ESA Photonic Components Qualifications activities

Intra-satellite Fibre Optic Links Workshop

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European Space Agency

Outline

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- Challenges for space industry
- ESA roadmaps and work plans
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- **Standardisation**
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- ESCC specifications for photonic components
- What is meant by qualification?
- ECSS standards
- ECSS standards for photonic components
- Criteria for choosing a photonic component for space application
- Procuring and approving use of photonic component

Introduction

In the recent years, a gradual substitution of different electrical sub-systems by optical systems has taken place for terrestrial applications arousing the interest of the space community for its own needs.

However, implementing new technologies on board is not straightforward

- Each space mission is a challenge
    - Pre-launch (storage) and Launch
    - Long duration operation
    - Harsh environment: T/C, radiations
- Reliability assessment & ground testing are essential
    - Reliability testing addressing all the constraints at an affordable cost
    - Needs differ from terrestrial applications: hermetic packages, Al wires, SnPb terminations, radiation tolerance, compatibility of high pin count packages …
- Last but not least, one challenge is also to deal with rapidly evolving technologies and constant needs for performance evolution.

Challenges for space industry

1. Technical Challenges we are facing nowadays
   - optoelectronic technologies essentially available in commercial grade
   - power dissipation -> no convection in vacuum
   - packaging -> non hermetic packages ?
   - new materials and processes
   - temperature ranges: stable perf. from -55C to +125C ?
   - rapid process changes – repeatability - technology availability
   - radiations

2. “Industry” challenges
   - **limited offer** in terms of HiRel parts
   - **limited support** for small volume markets
   - **access** to test and reliability data
   - **stability of the supply chain**
   - **long term availability**

