



TN - Space Grade Modulators

Definitions

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Introduction

Exail modulators address the space market with highly reliable solutions for a wide range of applications:

- > Navigation.
- > Precision positioning.
- > Inter-satellite communication.
- > Laser communications between ground base stations and satellites.
- > Laser stabilization ...



Figure 1: Space applications using Exail LiNbO₃ modulators

To address all these markets Exail masters both Ti-in-Diffusion and APE waveguide processes and provides a solution for all possible demands:

- > Phase and amplitude modulators in the Near Infra-Red and the C-Band.
- > High Extinction Ratio Modulators ([the MXER serie](#)), with ER higher than 30 dB.
- > EO-bandwidth from 100 MHz to 40 GHz.

Exail is a world-leading manufacturer of high-reliable LiNbO₃ modulators for space use and first started to study the space industry and designed modulator prototypes in 2002. These modulators passed successfully all the tests of reliability to be used in space (radiations, vibrations, mechanical shocks, endurance tests such as thermal cycling and life tests in vacuum, ...). Since 2009, modulators from Exail have been launched in space in more than 13 missions with successful operations.

Components sent in space face a lot of challenges - from extreme temperature variations to space radiations passing by mechanical vibrations during the launch. These harsh conditions mean that any component cannot be used for space missions. Certain certifications are thus used to ensure the quality and reliability of the components in space. The components have to undergo a very strict and wide range of tests, screenings and qualification processes. The aim of this document is to explain all the different certifications Exail can guarantee on its Space Grade components.

Categories of Electro-Optical Modulators

The following guidelines are intended to define the LiNbO₃ modulator models involved in the verification process and the selection of the associated model:

- > Terrestrial grade.
- > Engineering Model (EM).
- > New Space Flight Model (NS-FM).
- > Qualification model (QM).
- > Flight Model (FM).

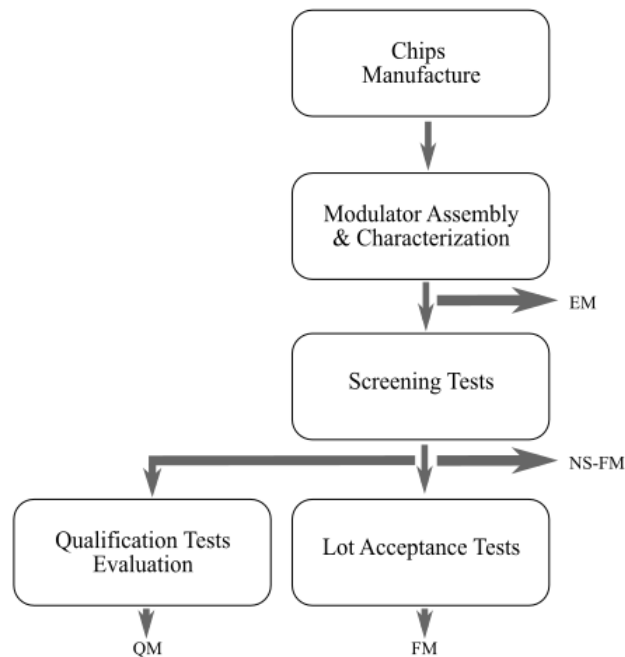


Figure 2: Exail Space Grade modulators fabrication, tests & qualification process diagram

A) Terrestrial grade

The **Terrestrial grade modulators** are commercial and standard LiNbO₃ modulators. Their performances are given in the corresponding datasheet and the products portfolio is available from our website for [phase modulators](#) and [amplitude modulators](#). If customers want a component with performances different than the one given in the datasheet it becomes a custom component – coming with higher prices and delay.

B) EM – Engineering Model

The **Engineering Model modulators** are flight representative in form, fit and function. They are used for functional qualification, except redundancy verification, failure survival demonstration and parameter drift checking. The EM is also used for final validation of test facilities. (ECSS-E-10-02).

C) NS-FM – New Space Flight Model

The **New Space Flight Model modulators** are the modulators dedicated to fly, based on qualification heritage (available on request), which is ideal for low-cost development in New Space. These already-flight proven components are designed and manufactured like a flight hardware and are sampled after screening test to eliminate items whose behavior doesn't meet the specifications during temperature tests. However, these modulators are not evaluated with a Lot Acceptance Test. Moreover delta qualification will be performed only when new processes or elements are changed inside the modulator.

