

LibmCS: Mathematical Library for Critical Systems

Standards compliant and pre-qualified to ECSS Category B

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Why Your Important Project Needs the LibmCS

Mathematical libraries are used in **nearly any flight software**, in particular in the AOCS/GNC and scientific algorithms. As computing power increases and more calculations are done on OBCs and payloads, well characterized mathematical functions become more and more important. **Previously used libraries** might have **flight heritage** but do have **known bugs**, which will show up when doing more calculations, and are **not qualified** to any standard, thus having no sensible, standardized test-set and documentation. This may lead to **several issues** when integrated into application software, e.g:

- ▶ not easily detectable accuracy or timing issues, e.g. due to compiler issues/misconfiguration
- ▶ application software developers might not be aware of known issues in mathematical functions, because of missing documentation

Both issues can lead to **mission-critical errors**.

LibmCS Main Attributes

The Mathematical Library for Critical Systems (**LibmCS**) provides an **open source, standard compliant** (IEEE-754, ISO C18, and POSIX) mathematical library (**libm**), **pre-qualified** to ECSS E-ST-40 and Q-ST-80 Category B, so that project specific **integration** and **delta-qualification efforts** for this building block are **minimized** and its long term maintenance guaranteed.

- ▶ Standard compliance (IEEE-754-2019, ISO C18, POSIX, MISRA C:2012)
- ▶ ECSS Category B qualification evidence including ISVV
- ▶ Designed to support many processor architectures: x86-64, SPARC V8 (all LEON), ARM, RISC-V...
- ▶ Fully compatible with qualified RTEMS 6 SMP and EDISOFT RTEMS 4.8
- ▶ Provides step by step Qualification Guideline and qualification template
- ▶ Minimized project specific delta-qualification effort (below 2 days of test execution)
- ▶ Freely available (Qualification Kit also free for ESA Missions)
- ▶ Much extended functionality and improved test-suite over the precursor MLFS library
- ▶ Improved accuracy compared to the Newlib **libm**
- ▶ Clearly characterized accuracy and execution time behavior

Provided math.h Procedures in 32 bit and 64 bit Precision

- ▶ Classification macros: `fpclassify`, `isfinite`, `isinf`, `isnan`, `isnormal`, `signbit`
- ▶ Trigonometric functions: `acos`, `asin`, `atan`, `atan2`, `cos`, `sin`, `tan`
- ▶ Hyperbolic functions: `acosh`, `asinh`, `atanh`, `cosh`, `sinh`, `tanh`
- ▶ Exponential and logarithmic functions: `exp`, `exp2`, `expm1`, `frexp`, `ilogb`, `ldexp`, `log`, `log10`, `log1p`, `log2`, `logb`, `modf`, `scalbn`, `scalbln`
- ▶ Power and absolute-value functions: `cbrt`, `fabs`, `hypot`, `pow`, `sqrt`
- ▶ Error and gamma functions: `erf`, `erfc`, `lgamma`, `tgamma`
- ▶ Nearest integer functions: `ceil`, `floor`, `nearbyint`, `rint`, `lrint`, `llrint`, `round`, `lround`, `llround`, `trunc`
- ▶ Remainder functions: `fmod`, `remainder`, `remquo`
- ▶ Manipulation functions: `copysign`, `nan`, `nextafter`, `nexttoward`
- ▶ Maximum, minimum, and positive difference functions: `fdim`, `fmax`, `fmin`
- ▶ Fused multiply-add: `fma`
- ▶ Comparison macros: `isgreater`, `isgreaterequal`, `isless`, `islessequal`, `islessgreater`, `isunordered`
- ▶ Bessel functions (only in 64 bits): `j0`, `j1`, `jn`, `y0`, `y1`, `yn`

In addition all required standard complex functions of `complex.h` are provided for integration purposes.

