ALP LAB

E1M-AEN Reliability Report

MTBF / FIT prediction — Telcordia SR-332

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1 Summary

This report gives the predicted reliability of the **E1M-AEN System-on-Module** (`E1M-AEN301` through `E1M-AEN801`) expressed as **MTBF** (Mean Time Between Failures) and **FIT** (Failures In Time, where 1 FIT = 1 failure per 10^9 device-hours).

The prediction is a **parts-count reliability prediction** per **Telcordia SR-332 Issue 4**, summing the steady-state failure rate of every electrical component on the module. It is an **intrinsic, random-failure** estimate for the useful-life region of the bathtub curve. It does not model infant mortality (addressed by production screening / burn-in) or end-of-life wear-out (e.g. Flash write endurance, electrolytic dry-out — the E1M-AEN carries no electrolytics).

Note: **Headline figure — at the +55 °C operating reference (GF):** $\lambda \approx 856$ FIT, giving an **MTBF of ≈ 1 170 000 hours**, equivalent to a **5-year field survival of ≈ 96.3%** and a **10-year survival of ≈ 92.8%** under continuous 24/7 use. See Section 4 for the full result set and Section 5 for the +25…+85 °C sweep.

Vendor data update (rev 0.3): The Application SoC FIT is now the **Alif-published field-equivalent value** — ≈ 30 FIT at +55 °C / 60% confidence from the Ensemble (E4/E6/E8) HTOL qualification (**Alif REP-006**) — replacing the previous 100 FIT engineering estimate. This drops the headline from ≈ 1150 FIT / 867 000 h to ≈ 856 FIT / 1 170 000 h. The Wi-Fi / BLE module (†) remains the only major term on an engineering estimate.

Reading this figure: **MTBF is a fleet statistical measure, not a service life.** An MTBF of 1 170 000 h does **not** mean a unit lasts 133 years; it means that, across a large fielded population in the useful-life region, one intrinsic failure is expected per 1 170 000 cumulative operating hours — i.e. ≈ 37 failures per 1000 units over 5 years of 24/7 use. Always quote the failure rate (FIT) and the survival probability $R(t)$ over the actual service life alongside the MTBF, and always with the ambient temperature stated.

1.1 Reference Condition

The E1M-AEN is rated for the **industrial extended temperature range, – 40 °C to +85 °C**. The headline figure is a reliability prediction at a single **representative operating ambient** within that range; it is not tied to the rated extremes. The full ambient sweep — including the +85 °C hot corner — is in Section 5. This module is not rated to, nor predicted against, automotive (AEC-Q) or defense (MIL-HDBK-217) mission profiles.

Parameter	Value
Prediction standard	Telcordia SR-332 Issue 4, Method I (parts count)
Environment	Ground Fixed, Controlled (GF) — climate-controlled indoor
Rated operating range	– 40 °C to +85 °C (industrial extended)
Headline operating ambient	+55 °C (representative loaded operating point)
Component-FIT build-up	+40 °C (Telcordia generic-device reference)
Duty cycle	100% (continuous, 24/7)
Component quality	Commercial, Quality Level II (standard supply-chain)
Electrical derating	Per Alp Lab HW design rules (≤ 60% V/I/P on stressed parts)
Confidence level	50% (point estimate)

Table 1 Reference condition for the headline prediction

2 Method

The module failure rate is the sum of the failure rates of its parts:

$$\lambda_{\text{module}} = \sum_i n_i \cdot \lambda_i$$

where n_i is the quantity of part class i and λ_i is its per-unit steady-state FIT at the reference condition. The MTBF is the reciprocal of the total failure rate:

$$\mathrm{MTBF} = \frac{1}{\lambda_{\mathrm{module}}}$$

Because the parts are in a **series-reliability** arrangement (any one part failing is a module failure — there is no on-module redundancy), the failure rates add directly. Each λ_i already embeds the Telcordia quality factor (π_Q) and the reference-temperature / electrical-stress factors for that part class.

The bill of materials underlying this prediction was taken directly from the released E1M-AEN netlist. Non-electrical items (mechanical test pads, tooling and fiducial features) are excluded as they carry no operational failure rate.

3 Failure-Rate Budget

The budget table below lists the contribution of every component class, sorted by contribution. The module carries **209 electrical components** across the classes shown. Active silicon is ≈ **68%** of total FIT; with the Alif SoC now on vendor reliability data (Section 7), the **Wi-Fi / BLE module is the single largest term** (≈ 18%), and the SoC and Wi-Fi module together account for ≈ **21%**.

The per-class FIT is tabulated at the **Telcordia +40 °C reference** (where the generic device FITs are defined), giving a build-up total of ≈ 337 FIT. Scaled to the **+55 °C operating headline** (Arrhenius $\pi_T \approx 3.3$ on the silicon subtotal — see Section 5) the module total is ≈ **856 FIT**, i.e. an **MTBF of ≈ 1 170 000 h**. The dominance ranking below is temperature-invariant, so it holds at either point.

Component class	Qty	FIT/unit	FIT total	Share
Wi-Fi / BLE module †	1	60.0	60.0	17.8%
Ceramic capacitors (MLCC)	97	0.40	38.8	11.5%
Crystals & oscillator	3	—	34.0	10.1%
DC-DC switching regulators	2	14.0	28.0	8.3%
Ethernet PHY	1	18.0	18.0	5.3%
OSPI NOR flash §	1	15.6	15.6	4.6%
HyperRAM §	1	15.6	15.6	4.6%
Chip resistors	82	0.15	12.3	3.7%
EEPROM	2	6.0	12.0	3.6%
Board-to-board connector	1	12.0	12.0	3.6%
LDO regulators	2	6.0	12.0	3.6%
CAN transceiver	1	10.0	10.0	3.0%
Load switches	2	5.0	10.0	3.0%
Application SoC (Ensemble) ‡	1	9.2	9.2	2.7%
LED / backlight driver	1	8.0	8.0	2.4%
Real-time clock	1	8.0	8.0	2.4%
Secure element	1	7.0	7.0	2.1%
Voltage reference	1	5.0	5.0	1.5%
Level shifter	1	5.0	5.0	1.5%
Temperature sensor	1	5.0	5.0	1.5%
Power inductors	4	1.0	4.0	1.2%
PCB substrate (multilayer)	—	3.0	3.0	0.9%
MOSFET (small-signal)	1	2.5	2.5	0.7%
RF connector	1	2.0	2.0	0.6%
Total	**209**	—	**≈ 337**	**100%**

Table 2 E1M-AEN failure-rate budget by component class (+40 °C Telcordia reference build-up)

Notes: ‡ – **vendor-qualified**: the Alif-published field-equivalent FIT for the Ensemble SoC — 30 FIT at +55 °C, 60% CL, from the zero-failure HTOL qualification in **Alif REP-006** — back-referenced to the +40 °C build-up (÷ ≈ 3.27) so the silicon-Arrhenius

scaling reproduces the 30 FIT figure at the +55 °C headline. See Section 7.
† – engineering estimate from device complexity and comparable parts, **pending the vendor reliability report**. The Wi-Fi / BLE module is now the largest single-part contributor and must be replaced with supplier-published FIT before this report backs any contractual reliability commitment.
§ – derived as a **chi-square 60% upper confidence limit** on a zero-failure JEDEC JESD47 HTOL qualification (3 lots × 77 units × 1000 h at 125 °C), accelerated to the +40 °C reference with $E_a = 0.7$ eV. This is a **conservative** bound consistent with the vendors' public reliability data (Macronix Q&R monitor; Winbond AFR < 0.1%/yr, i.e. ≤ 114 FIT) and will tighten once a vendor aggregated-lot FIT is obtained.
Shares may not sum to 100% due to rounding.

4 Results

Metric	Value
Total failure rate, λ	856 FIT
MTBF	1 170 000 h
MTBF (years, continuous)	133 yr
Survival R(1 yr)	99.25%
Survival R(3 yr)	97.78%
Survival R(5 yr)	96.32%
Survival R(10 yr)	92.78%

Table 3 Predicted reliability at the +55 °C operating headline (GF)

For reference, at the +40 °C Telcordia build-up point the figure is 337 FIT / 2.97 M h MTBF; at the +85 °C rated corner it is 6046 FIT / 0.17 M h. See Section 5 for the full sweep.

Under the constant-failure-rate (exponential) model, the survival probability of one unit at mission time t is $R(t) = e^{-t/\,\mathrm{MTBF}}$. The complement is the expected fraction of a fielded population that experiences an intrinsic failure by time t:

Mission time	Survival R(t)	Fails / 1000 units
1 year	99.25%	≈ 7.5
3 years	97.78%	≈ 22.2
5 years	96.32%	≈ 36.8
10 years	92.78%	≈ 72.2

Table 4 Expected intrinsic failures per 1000 fielded units (24/7, +55 °C)

Note: These are **intrinsic random-failure** expectations only. Field returns also include infant mortality, mishandling (ESD, mechanical), and application-board faults, which are outside the scope of a parts-count prediction.

5 Temperature & Environment Sensitivity

Failure rate is strongly temperature-driven: the silicon portion of the budget scales by an Arrhenius factor $\pi_T = \exp\left[\frac{E_a}{k}(1/T_{\mathrm{ref}} - 1/T)\right]$. The table below applies a generic activation energy $E_a = 0.7$ eV to the **silicon** subtotal while holding passives, crystals, connectors and the PCB roughly constant. Each row is stated at the given **ambient**, assuming device junctions approximately track ambient — representative of light-to-moderate electrical load.

Hot corner: Under heavy SoC / NPU load the junction **self-heats above ambient** by $\theta_{\mathrm{JA}} \times P_{\mathrm{diss}}$, so at the +85 °C rated corner the effective silicon temperature — and therefore the FIT — is **higher** than the +85 °C row shows. The +85 °C figure here is an **ambient-only** value; a full-load hot-corner number requires the integrator's thermal solution (θ_{JA}) and the workload power, and should be treated as optimistic until that thermal data is folded in. The cold corner (− 40 °C) **lowers** steady-state FIT

and is not a reliability concern; however − 40 °C ⟶ +85 °C **thermal cycling** drives a separate solder-joint fatigue mechanism (Coffin–Manson, see Section 8) that a steady-state MTBF does not capture.

Ambient	π_T	λ (FIT)	MTBF (h)	MTBF (yr)	R(5 yr)
+25 °C	0.27	170	5 870 000	670	99.3%
+40 °C †	1.00	337	2 970 000	339	98.5%
+55 °C *	3.27	856	1 170 000	133	96.3%
+70 °C	9.66	2315	432 000	49	90.4%
+85 °C ‡	26.0	6046	165 000	19	76.7%

Table 5 MTBF vs. ambient temperature (junction ≈ ambient)

* Headline operating point (quoted figure). † Telcordia +40 °C generic-device build-up reference. ‡ Rated maximum ambient (industrial extended range).

The practical takeaway: keeping the SoC junction — and hence the local ambient — **down** is the single highest-leverage reliability action available to the integrator. Every ≈ 15 °C of ambient reduction buys roughly a factor of 2–3 in module MTBF.

6 Dominant Contributors & Design Notes

- **Wi-Fi/BLE module = ≈ 18% of FIT — now the single largest contributor** and the only major term still on an engineering-estimate FIT (†). It is also a hot part, coupling directly into the temperature sensitivity of Section 5. The **Application SoC**, previously co-dominant at the 100 FIT estimate, is now **vendor-qualified** (‡, Section 7) at ≈ 3% of FIT, so the Wi-Fi module's supplier FIT is now the single biggest lever on the headline number.
- **No wear-out-limited parts in the steady-state budget.** The module uses ceramic (MLCC) capacitors throughout — there are no aluminium electrolytics, so there is no temperature-accelerated dry-out wear-out mechanism. NOR Flash and EEPROM endurance is a **write-cycle** limit, not a time limit, and is governed by firmware usage rather than this prediction.
- **Connectors are a small but real contributor.** The board-to-board module connector and the RF connector together contribute ≈ 3.3% of FIT; their real-world reliability is dominated by mating cycles and contact environment at the carrier-board level, which the integrator controls.
- **Passive count is high but low-risk.** 179 passives (capacitors + resistors + inductors) contribute only ≈ 16% of FIT combined — expected for derated commercial MLCCs and thick-film chip resistors (their share rose only because the SoC's vendor FIT shrank the denominator, not because they changed).

7 Vendor Reliability Data (Alif Ensemble SoC)

The Application SoC FIT used above is no longer an engineering estimate: it is the Alif Semiconductor field-equivalent figure for the Ensemble family (E4/E6/E8), which the E1M-AEN uses. Alif manufactures the Ensemble on GlobalFoundries' 22 nm FD-SOI process with embedded MRAM (eMRAM), in the FBGA194 package used on the module.

Parameter	Value
Life test	HTOL, readouts at 168 / 500 / 1000 h, multiple lots
Sample	395 units × 1000 h = 395 000 device-hours, **0 failures**
Acceleration	Arrhenius, $E_a = 0.7$ eV, $T_{\text{stress}} = 125°C$, $T_{\text{use}} = 55°C$ (AF ≈ 78.4)
FIT @ 55 °C, 60% CL	≈ **30 FIT** ⟶ MTBF ≈ 3.38 × 10^7 h
FIT @ 55 °C, 90% CL	≈ 74 FIT ⟶ MTBF ≈ 1.34 × 10^7 h

Table 6 Alif Ensemble SoC field-equivalent reliability (Alif REP-006, Rev 1)

This report adopts the **60% CL** value (30 FIT) for consistency with the § memory terms and the DeepX/vendor convention across the E1M reliability set. The 30 FIT is the **SoC device** figure at the +55 °C use condition; it enters the module budget back-referenced to the +40 °C build-up (÷ ≈ 3.27) so the silicon-Arrhenius scaling of Section 5 reproduces 30 FIT at the +55 °C headline.

The Ensemble family additionally completed the full JEDEC/AEC production qualification (**Alif REP-004, Rev 3**, FBGA194, all lots 0 failures / PASS):

Stress	Condition	Result
HTOL	$T_j = 125°C$, biased, 1000 h (JESD22-A108)	PASS
HTS	$T_a = 150°C$, 1000 h (JESD22-A103)	PASS
Precon / MSL	MSL3, 30 °C/60%RH/192 h, 3× reflow 260 °C	PASS
uHAST	130 °C / 85% RH, 96 h (JESD22-A118)	PASS
Temp cycle	− 55 °C ↔ +125 °C, 1000 cyc (JESD22-A104)	PASS
Vibration	20 Hz–2 kHz, 20 g (JESD22-B103)	PASS
Mech. shock	1500 g, 0.5 ms, 6 dir (JESD22-B104)	PASS
ESD	HBM 2 kV (A114), CDM 250 V (C101)	PASS
Latch-up	± 50 mA, $V_{dd} + 10\%$ (JESD78)	PASS

Table 7 Alif Ensemble FBGA194 qualification summary (Alif REP-004, Rev 3)

Note: Alif reports are provided under NDA; the figures above are the customer-releasable summary values. Latch-up was qualified to ± 50 mA (vendor-stated maximum safe stress for the advanced node / fine-pitch package), below the JESD78 ± 100 mA default.

8 Assumptions & Limitations

1. **Parts-count, not parts-stress.** Method I uses per-class reference FITs rather than computing each part's individual electrical/thermal stress (Method II). Method I is the accepted approach at the design / datasheet stage and is typically **conservative** for a well-derated design.
2. **Series reliability.** Any single part failure is treated as a module failure. There is no on-module redundancy to credit.
3. **Mixed FIT provenance.** The Application SoC is now on **vendor field-equivalent data** (‡ — Alif REP-006, Section 7). The Wi-Fi / BLE module (†) is the one remaining engineering estimate pending a vendor reliability report. Two classes (NOR flash §, HyperRAM §) are chi-square 60% upper-confidence limits derived from the JEDEC JESD47 HTOL qualification — defensible but conservative; a vendor aggregated-lot FIT will most likely **lower** them. Substituting the † Wi-Fi term is now the main remaining path to tightening the prediction.
4. **Excludes solder-joint thermal fatigue.** Board-level solder-joint life under power/thermal cycling (an IPC-9701 / Coffin-Manson analysis) is a separate study driven by the integrator's duty cycle and is not part of a steady-state parts-count MTBF.
5. **Excludes infant mortality and end-of-life wear-out.** The figure describes the flat region of the bathtub curve only.
6. **Point estimate at 50% confidence.** A lower-confidence-bound figure (e.g. 90%) can be produced on request once vendor data fixes the dominant terms.

9 Revision History

Revision	Changes	Date
0.1	Initial parts-count MTBF prediction (Telcordia SR-332 Issue 4) from the released E1M-AEN netlist. SoC, Wi-Fi module, HyperRAM and NOR-flash FITs are engineering estimates pending vendor data.	June 2026
0.2	NOR-flash and HyperRAM FITs replaced with chi-square 60% UCL values derived from the JEDEC JESD47 HTOL qualification (15.6 FIT @ 40 °C each). Headline rebased to the +55 °C operating point: ≈ 1150 FIT / 867 000 h. SoC and Wi-Fi module remain on engineering estimates.	June 2026
0.3	Application SoC FIT replaced with Alif vendor field-equivalent data (30 FIT @ 55 °C, 60% CL; Alif REP-006). Added the Vendor Reliability Data section (Section 7) summarising Alif REP-006 MTBF and REP-004 Rev 3 qualification (FBGA194, all PASS). Headline improves to ≈ 856 FIT / 1 170 000 h; budget reordered (Wi-Fi module now the largest single term). Wi-Fi / BLE module is the only remaining engineering-estimate (†) term.	July 2026

Table 8 Document revision history