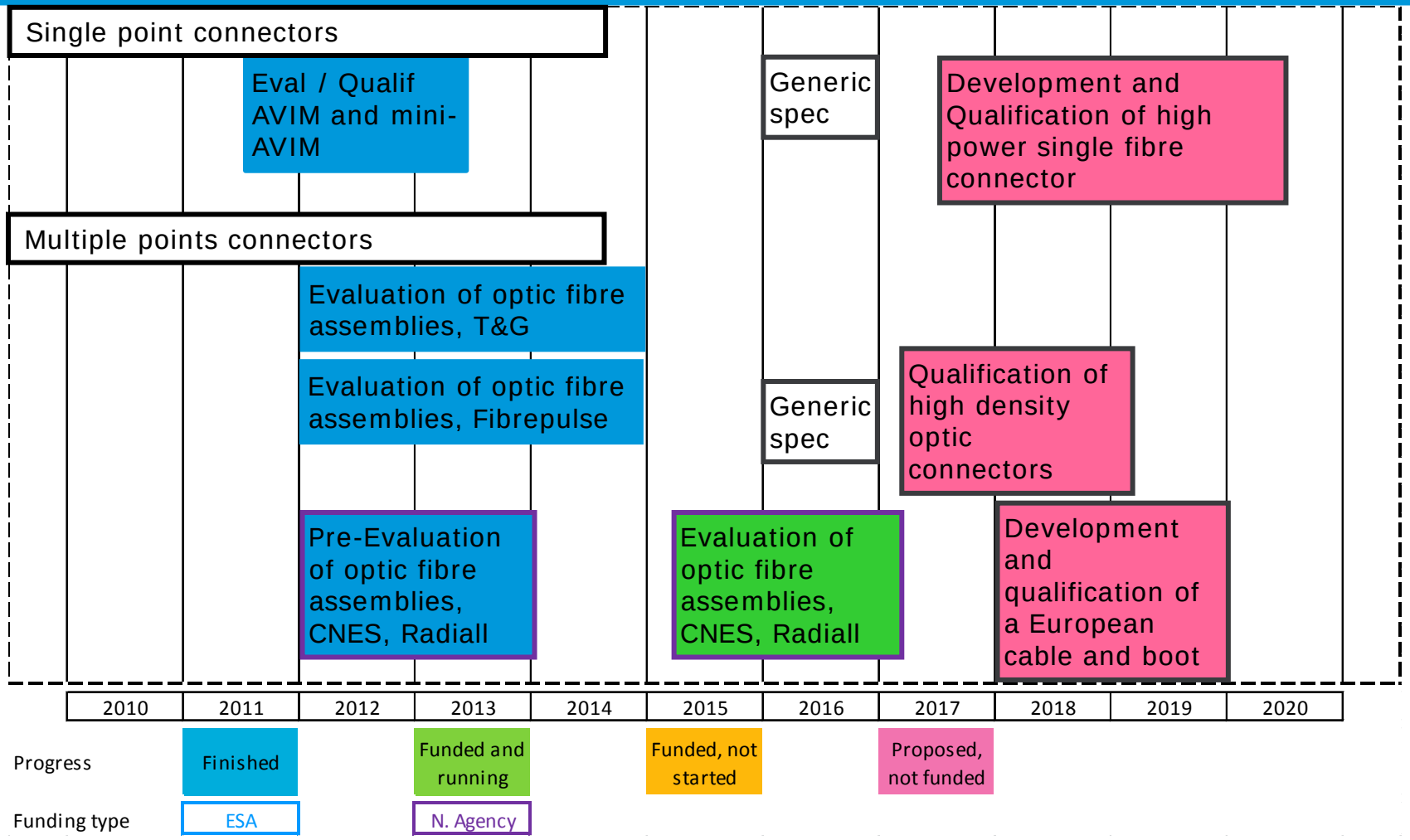
ESA Roadmaps and work plans

- In order to answer to both ESA and European space community needs, roadmaps are established between ESA and industry.
- Developments follow 2 paths:
  - Targeted developments aimed at specific missions or mission types
  - Technology developments aimed at improving European capability in support of future missions
- The following ESA work plans for the coming years are related to space validation, methods, performance improvement for various photonic / optoelectronic devices.
- These activities are funded via the different ESA schemes including the European Component Initiative (ECI), the ESA's TRP and GSTP but strategies are harmonized.

TEC-QTC section, photonics activities for ISL

SPACE ASSESSMENT ACTIVITIES

Optic connectors and optical harness



Generic specification for single point optical connector sets

Generic ESCC specification

OPTICAL SINGLE FIBRE CONNECTOR SET ASSEMBLIES

ESCC Generic Specification No. 31

- Exists as a draft, but more clarification on IEC standard use is necessary
- Screening tests: temperature cycling and sinusoidal vibrations. Fibre / cable retention may be recommended on some assemblies types.
- Periodic testing sequences:
  - torsion + static side load + cable retention
  - temperature cycling + humidity testing
  - random vibrations + shocks
  - temperature storage + mating durability

To be noted: hybrid patch cords need to be specifically manufactured for the qualification tests in order to qualify the full connector set.

Evaluation and qualification of single point optical connector sets, Diamond

Single point optical connectors

Tested configuration:

- PM fiber Fujikura SM.15-P-8/125-UV/UV-400 1550nm, acrylate coating
- PEEK 1mm loose tube

Evaluation and qualification tests results published at ICSO 2012 & 2014, as well as recommendations for procurement.

Detail specification in draft version

Both connectors could apply to QPL then

AVIM:

Mini-AVIM:

Qualification tests sequence

Assembly tests flow:

- Torsion
- Static side load
- Cable retention

Environmental tests flow 1:

- Temperature cycling
- Humidity

Environmental tests flow 2:

- Random vibration
- Mechanical shocks

Endurance test flow:

- Temperature storage
- Mating durability

Outgassing tests: Some elements fail the outgassing tests on TML and CVCM.

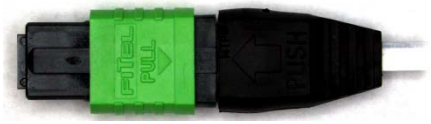
Evaluation of Optic Fibre Cable Assembly, T&G

High density optical connector

T&G tested configurations:

- Assembly 1: MPO USConec connector, PC-polish in accordance with IEC with MT insert and MM ribbon cable 12 channels GORE FON1214/4/12, 50/125/250

- Assembly 2: MTP Furukawa connector, APC-polish with 150 nm reduced protrusion for vibration sensitivity with MT insert and MM ribbon cable 12 channels GORE FON1214/4/12, 50/125/250



- Operating wavelength 850 nm, loss 4 dB/km, maximum operating temperature 125 °C

Evaluation tests sequence

- High and low temperature step stress
- Temperature Cycling
- Random Vibration
- Retention
- Static Side Load
- Torsion
- Mating durability
- Radiation

Assembly 2 is more robust than Assembly 1.

- Outgassing

Some elements fail the outgassing tests on RML and CVCM on Assembly 1 and 2.

