 / 4008/001 [1, 2]**	**MGA-X approach**
High temperature operating life	MIL-STD-202 M108, 1000 h at maximum operating temperature, once per qualification	Operating life (para. 8.8): MIL-STD-202 M108, 2000 h at +125 °C and 95 % IR, periodic (24 months)	AEC-Q200 in qualification; in addition 1-week high temperature operating life test on samples from every production lot (ongoing reliability test)
Temperature cycling / rapid change of temperature	JESD22-A104, 1000 cycles between minimum and maximum operating temperature	Rapid change of temperature (para. 8.9): IEC 60068-2-14 Na, −55/+150 °C; 200 cycles for the MGA-S per 4008/001 Appendix A	Covered by AEC-Q200
High temperature exposure (storage)	MIL-STD-202 M108, 1000 h at maximum operating temperature	Not included (storage temperature rating only)	Covered by AEC-Q200
Humidity	Biased humidity: MIL-STD-202 M103, 1000 h at +85 °C / 85 % RH	Damp heat, steady state (para. 8.12): IEC 60068-2-78, 56 days at +40 °C / 93 % RH, unbiased	Covered by AEC-Q200
Mechanical shock and vibration	MIL-STD-202 M213 (100 g, 6 ms) and M204 (5 g, 10–2000 Hz)	Shock (para. 8.11): IEC 60068-2-27, 100 g, 6 ms, 18 shocks; vibration (para. 8.10): MIL-STD-202 M204 cond. D; half of the samples under rated current	Covered by AEC-Q200
Terminal strength / board flex	AEC-Q200-005 (board flex) and AEC-Q200-006 (terminal strength) for SMD	Robustness of terminations (para. 8.14): IEC 60068-2-21 Ue1	Covered by AEC-Q200
Solderability, resistance to soldering heat	J-STD-002; MIL-STD-202 M210 (reflow)	Solderability (para. 8.4); resistance to soldering heat (para. 8.13): IEC 60068-2-58 Td2, +260 °C, 10 s	Covered by AEC-Q200; Au-Ni terminal finish (see below)
Thermal vacuum	Not included	Thermal vacuum (para. 8.15): 48 h at +125 °C under vacuum carrying the maximum continuous current, then overload operation at 400 % IR on half of the samples; 6 samples, periodic	Added to the MGA-X qualification (once per qualification, not periodic); hermetic seal verified 100 % on every lot
Hermetic seal	Not included	Not specified in ESCC 4008; performed 100 % as SCHURTER production control for the MGA-S	100 % lot-level test (as for MGA)
Breaking capacity (interruption at rated voltage)	Electrical characterisation per UL 248 / IEC 60127, once per qualification	Verification of overload operation at DC rated voltage (para. 8.6), at room and minimum operating temperature, in qualification and periodic testing	Lot acceptance test on every lot
Time-current characteristic	Electrical characterisation, once per qualification	Fusion characterisation tests (para. 8.5) in screening (sample basis) and periodic testing	Final check on every lot
Burn-in screening / FIT from burn-in	Not included	Burn-in (para. 8.3): 168 h at +80 °C and 95.7 % IR, 100 %; FIT data	Not included; reliability figures derived from the ongoing reliability test instead
Periodic tests	Requalification on change of design, material or process only	Periodic testing of all Chart F4 subgroups every 24 months	Not included
Radiation	Not included	Not included	Not affected (passive thin-film element)

Test / requirement	AEC-Q200 Rev E, Table 15 [3]	ESCC 4008 / 4008/001 [1, 2]	MGA-X approach
Component marking	Not required beyond user specification	Required per ESCC 21700 (para. 4.4); permanence of marking (para. 8.16)	Marking on the component
Documentation	PPAP (production part approval process) on request	Certificate of conformity and test data per ESCC 4008 Section 9	Certificate of conformance, test report (lot acceptance tests)

The gap analysis leads to a simple conclusion. AEC-Q200 covers the mechanical and climatic robustness of the part well; the elements it does not address are the quantification of reliability over the production lifetime, the interruption performance of each lot, the behaviour under thermal vacuum and the identification of the part. These are exactly the additions selected for the MGA-X.

Measures Added Beyond AEC-Q200

The measures selected for the MGA-X are summarised in Table 3 in comparison with the commercial MGA and the ESCC qualified MGA-S.

Rating philosophy. The MGA-X retains the rated-current definition of the commercial MGA (safety factor 1) rather than the √2 margin of the MGA-S. The thermal margin for a given application is to be provided by derating at system level, as is common practice for commercial parts.

Ongoing reliability test. Samples from every production lot (30 parts) are subjected to a one-week high temperature operating life test (HTOL) of 168 h at +125 °C and rated current, i.e. at the temperature of the ESCC operating life test but for the duration of the ESCC burn-in. Unlike the 100 % burn-in of the MGA-S, this test is not a screening of the delivered parts; it is a continuous monitor of the production process. Over time it generates an accelerated device-hour count from which reliability figures can be derived [4].

Lot acceptance tests and final checks. In addition to the 100 % cold resistance and hermetic seal tests of the commercial MGA, every MGA-X lot is subjected to a breaking capacity test and a time-current characteristic check on a sample basis. The breaking capacity test is the most significant addition: for the commercial MGA it is not performed per lot, and for the MGA-S it is part of qualification and periodic testing, not of lot screening.

Marking. The MGA-X carries a marking on the component, as does the MGA-S, whereas the commercial MGA is unmarked. This allows a mounted part to be identified during inspection and failure analysis.