Exail is able to deliver these modulators thanks to its high mastery and control of the supplier's technology and processes. The production was standardized and dedicated to the small and medium production volume offering low-cost or cost-effective space solutions. This approach is dedicated to short lifetime satellite projects.

D) FM – Flight Model

The High Reliability **Flight Model modulators** are the modulators dedicated to fly, based on legacy space standards. These modulators are assembled from a unique batch and are submitted to acceptance-level testing (Lot Acceptance Tests corresponding to a relaxed qualification tests program) after preliminary selection by temperature screening tests. They are dedicated to a small volume modulators production project due to their high reliability coming from the whole qualification the modulators undergo. This approach is usually dedicated to long-life satellites.

Components coming from the same fabrication batch are used for a dedicated qualification program. These Qualification Models (QM) are selected after screening (such as NS-FM models). The most drastic qualification program is described in Reliability assurance guideline for lithium niobate-based electro-optical modulators guideline (ISROS_GL_001_V01). However, based on Exail heritage & background, the number of components used for qualification can be reduced, and the qualification program simplified.

The screening Test

The Screening procedures aim to detect potential failures and defects as early as possible during the test sequence. They are performed on all space modulators except the EM.

The bathtub curve for failure rates is the diagram showing the lifetime against the failure rate of any components (see figure 3).

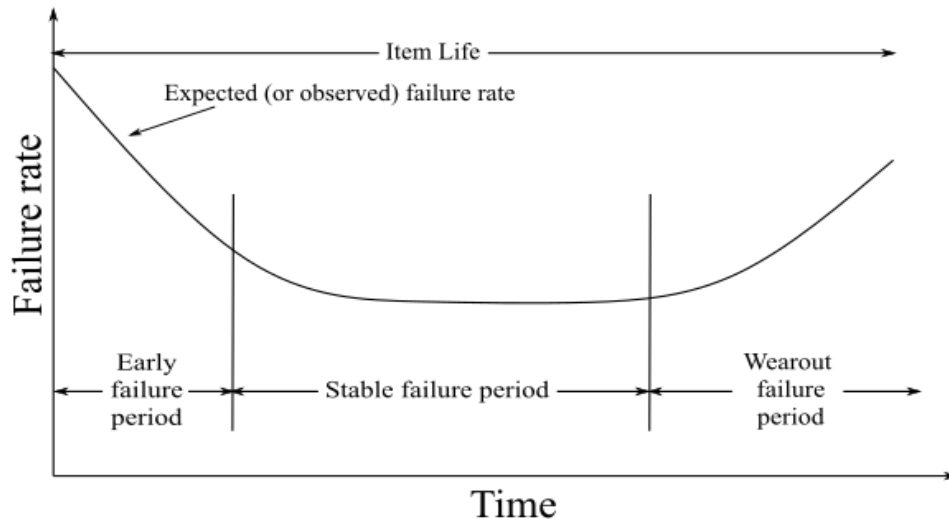


Figure 3: Bathtub curve figure

On the bathtub curve diagram we can see the three periods of a component's life:

- > **Early failure period** (also called infant mortality failure period): During this period, the weak or marginally functional modulators are weeded out.
- > **Stable failure period** (also called intrinsic failure period): The failures occur at a random, uniform or constant rate.
- > **Wear-out failure period**: One of the main purposes of the reliability testing is to ensure that the onset of the wear-out period occurs far enough out in time as to not be concerned during the useful life of the product.

The Qualification Tests Evaluation

The objective of the Qualification Tests is to formally demonstrate that the design implementation and manufacturing methods have resulted in a hardware and a software conforming to the specification requirements. They are performed on components dedicated for qualification (NS-FM type).

The purpose of qualification testing is to demonstrate that the items perform satisfactorily in the intended environments with sufficient margins. The qualification test levels shall exceed the maximum predicted levels by a factor of safety which assures that, even with the worst combination of test tolerances, the flight levels shall not exceed the qualification test levels.