- Construction Analysis

Evaluation of Optic Fibre Cable Assembly, Fibrepulse

High density optical connector

Fibrepulse tested configurations:

- Assembly 1: MTP/APC USConec connector, SM round cable 12 channels Carlisle Group NFO(HD)-125-3M3-12, 3.8mm Jacket, SMF-28e

- Assembly 2: LC2 Molex connector, MM single channel, MM Carlisle Group NFO(EP)-125-3M4R, 1.8mm OM4

- Operating wavelength 850 nm, loss 2.7 (SM) to 3.5 (MM) dB/km, maximum operating temperature 125 °C

Evaluation tests sequence

- Temperature Step Stress
- Static Side Load & Cable Retention
- Torsion
- Strength of coupling
- Mechanical Shock & Random Vibration
- Temperature Cycling
- Mating Durability
- Cable Storage Life
- Radiation

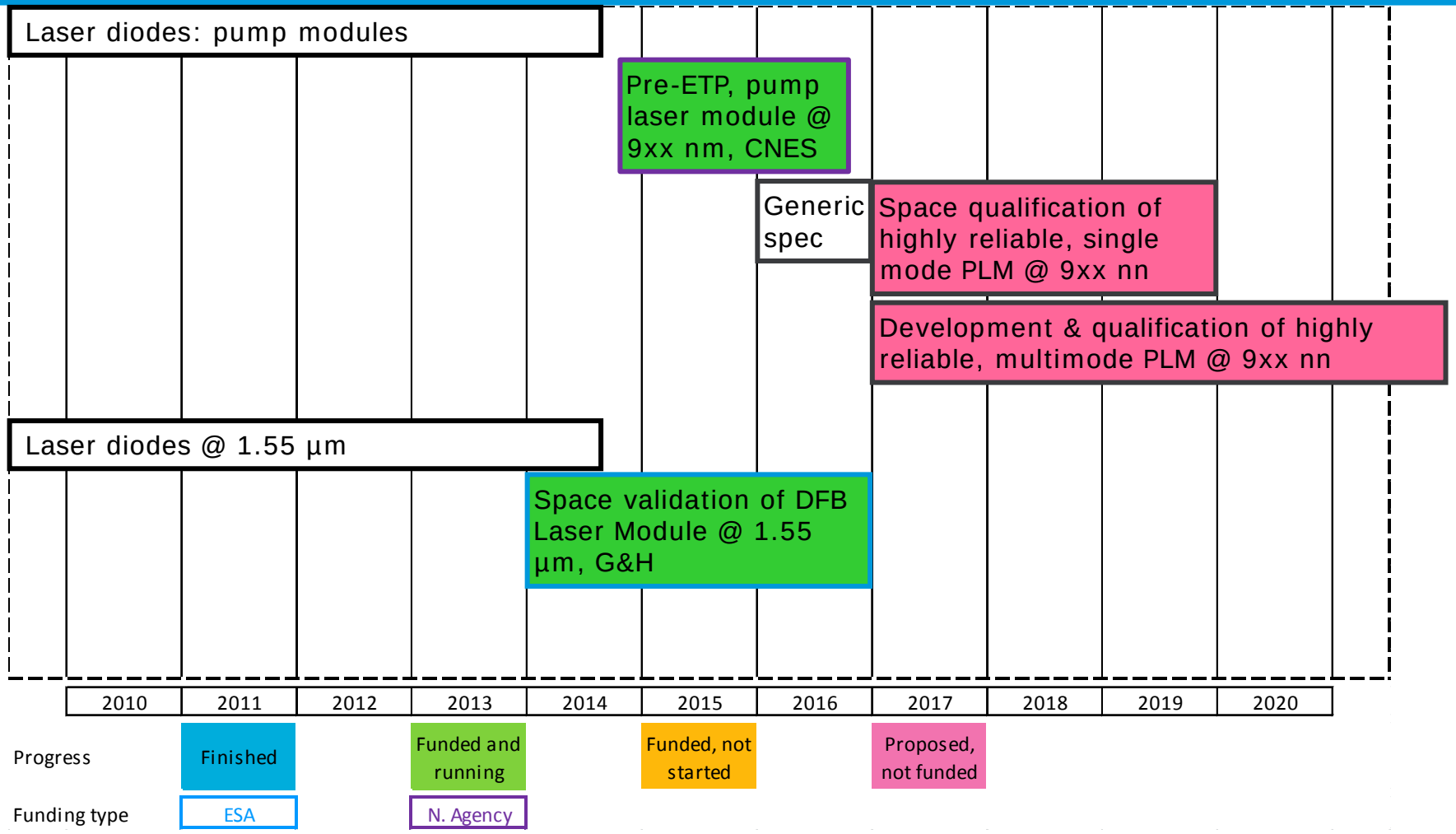
Assembly 1 is not suitable for high temperature due to loose fibers. Assembly 2 shows good robustness however static side load max at 4N.

- Outgassing

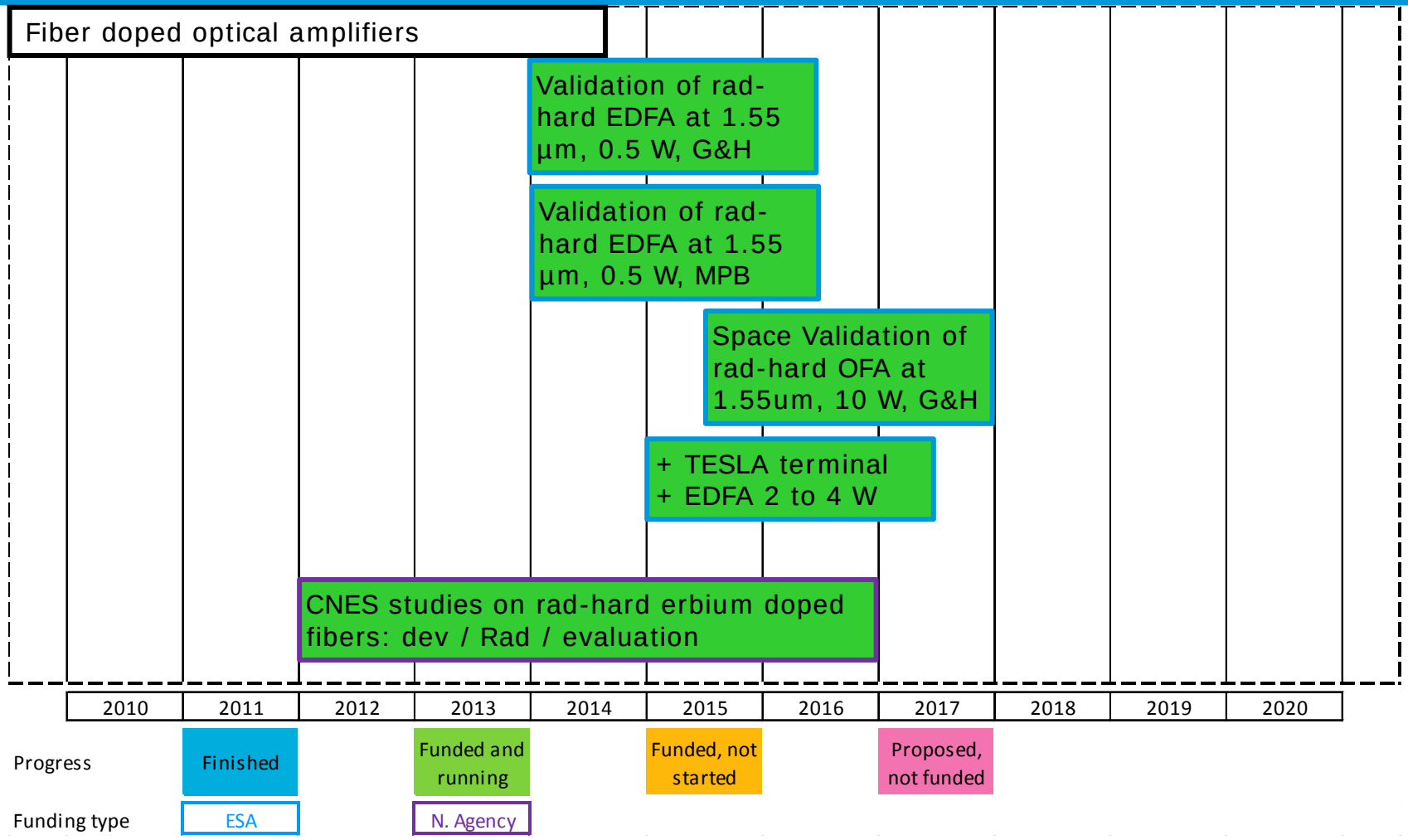
Some elements fail the outgassing tests on RML and CVCM on Assembly 1. Assembly 2 not tested.

- Construction Analysis

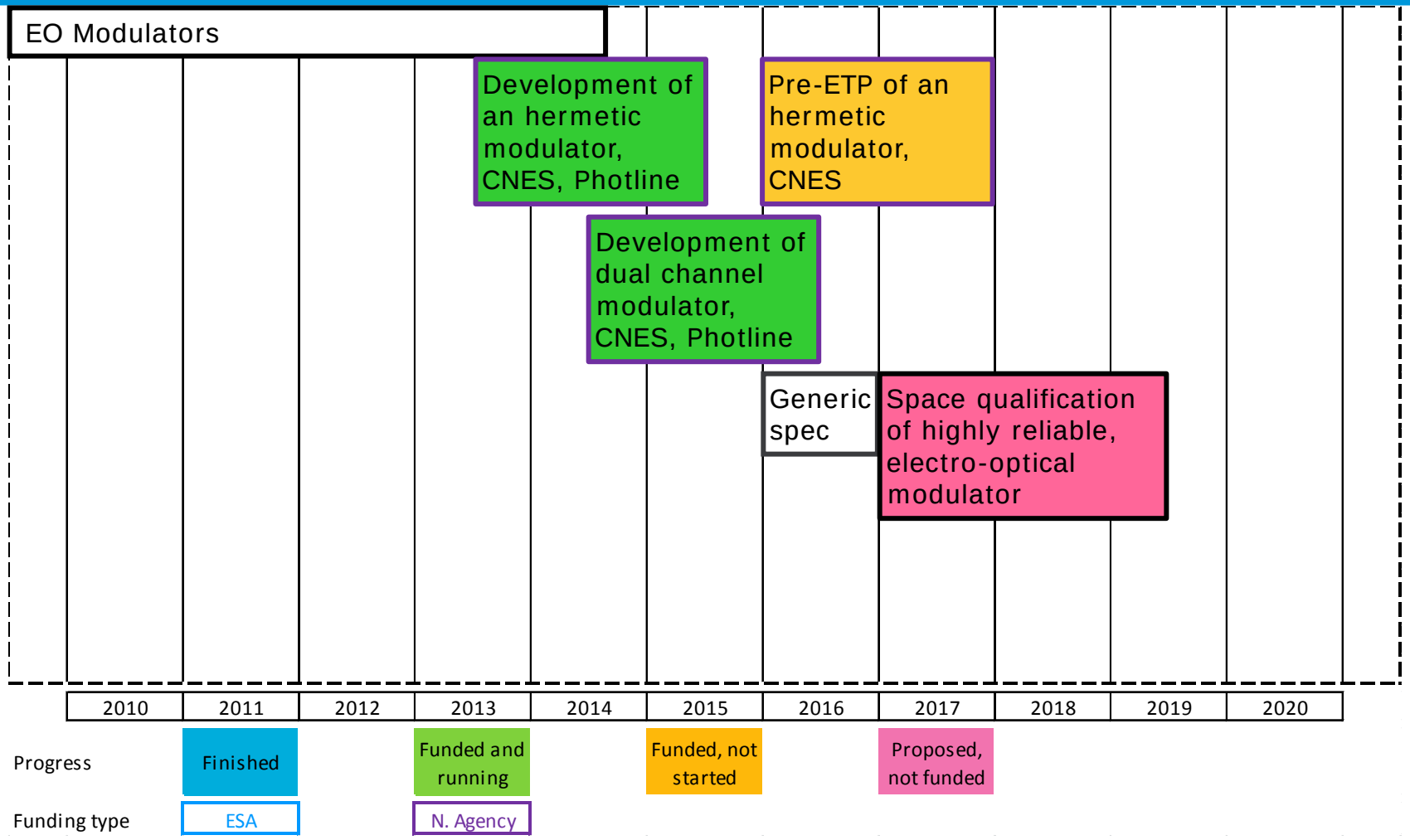
Photonics Components for intra-satellite optical link



Photonics Components for intra-satellite optical link



Photonics Components for intra-satellite optical link



Space validation of DFB Laser Module at 1.55 µm, G&H

1.55 µm DFB laser diode

Purpose:

To create a space-validated DFB laser module emitting at 1.55um for laser comm terminals and scientific / EO missions requiring 1.55 µm or other wavelengths in the payload.

Tested configuration:

- DFB laser, output power 77 mW
- 14 pins Butterfly package
- Active cooling (TEC)

Standard used

- ESCC-Q-ST-60-05C Rev. 1: Generic procurement requirements for hybrids
- ESCC 23201: ETP programme guidelines for laser diode modules

Pre-LAT measurements performed.

Programme should end in proposing an entry to the EPPL.

Qualification tests sequence

Temperature and power step stresses

TID and TNID irradiations

Mechanical shocks & vibrations tests

Construction analysis

Depressurization tests

Thermal vacuum tests

Low temperature tests

Thermal cycling

Humidity

ESD

COD

High temperature Operating life test

Space validation of rad-hard EDFA at 1.55 µm, 0.5 W and 10 W, G&H

1.55 µm rad hard EDFA

Tested configurations:

- Optical pre-amplifier, C band, +15 dBm output power
- Mid-power booster PM, C band, +10 to +20 dBm output power
- High-power amplifier, C band, +37 to +40 dBm output power

Several fibers and manufacturers under investigations.