Terminal finish. The commercial MGA uses a tin-plated nickel (Sn) finish, which is not accepted in space applications because of tin whisker growth, and the MGA-S uses a tin-lead (Sn-Pb) finish, whose long-term availability is subject to RoHS exemption decisions [7]. For the MGA-X an Au-Ni finish was selected: it is whisker-free and offers good solderability with both leaded and lead-free processes.

Thermal vacuum. Although not part of AEC-Q200, a thermal vacuum test is added to the MGA-X qualification, since behaviour under vacuum is a significant criterion for space applications and the hermetically sealed package is the element most directly concerned. The test is performed once per qualification, not periodically as for the MGA-S, using the method of ESCC 4008 para. 8.15.

Documentation. Each MGA-X delivery is accompanied by a certificate of conformance and a test report covering the lot acceptance tests.

Equally important is what was deliberately not included. There is no 100 % burn-in, and therefore no burn-in-based FIT figure; and there are no periodic tests as in ESCC 4008 Chart F4. Each of these was assessed as adding cost and lead-time out of proportion to the risk it mitigates for the target mission class, given that the fuse element and the hermetic package are unchanged from the qualified MGA-S design.

Table 3. Attributes of the MGA-X in comparison with the commercial MGA and the ESCC qualified MGA-S

Attribute	MGA	MGA-X	MGA-S
Component grade	COTS	Enhanced Grade	Space Grade
Industry standard	UL 248-1/14	UL 248-1/14	-
Qualification standard	None	AEC-Q200	ESCC 4008 (Chart F4)
Rated current safety factor	1	1	√2
Marking on component	No	Yes	Yes
Terminal finish (whisker mitigation, solderability)	Sn	Au-Ni	Sn-Pb
Thermal vacuum test	No	Yes (qualification)	Yes (periodic)
Lot acceptance: time-current characteristic	Yes	Yes	Yes
Lot acceptance: breaking capacity	No	Yes	Qualification and periodic testing
FIT values from burn-in	No	No	Yes
FIT values from ongoing reliability test	No	Yes (1-week HTOL per lot)	No
Certificate of conformance	No	Yes	Yes
Test report	No	Yes (lot acceptance tests)	Yes
Periodic tests	No	No	Yes

QUALIFICATION PLAN

The plan, summarised in Table 4, consists of three parts. First, the AEC-Q200 qualification of the MGA-X is executed with the test set, sample sizes and acceptance criteria defined in Table 15 of the standard for fuses, on three production lots in order to generate family data for the MGA-X range. Second, the additional lot-level tests are implemented in production and validated on the first lots: the ongoing reliability test, the breaking capacity lot acceptance test and the time-current final check. Third, the changes to the product itself, the Au-Ni terminal finish and the component marking, are qualified as part of the AEC-Q200 flow, since both constitute a change of material or process relative to the commercial MGA. A thermal vacuum test is added to this qualification as the one space-specific environmental test not covered by AEC-Q200.

Table 4. Qualification and validation plan for the MGA-X

Activity	Reference	Samples	Acceptance criterion
AEC-Q200 stress test qualification	AEC-Q200 Rev E, Table 15 [3]	Per AEC-Q200 (30 per destructive test)	Per AEC-Q200, zero failures
Ongoing reliability test (HTOL, 1 week)	Internal specification; conditions per ESCC 4008/001 operating life (+125 °C, rated current)	30 per lot	No failure; cold resistance drift ≤ 10 %
Breaking capacity lot acceptance test	Internal specification; method per UL 248-14 / ESCC 4008 para. 8.6	10 per lot	Safe interruption at the rated interrupt current and voltage per datasheet
Time-current characteristic final check	Internal specification	30 per lot	Within datasheet limits
Thermal vacuum	ESCC 4008 para. 8.15 as method	6	Time-current characteristic within datasheet limits after test
Au-Ni terminal finish	Solderability per AEC-Q200 (J-STD-002)	Per AEC-Q200	Per AEC-Q200
Component marking	Marking permanence per AEC-Q200 (resistance to solvents, MIL-STD-202 M215)	tbd	Legible after stress tests

The AEC-Q200 qualification is expected to be completed in Q2 2027, with the 1000-hour operating life test as the critical-path item.

DEVELOPMENT ROADMAP

The planned development roadmap comprises the following stages:

- **Prototype validation**: production of the first MGA-X lots with Au-Ni finish and marking, and validation of the lot-level tests.
- **AEC-Q200 qualification**: execution of the qualification plan in Table 4 and release of the MGA-X datasheet and documentation package (certificate of conformance and test report formats).
- **Customer engagement**: evaluation lots for selected New-Space customers and collection of application feedback, in particular on the documentation format and the derived reliability figures.
- **Industrialisation**: integration of the MGA-X flow into the standard MGA production and logistics processes.

CONCLUSION

The New-Space market has created a demand for circuit protection components that offer more assurance than industrial parts but do not carry the full cost and lead-time of ESCC qualification. SCHURTER has addressed this demand by defining the enhanced grade fuse MGA-X on the basis of its established MGA thin-film technology. The definition process showed that the gap between the existing grades lies in the assurance generated around the part rather than in the technology itself. The chosen approach, an AEC-Q200 stress test qualification complemented by a lot-level reliability test, a breaking capacity lot acceptance test, a thermal vacuum test, a component marking and a whisker-free terminal finish, closes a meaningful part of that gap at a fraction of the effort of a full ESCC qualification, and does so on the basis of a standard that customers already know.

The programme is now entering qualification. SCHURTER regards this development as a contribution to the ongoing discussion within the European space component community on how to make trusted components available to a broader range of missions.

REFERENCES

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