The following tests are performed on:

- > **Radiation Environment**: The space environment can induce degradation to a majority of optoelectronics components employed in a space mission.
- > **Damp heat**: The purpose of this test is to evaluate, in accelerated manner, the resistance of the component to the deteriorative effects.
- > **Random & Sine Vibration**: Vibration tests verify the ability of the samples to withstand the dynamic stress applied by vibration.

- > **Mechanical Shocks:** The purpose of the mechanical shocks test is to examine the modulators shock resistance.
- > **Thermal Vacuum & Air cycling:** The modulator being exposed to thermal vacuum during space flight, the large temperature variations may directly affect the characteristics of the modulator.
- > **Accelerated Aging test:** The method consists of simulating long term operation in a relatively short period of time in harmful test conditions (to anticipate the lifetime of the modulators).

The Lot Acceptance Tests (LAT)

The purpose of acceptance testing is to demonstrate the conformance to specification and to act as quality control screens to detect manufacturing defects, workman-ship errors, the start of failures and other performance anomalies, which are not readily detectable by normal inspection techniques. They are performed on the FM models.

The acceptance tests shall be formal tests conducted to demonstrate the adequacy and readiness of an item for delivery and subsequent usage. Thus they are conducted under environmental conditions not more severe than those expected during the mission.

Example of Qualification Test and LAT

The modulators follow the Qualification Test (QT) and the LAT which correspond to different tests according to their category. The different steps they have to undergo for each category are listed in figure 4 - which shows the whole process.

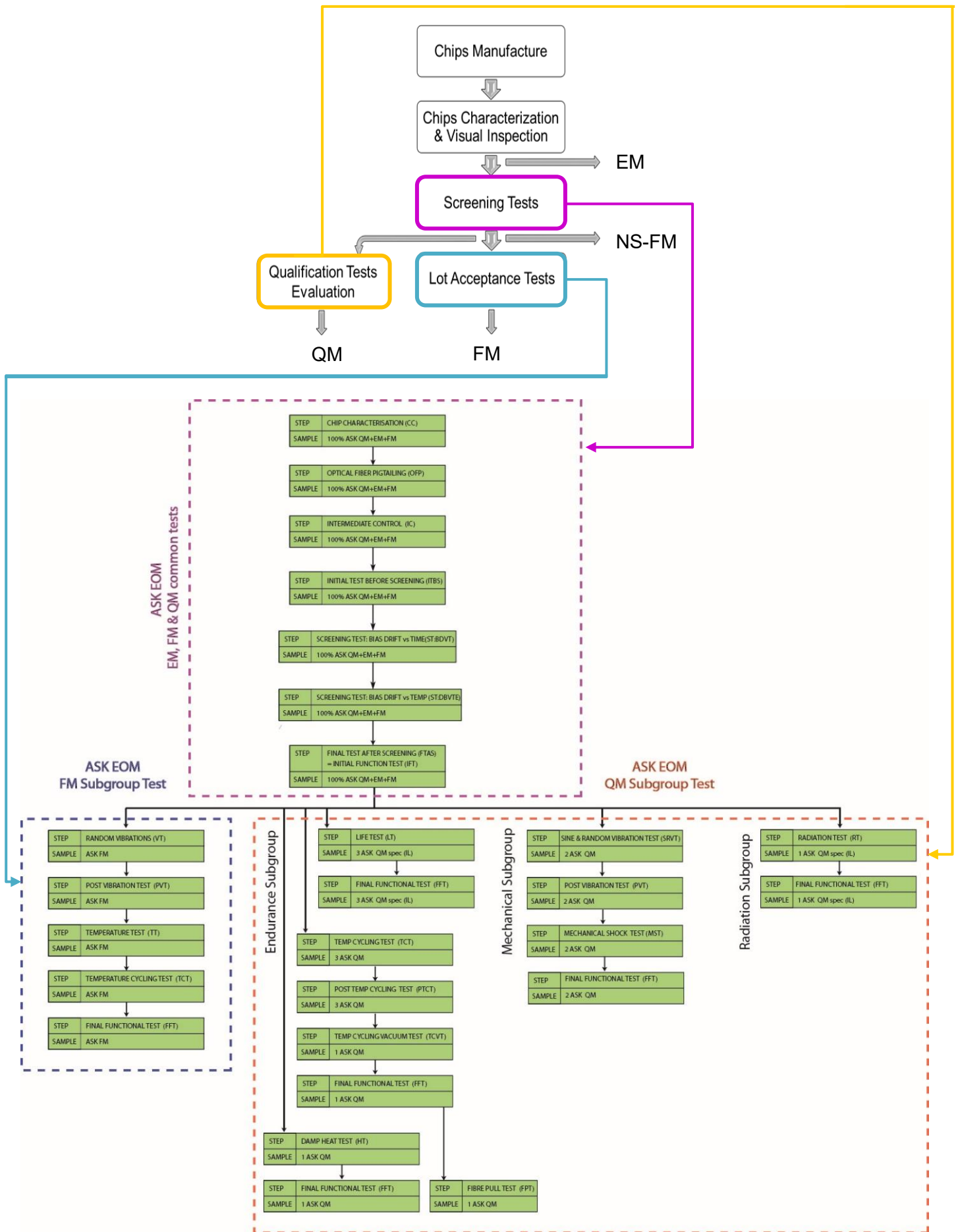


Figure 4: Example of QT and LAT

Standard and Space Assembly Process

The Assembly Process for space components requires more steps in order to guarantee the reliability of the modulators in this harsh environment. Below is a summary of the main differences in this Assembly Process for a standard and a space graded Exail modulator.

Main differences	Terrestrial	Space
Pre-test on electrical bonding by using a control sample	No	Yes
Post-test on electrical bonding by using a control sample (pull-test)	No	Yes
Seal welding pre-test on a control sample	No	Yes
Seal welding post-test on a control sample	No	Yes
Visual inspection (Internal elements and/or external)	Yes (~ 3 times)	Yes (~ 5 times)
Metal Housing semi-hermetic	No (Optical feedthrough screwed)	Yes
Number of manufacturing steps for Front End to EOM final test	~ 20	~ 27

The applicable standard for Space Products is ESCC and/or MIL-STD

Due to the intensive care during the manufacture Exail guarantees the best of its modulator quality. Note that 2 engineers continuously follow the modulators during the standard manufacturing process and additional control tests are added (see chart above). This leads to around 27 tests for a Space product compared to the 20 for a Terrestrial grade.

Traceability

The **traceability** is the ability to verify the manufacture history of the Modulators by means of documented recorded identification. It follows the guideline:

- > Each wafer is defined by its origin from a bulk lithium niobate crystal and is identified with its own serial number.
- > The “Product Line” document defines all the fabrication steps of the LiNbO₃ wafer and follows the wafer during the fabrication steps.
- > Each step is defined by a detailed fabrication document, named “Processing methods”.
- > Each step is checked, dated and signed by the operator on the paper document.

The traceability is especially relevant when developing safety-critical systems such as space grade components.

Conclusion

The differences between the different models of modulators are summarized in the figure 5. The Space Grade Modulators undergo a lot more inspections and tests than the Terrestrial Grade Modulators and the Flight Models are components with the most complete test program. To sum up the process to get a Flight Modulator we perform:

- > LAT on NS-FM.
- > The best NS-FM during LAT become FM.
- > Some NS-FM from the batch undergo QT and the best become QM.

Modulator Grade		Terrestrial Grade (TG)	Engineering Model (EM)	New-Space Flight Model (NS-FM)	Flight Model (FM)
Assembly	Flight compatibility	x	x	o	o
	Space compatible raw material	x	o	o	o
	Batch unicity	x	x	x	o
	Space compatible assembly process	x	x	o	o
Test	Screening test	Partial	Partial	o	o
	Space qualification test heritage	x	x	o	o
	Lot acceptance test	x	x	x	o
	Qualification program	x	x	x	o
Documentation	Acceptance test report	o	o	o	o
	Interface control document	x	o	o	o
	Certificate of conformity	x	o	o	o
	Screening test report	x	x	o	o
	Lot acceptance test report	x	x	x	o
	Handling manual	o	o	o	o

o : apply / x : do not apply

Figure 5: Summary Chart

Acronyms

- > EM : Engineering Model
- > NS-FM : New Space – Flight Model
- > QM : Qualification Model
- > FM : Flight Model
- > LAT: Lot Acceptance Tests
- > QT : Qualification Test