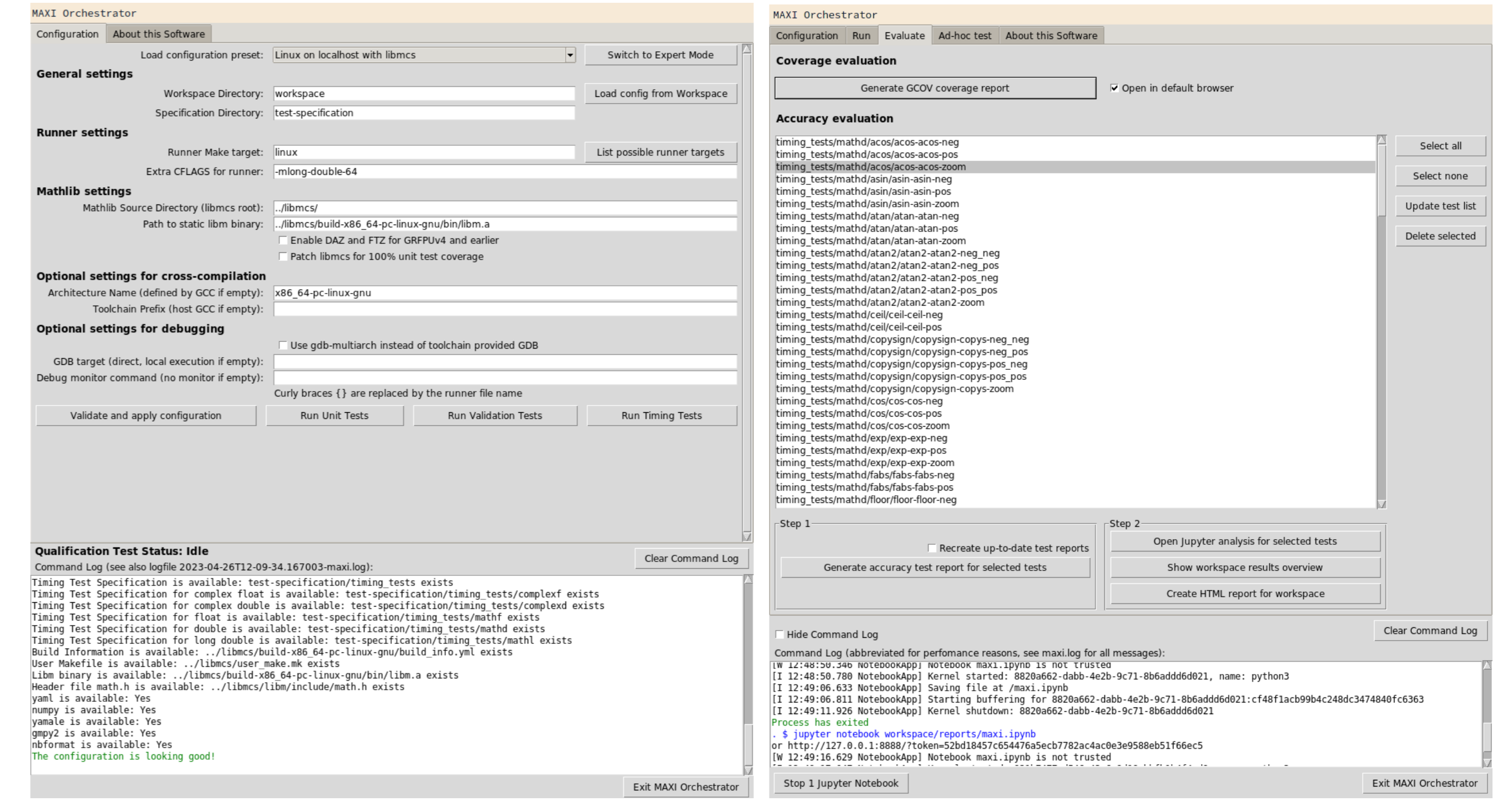
Acknowledgements

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The Test-Suite (MAXI Toolbox)

The provided Test-Suite enables through its GUI:

- ▶ the assessment (numerical and timing behavior) of the mathematical procedures and
- ▶ their **fully automated qualification** on target through GDB
- ▶ including generation of **Qualification Reports**
- ▶ if necessary, interactive analysis of test results with Jupyter Notebooks
- ▶ and, easily extensible for custom mathematical functions