Irradiations on the first 2 configurations are finished, EM manufacturing on-going.

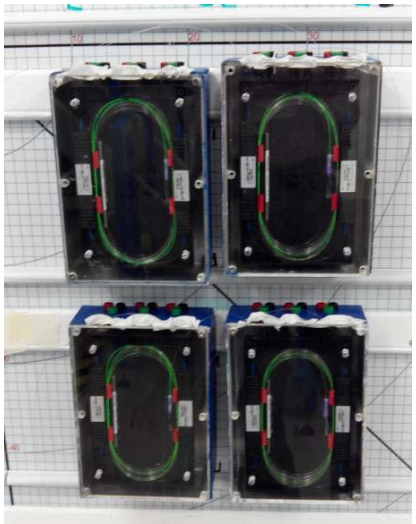
Third configuration: Test plan of the first irradiation on-going.

Qualification tests sequence

TID irradiation of doped fibers

Environmental testing of the selected fibre

Thermal cycling and vacuum thermal cycling of the OA



Space validation of rad-hard EDFA at 1.55 µm, 0.5 W, MPB

1.55 µm rad hard EDFA

Tested configurations:

- Pre-amplifier, C band, gain up to 44 dB
- Mid-power booster, C band, gain up to 18 dB

Several fibers and manufacturers under investigations.

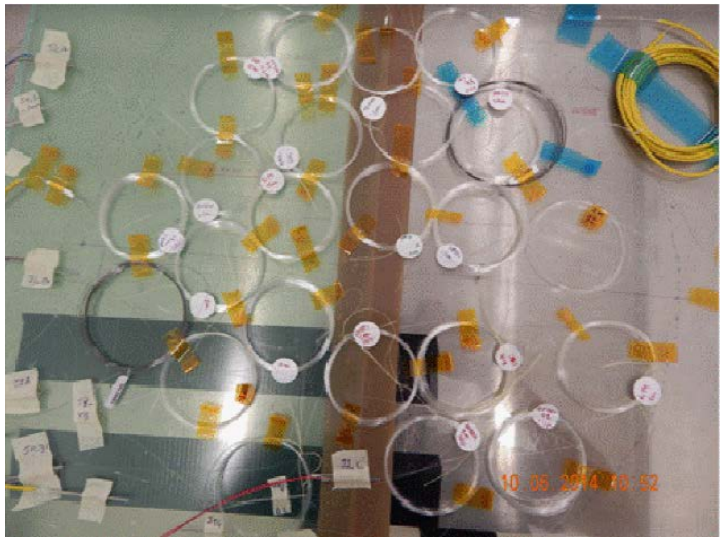
Irradiations of fibers on-going.

Bread board manufacturing about to start.

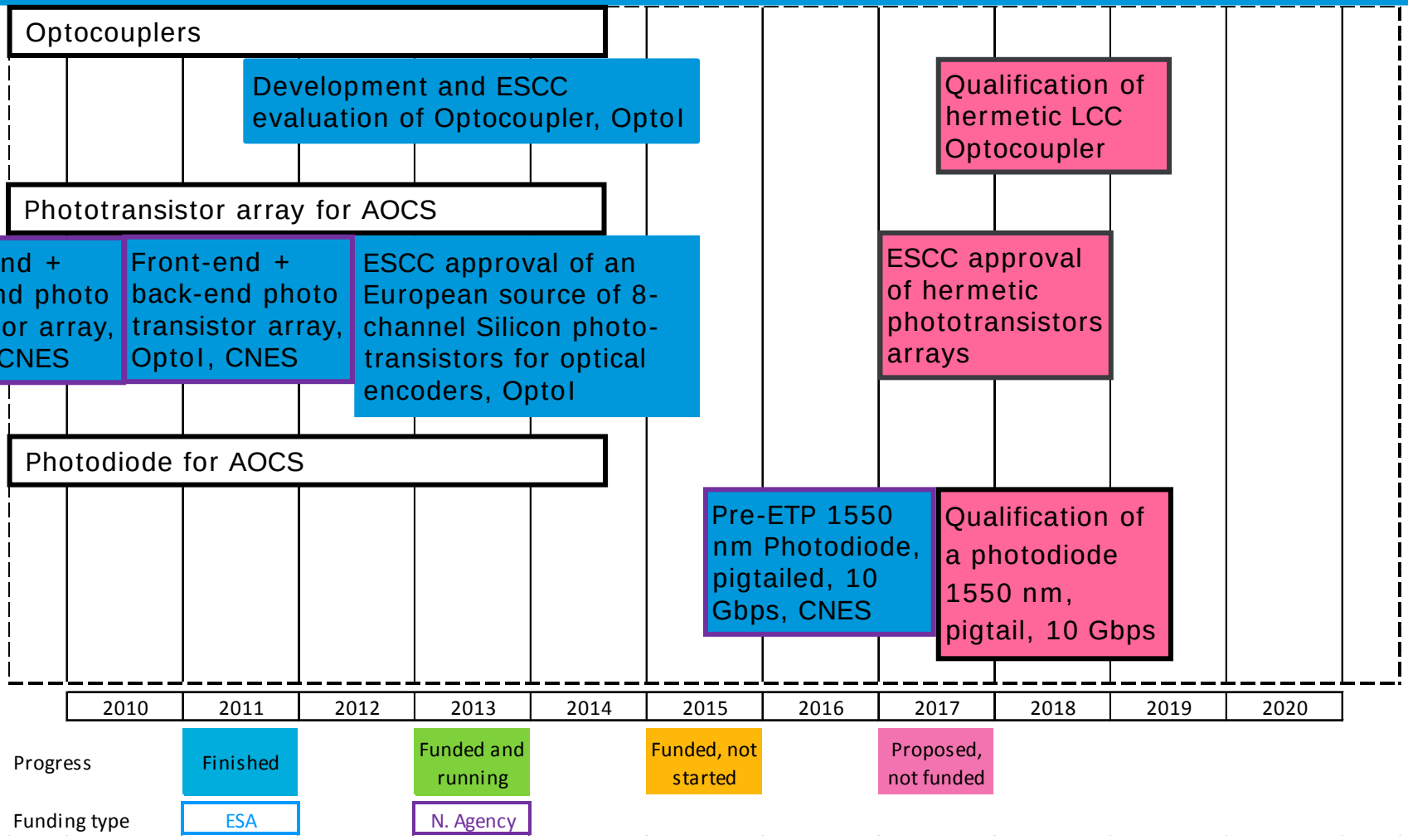
Qualification tests sequence

TID irradiation of doped fibers

Vacuum thermal cycling and vibrations of the OA



Photonics Components for Platform and AOCS



Development and ESCC evaluation of an European radiation tolerant Optocoupler, OptoI

European Optocoupler

Tested configurations:

- LED is an European one
- Phototransistor is developed by OptoI/FBK
- 3 packages: TO5, LCC6, LCC4.
- TO5 discontinued after evaluation

Optocouplers mounted on TO-5, LCC6 and LCC4 packages

Designs improvements required

- Pin-to-pin compatibility and package finish of LCC devices
- Development of an hermetic package

Evaluation tests sequence

- TID and protons irradiation
- Step stress: electrical, temperature, power
- ESD sensitivity
- Mechanical shocks and random vibrations
- HTRB
- High temperature storage
- High temperature Operating Life test
- Thermal cycling and thermal shocks
- Humidity testing

CTR drifts by 10 % for 180 krad, by 17% for 3E10 60 MeV p/cm²

TO5 parts proved less robust than LCC6 counterparts

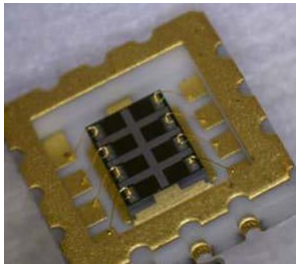
- Construction analysis
- RGA: TO-5 reaching up to 2.33% moisture

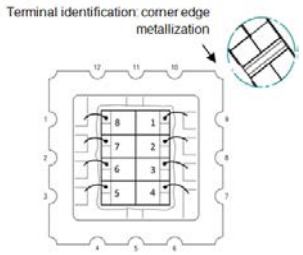
ESCC approval of an European source of 8-channel Silicon phototransistors for optical encoders, OptoI

8-channel phototransistors

Tested configuration:

- Ceramic LCC12 package
- 8 independent channels phototransistors
- Glued or soldered lid attach





Detail specification exists

2 grades available: commercial and space grade

Drift under thermal stress to be investigated, too large for the application

Eutectic lid attach version to be further evaluated, subjected to funding

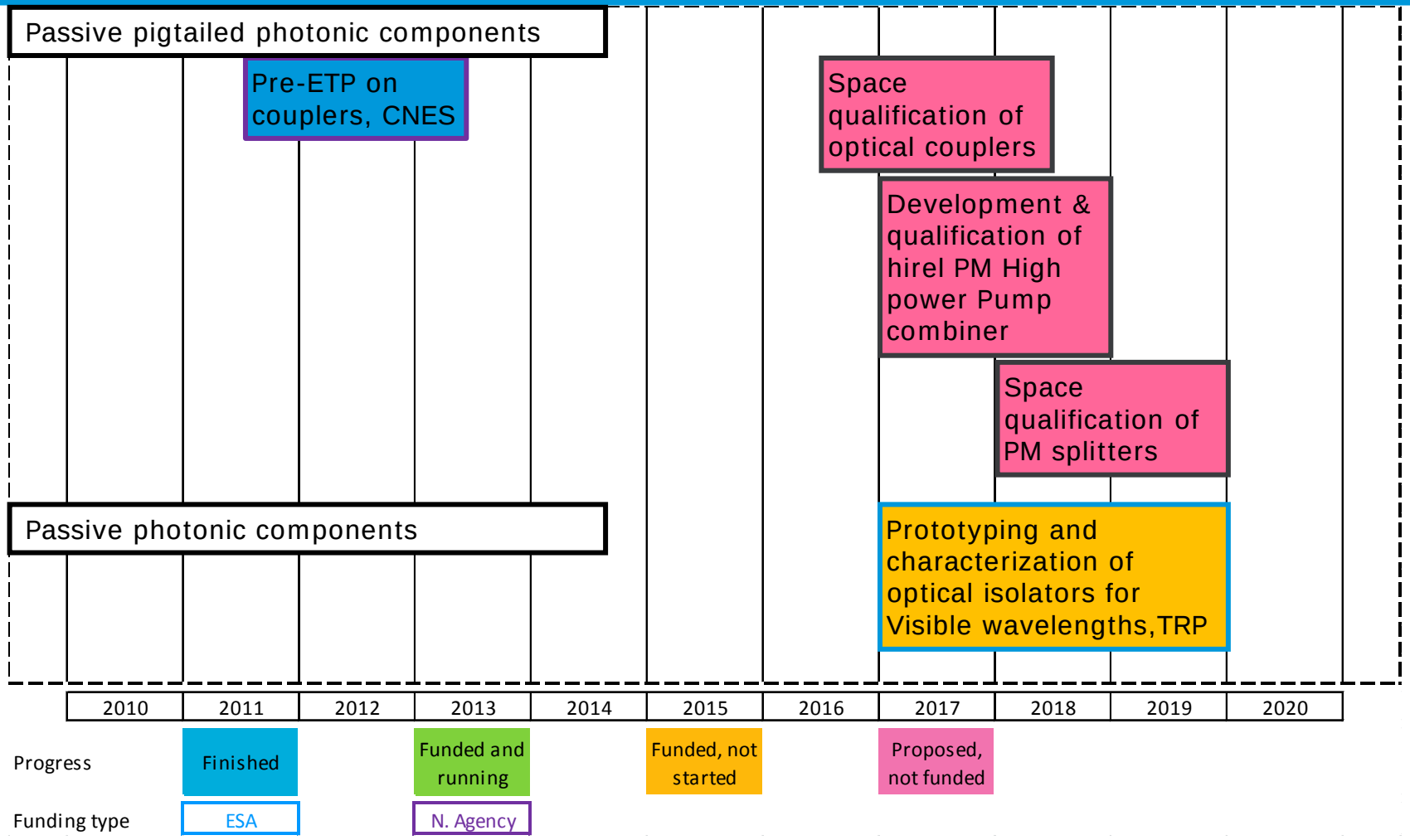
Evaluation tests plan

- TID and protons irradiation
- ESD sensitivity: class 3
- Resistance to soldering heat
- Mechanical shocks and sine vibrations
- Constant acceleration
- HTRB
- High temperature storage
- High temperature Operating Life test
- Thermal cycling
- Humidity testing

TID robustness confirmed and competitive. Photocurrent drifts by 10% after HTRB and after any high temperature steps.

- Construction analysis
- RGA: humidity is intrinsically trapped in the device, eutectic version satisfactory

Passive Photonics Components



STANDARDISATION

The ESCC system in brief

1. ESCC is the European Space Components Coordination
   - Collaborative activity between Space Agencies, the European Space Industry, and European component manufacturers related to procurement of EEE components suitable for space applications
   - https://spacecomponents.org/
2. ESCIES is the European Space Components Information Exchange System
   - Portal is here: https://escies.org/

+ **Photonics** portal in the menu list

ESCC specifications

For users, 3 levels of specifications:

- