High Reliable Fuses versus COTS Fuses

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INTRODUCTION

The aim of this article is to outline the differences between the high reliable ESA ESCC qualified and the Commercial-Off-The-Shelf (COTS) fuse variants from SCHURTER AG for space and related applications. In this century, companies from the private sector have been pursuing business for space applications and setting challenging goals when it comes to accessing the outer frontier. Visions of access to space for everyone, while accessing the global digital community with the installation of thousands of low-cost telecom satellites in low earth orbit, become more in reach every day. This phenomenon is a paradigm change in aerospace and related businesses. One of the most critical aspects to support this plight is the need to significantly reduce the total costs of a spacecraft. The tendency to use more affordable COTS components instead of fully space qualified components is clearly recognized. In mission-critical or long term missions, failure or component defects are not an option. At this point it is important to understand the risk of using COTS components in such applications without doing careful part selection, qualification and screening tests.

SCHURTER SPACE FUSES AND DERIVED COTS FUSES

With the established and ESA ESCC qualified space fuse called MGA-S (MGA Space) and the new qualified space fuse called HCSF (High Current Space Fuse), SCHURTER AG provides high quality circuit protection components for demanding and mission-critical applications where the highest reliability, availability and strong whisker mitigation is needed. These fuses cover nominal currents from 0.14 A up to 15 A or even more, if they are set in parallel. All fuse types are sealed, based on solid state thin film technology and comply with the strict requirements of aerospace. The non-qualified COTS variants, called MGA and HCF, are similar in respect in terms of the electrical characteristic, size and fuse performance as shown in table below.

Table 1: Overview ESCC qualified fuses and commercial variants, as in [5], [6], [7] and [8], from SCHURTER AG

Product	MGA (COTS)	MGA-S (ESCC QPL)	HCF (COTS)	HCSF (ESCC QPL)
Space Qualification	Non-qualified	ESA ESCC 4008	Non-qualified	ESA ESCC 4008
Terminal Plating (finish)	Sn	SnPb (Whisker Mitigation)	Sn	SnPb (Whisker Mitigation)
Fuse Acting	Very fast	Very fast	Fast	Fast
Rated Current Range	0.2 A – 5 A	0.14 A – 3.5 A	5 A – 15 A	5 A – 15 A
Rated Voltage	125 VDC	125 VDC	125 VDC	125 VDC
Breaking Capacity	300 A	300 A	1000 A	1000 A
Mounting + Size	SMD 1206	SMD 1206	SMD 3220	SMD 3220
Basic Failure Rate		< 1 FIT		< 1 FIT

SCHURTERs high reliable fuses are based on solid state thin film fuse element technology. This fuse element is put in a sealed ceramic housing as shown in Figure 1. Compared to commercial fuses in similar sizes these fuses do not use a melting wire in air, sand as filler to extinguish the electric arc during tripping event or a polymer based material as carrier or body. This mechanical, very stable, and non-flaming fuse construction sets the foundation to having a high quality and highly reliable fuse for demanding applications. The outgassing rate of the fully space qualified versions are very low and pass the criteria for space regarding ECSS-Q-ST-70-02C.