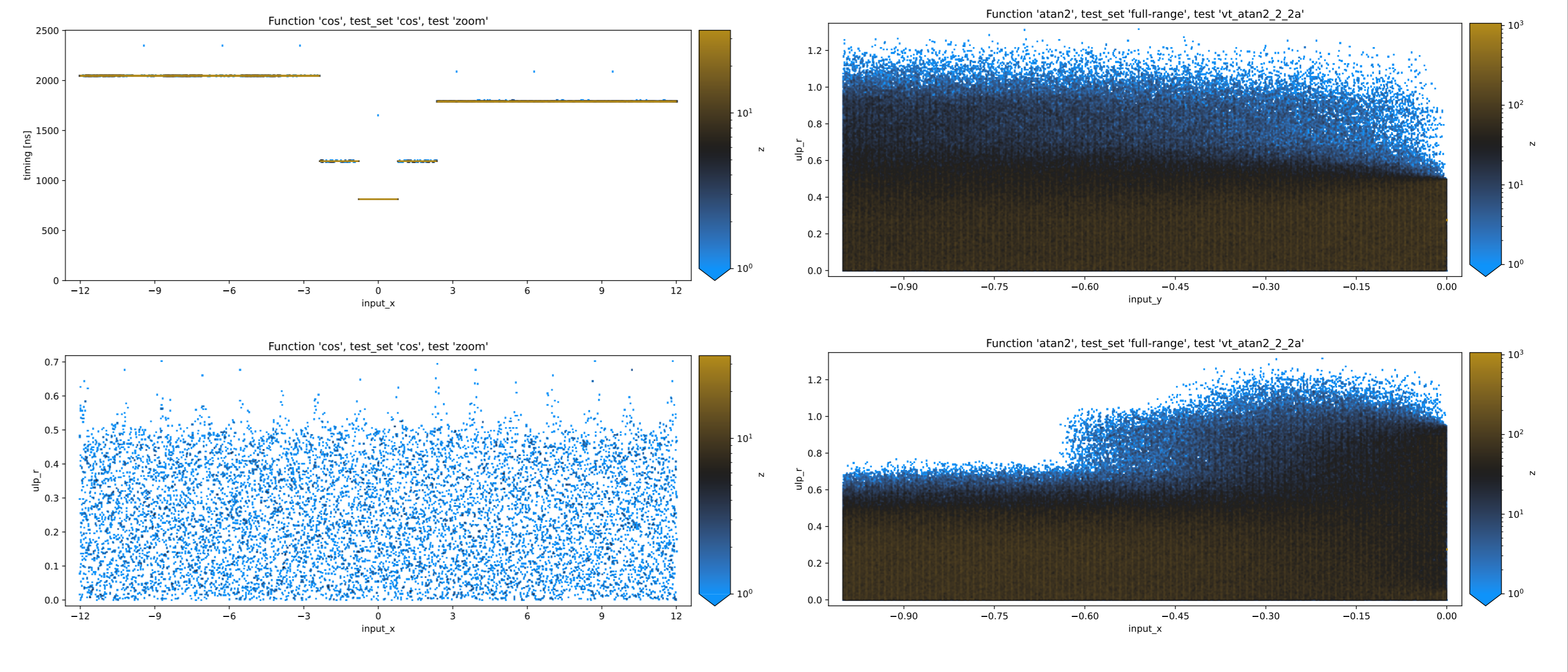
The Test Specification

- ▶ Over 4.000 Unit-Tests achieving full statement, decision, and even 100% MC/DC coverage
- ▶ Over 1.000 single value Validation-Tests
- ▶ Over 250.000.000 floating-point accuracy tests

Qualification Reports

The Test-Suite creates a detailed Qualification Report including:

- ▶ Test Environment Meta Data
- ▶ Numerical results overview
- ▶ Accuracy and Timing Plots
- ▶ Source Code coverage on target CPU using GCov



Provided Data Package

The complete Qualification-Kit includes:

- ▶ Full ECSS engineering documentation in compliance with E-ST-40 and Q-ST-80
- ▶ Full qualification evidence on x86-64, LEON2 (AT697), and LEON4 (N2X) platforms
- ▶ Qualification Guideline and qualification template

Availability and Contact

- ▶ ESA ESSR: <https://essr.esa.int/project/libmcs-mathematical-library-for-critical-systems>
- ▶ LibmCS on GitLab: <https://gitlab.com/gtd-gmbh/libmcs>
- ▶ GTD GmbH Information and Support: <https://gtd-gmbh.de/libmcs>
- ▶ [@libmcs@gtd-gmbh.de](mailto:libmcs@gtd-gmbh.de)