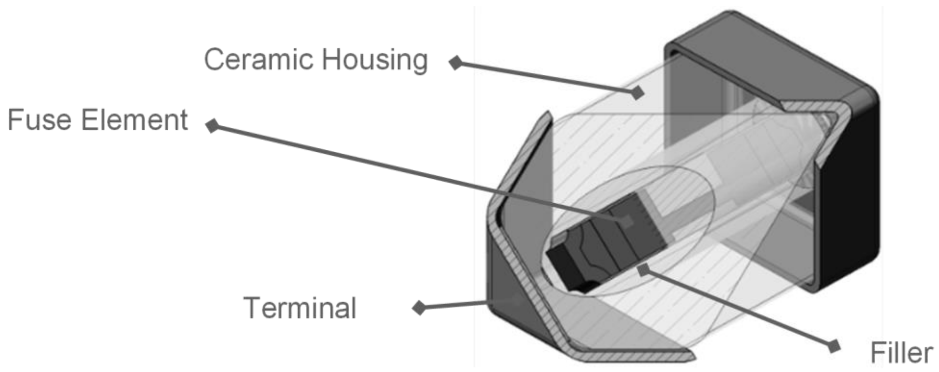

Figure 1: Solid state thin film fuse design of SCHURTER HCF and HCSF

DIFFERENCES BETWEEN SPACE QUALIFIED FUSES AND COTS FUSES FROM SCHURTER AG

As introduced in the chapter before, SCHURTER ESA ESCC qualified and COTS fuse variants are basically built on similar component technology. These fuse families are basically manufactured in the same manner, and with the same materials except for the galvanized terminal plating. Compared to the well-known whisker mitigation effects of lead content in tin plating, the COTS variants from SCHURTER use pure tin over a nickel under plating. Another difference of the cost-effective COTS variants is that production controls, like 100% x-ray inspection and several manual optical inspections in the production line, are not included like they are for the space qualified variants.

The most important difference between the space qualified and COTS components from SCHURTER is the ESA ESCC qualification approval. This approval is a status given to the components which are manufactured and tested under controlled conditions by SCHURTER, according to the requirements of the ESCC Generic and Detail Specification. The ESCC Generic Specification no. 4008 defines the general requirements for the qualification, qualification maintenance, procurement, and delivery of fuses for space applications; whereas the ESCC Detail Specification defines the specific parameters of the component like current rating and electrical characteristics. An important quality assurance procedure for all production lots of components is the extensive production control sequence as shown in diagram Chart F2, see Figure 2 below. The screening tests are shown in Chart F3, see Figure 3 below. An important part of this sequence is the burn-in test. All components of a production lot are electrically tested during a one week period at nearly nominal current and ambient temperature of 80°C. Before and after this burn-in test the cold resistance and voltage drop at rated current is measured. Strong electrical parameter drifts or parameter failures will be identified. In fact, failed components like infant mortals, or wrong components in a production lot would be detected early and removed.

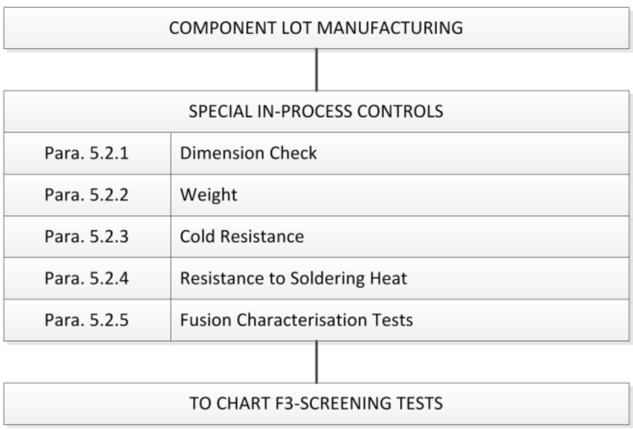

Figure 2: ESCC 4008 Chart F2, as in [1]

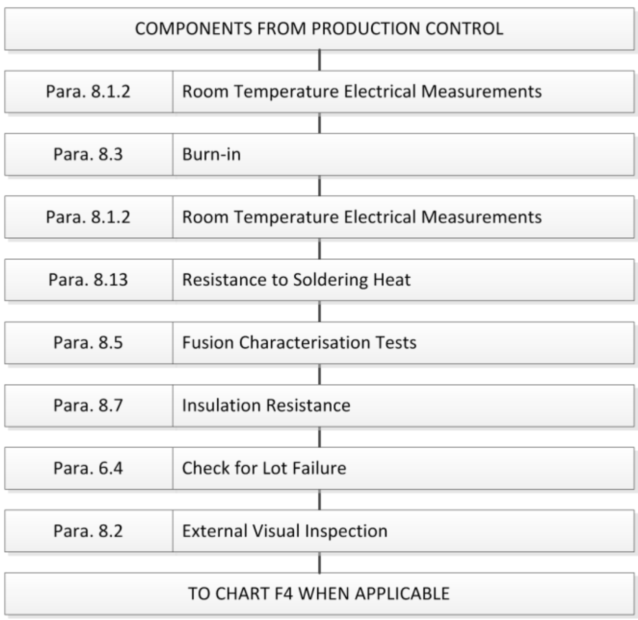

Figure 3: ESCC 4008 Chart F3, as in [1]

Another essential process for approval is the ongoing maintenance of qualification, which is repeated every two years. This test procedure is performed with a minimum of three different rated currents in each fuse family. The diagram Chart F4 in ESCC Generic Specification no. 4008 describes this test procedure in sequence as shown in Figure 4 below.

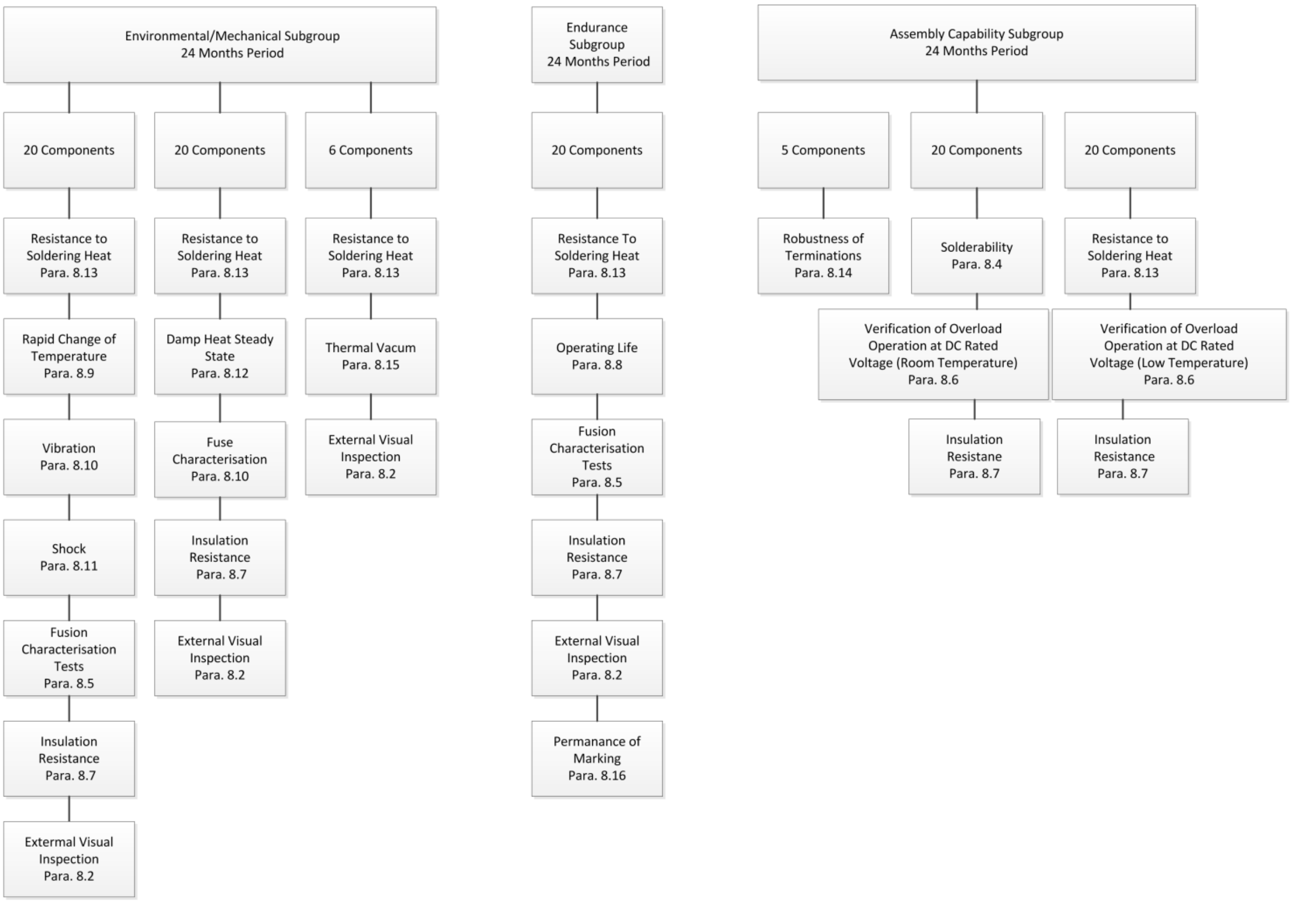

Figure 4: ESCC 4008 Chart F4, as in [1]

Thermal Vacuum Acceptance Test

A key requirement of space fuses is that they are able to operate safely and reliably under high vacuum and elevated ambient temperature conditions. The thermal vacuum test in Subgroup 1 of Chart F4 is specifically defined to verify the capability of the fuse to perform in this environment. The fuses are electrically loaded at 125 °C at high vacuum conditions over a minimum of 48 hours. The fuses HCF and HCSF have been tested at even tougher test conditions for customer specific requirements. Instead of applying 80 % of the rated current, a 90 % load was applied for 168 hours at an operating temperature of 125 °C with high vacuum conditions.

Table 2: Test parameter and sample size

Pressure (vacuum level)	$< 10^{-5}$ mbar
Operating temperature	>= 125°C
Static electric current	Half of sample size, each: 90 % of rated current (13.5A and 4.5 A) or 80 % of rated current (12 A and 4 A)
Test duration	> 168 h
Samples (devices under test)	HCSF 15 A, HCSF 5 A HCF 15 A and HCF 5 A
Sample size	60 pieces HCF and HCSF 15 A 40 pieces HCF and HCSF 5 A

This test has been performed in cooperation with RUAG Space in Zurich, Switzerland.

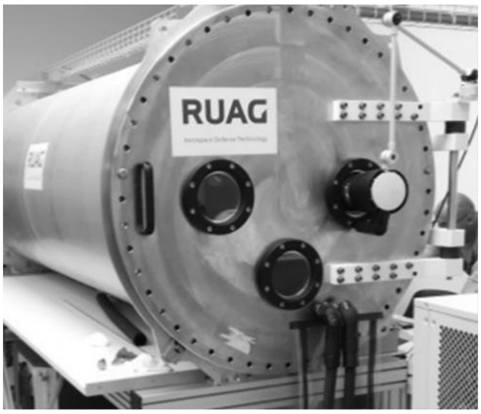

Figure 5: Vacuum chamber at RUAG Space in ZH, Switzerland

Figure 6: SCHURTER HCF and HCSF samples under test in vacuum chamber at RUAG Space in ZH, Switzerland

Test results and conclusion

Table 3 below shows the parameter drift of the cold resistance and voltage drop. The drift is calculated from initial measurement before test start and final measurement after test.

Table 3: Test results – electrical measurement

Test condition	Parameter drift	HCF / HCSF 5 A	HCF / HCSF 15A
80 % rated current	Cold resistance AVG drift in %	< 0.2	< 0.2
	Voltage drop AVG drift in %	< 0.2	< 0.5
90 % rated current	Cold resistance AVG drift in %	< 0.5	< 3
	Voltage drop AVG drift in %	< 1	< 5

- No aging effects on HCF and HCSF samples observed at 80 % of rated current
- Early indication of aging effects observed at 90 % of rated current on two HCF 15 A samples only
- All samples, HCF and HCSF passed the tests at 80 % and at 90 % of rated current

The final fusion characterisation test were performed at different current levels, 125 %, 250 %, 600 % and 1000 % of rated current. The acceptance criteria: safe interrupt time within specification for all test levels except at 125 %. Samples at this current level have to survive without blowing or excessive aging within 1 hour at load current. As shown in the Figure 7 and Figure 8 below, all of the stressed samples interrupted within the specification.

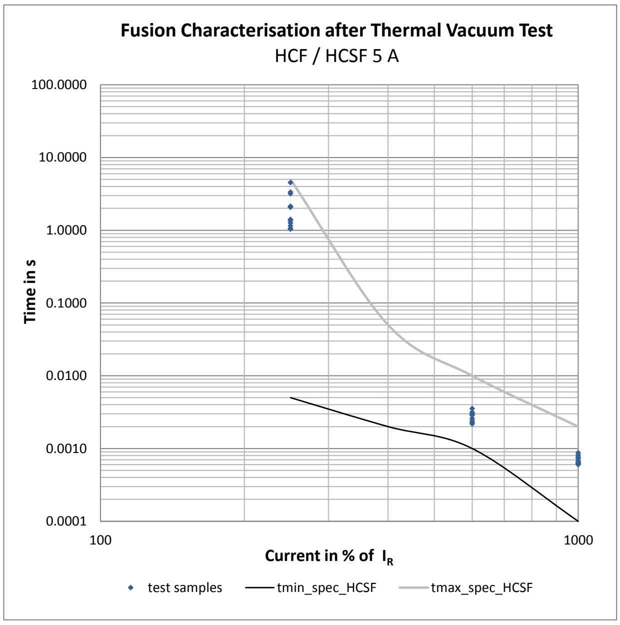

Figure 7: Fusion characterisation HCF and HCSF 5 A

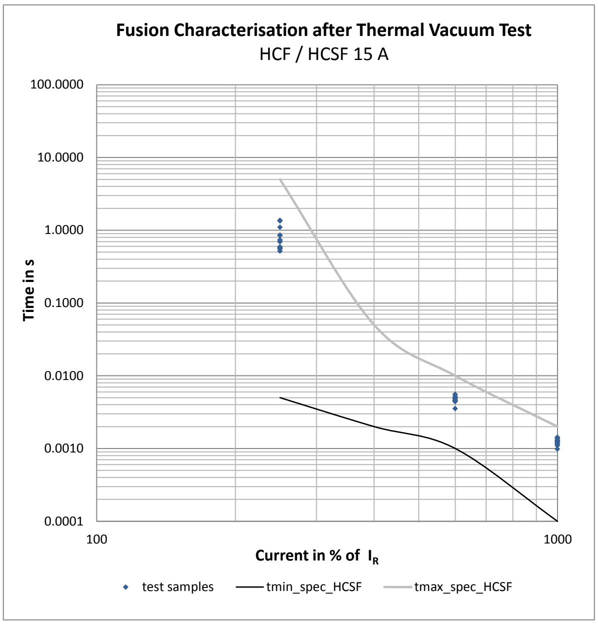

Figure 8: Fusion characterisation HCF and HCSF 15 A

Differences between SCHURTER's high reliability space qualified fuses and COTS variants

The space qualified fuses MGA-S and HCSF from SCHURTER include

- Sn/Pb plating – strong tin whisker mitigation
- ESA ESCC QPL, ESCC 4008
- Every two years repeated full "Maintenance of Qualification" according to ESA ESCC 4008, Chart F4
- Control and screening tests according to ESCC 4008 Chart F2 and F3
- Extended production controls (e.g. 100% x-ray and visual inspection) and records
- Reliability Monitoring (report based on burn-in data)
- Full documented test data of production lot – part of the delivery package
- Extended test data (e.g. E-HB) and extensive technical support from SCHURTER for specific design-in tasks

Several deviations between the space qualified and COTS variants can be identified in the list above. But, since the COTS variants MGA and HCF are inherently the same as the space qualified variants, with respect to design and technology, the COTS variants match the requirements for demanding applications and perhaps even those close to full space missions.

The MGA and HCF from SCHURTER are "COTS Plus" components because:

- Similar component technology and construction to the space qualified variants
- Similar manufacturing processes – high control level in manufacturing
- Well documented product information and qualification report
- Extended environmental test data available like 4'000h life test

FUSE SELECTION FOR APPLICATION SPECIFIC CIRCUIT PROTECTION

In the case of fuses, the important criteria for effective and reliable circuit protection varies depending on the application requirements, like the protection functionality level and selected fuse type. For space applications in particular, with the extreme environmental conditions, the safety requirements for high reliability and availability of the system need additional considerations to determine the best fitting fuse. High current pulses or repeating pulses affect the expected life-time of a fuse. Depending on several parameters like duty cycle, operating temperature, current peak, melting energy I^2t etc. A large number of pulses might therefore affect the life-time of the fuse. However, since many factors are involved, extended data and technical support for customer specific applications are necessary to ensure selection of the right fuse. The most important design parameters for fuses and their related data are in Table 4 below.

Table 4: Design parameter

Application Requirements / Parameter	**Relation**	**Fuse performance data**	**SCHURTER fuses for demanding applications**	
			MGA-S / HCSF	**MGA / HCF**
			Space Qualified	**COTS**
Safety requirements (electrical protection reaction sensitivity – fail safe)	←→	Fuse tripping characteristic - quick acting F, very fast acting FF	FF / F	FF / F
Safety requirements (reliability, availability)	←→	Fuse design / technology – e.g. solid state, qualification and reliability data, safe-life concept	Solid state ESCC QPL Rel. data available	Solid state
		Whisker mitigation	Yes, SnPb plating	
Environment requirements (space, ground, etc.)	←→	Qualification and approval as in [1], ESCC-Q-ST-30-11C as in [4]	ESCC 4008001 ESCC 4008002	Different test data available
Supplied voltage	←→	Rated voltage	125 VDC	125 VDC
Average load current	←→	Rated current	0.14 – 15 A	0.2 – 15 A
Short circuit current	←→	Breaking capacity (e.g. HCSF safe-operating area)	MGA-S: 300A HCSF: 1kA, See Safe-Operating Area data in E-HB HCSF	MGA: 300A HCF: max. 1kA
Current pulse profile (duty cycle, peak current, amount of pulses during mission time)	←→	I^2t, current pulse derating factor	See Data Sheet as in [5] and [6]	See Data Sheet as in [7] and [8]
Ambient temperature	←→	Temperature derating	See Data Sheet as in [5] and [6]	See Data Sheet as in [7] and [8]
Size and mounting	←→	E.g. SMD	SMD 1206 / 3220	SMD 1206 / 3220

RELIABILITY MONITORING REPORT MGA-S BURN-IN SCREENING 2008- 2016

As already stated, the SCHURTER MGA-S and HCSF are considered high reliable robust fuses, which have a basic failure rate clearly under 1 FIT. Over the last couple of decades, SCHURTER AG produced several millions of the standard fuses and of the ESCC qualified fuse variants for satisfied customers. The ESCC qualified parts undergo several screening tests during production control according to ESCC 4008. The burn-in test is one of the required screening procedures. SCHURTER AG continuously monitors and analyses this data to keep up the product quality level and get the latest reliability data. Since the very beginning of the MGA-S production, no single part has failed in these internal test procedures; most critically, no electrical failure.

Table 5: Reliability data of the MGA-S based on burn-in measurement

Production time frame	**2008 - 2016**
Data base	Burn-in (screening), temperature acceleration
Total screened parts/ device quantity n	195’680
Accelerated device hours (cumulated) T_{use} = 55 °C	130’265’743
Accelerated device hours (cumulated) T_{use} = 23 °C	1’065’505’180
Failed parts	0
Upper average FIT value at 55 °C ambient temperature	7.02
Upper average FIT value at 23 °C ambient temperature	0.86

The acceleration factor is determined by the Arrhenius Equation (3).

$$Acceleration\ factor = e^{\frac{E_A}{k_B}\times\left(\frac{1}{T_{operation}}-\frac{1}{T_{stress}}\right)} \quad (3)$$

The accelerated device hours result from the multiplication of the total screened parts quantity, the screening test duration and the calculated acceleration factor, as in (4).

$$Acceleration\ device\ hours = n \times t_{burn-in} \times acceleration\ factor \quad (4)$$

Table 6: Burn-in test conditions and calculation data

Activation Energy E_A	< 0.7 eV, for more details please contact SCHURTER
Boltzmann Constant k_B	
Operation Temperature $T_{operation} = T_{use}$	55 °C
	23 °C
Stress Temperature T_{stress}	80 °C
Screening test duration $t_{burn-in}$	168 h
Supply current	Continually rated current at stress temperature

Early failures significantly affect the time dependent on the failure rate of the parts. Caused by weak parts these failures occur at the beginning of the life time – stage 1 see Fig 9. In particular, the burn-in test is an effective and well established method to select this weak fuses in the stage 1.

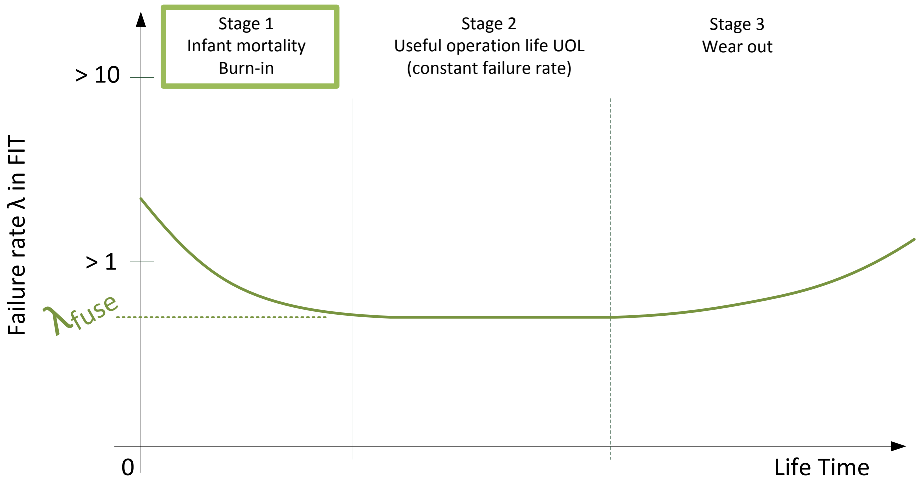

Fig 9: Bathtub curve of a fuse

As stated before, no weak fuses have ever been observed since the very beginning of the MGA-S production in 2008. The figure below represents the determined upper bound average failure rate in time, based on MGA-S burn-in production data from the period between 2008 till 2016.

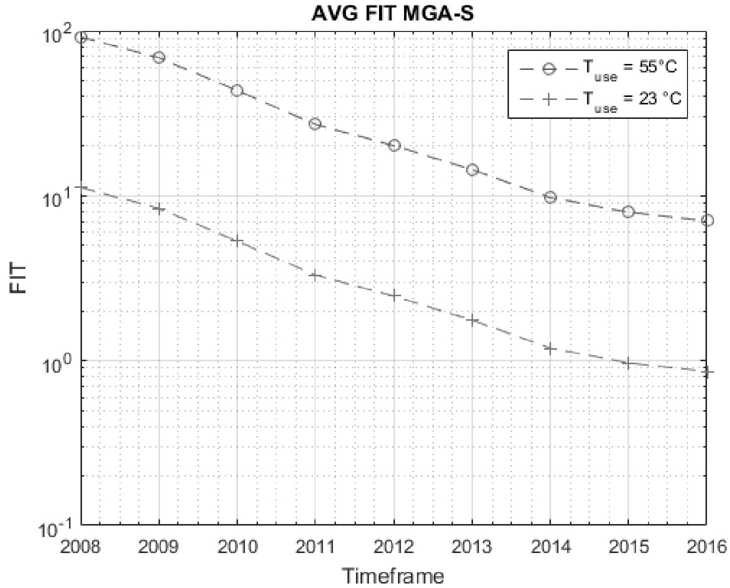

Fig 10: Upper average failure rate based on burn-in data of MGA-S production period 2008 – 2016, as in [9]

Depending on the year's production quantity the calculated upper average failure rate according to (5) is decreasing strongly. The latest reliability analysis data shows an average failure rate of the MGA-S which includes potential early failures in stage 1 of about 7 FIT. This statistical calculation respects the chi-square distribution and includes the 60 % confidence level for zero failure criteria.

$$Average\ failure\ rate = \frac{\chi^2/2}{acceleration\ factor \times n \times t_{burn-in}} \quad (5)$$

CONCLUSION

The high reliable space qualified fuses, MGA-S and HCSF and derived fuse variants MGA and HCF from SCHURTER stand for their robust construction based on established solid state thin film technology. The COTS variants are inherent to the space qualified versions. But, since these fuses are basically not screened and undergo less production control checks they will not reach the same level of reliability as the space qualified variants. In fact, the full space qualified fuse variants are the right fuse for mission-critical space missions or related demanding applications. However the MGA and HCF variants stand for the same quality. It is important to choose the right fuse for a specific application in order to have a reliable and highly available circuit protection solution. Specialists from SCHURTER AG are glad to support any design-in issues offering the best fitting protection device.

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[8] Data Sheet, *HCF*, SCHURTER AG, D10-006-852 Rev. A, March 2017

[9] Reliability Monitoring Burn-In, *MGA-S*, SCHURTER AG, D10-015-697 Rev. B, May 2017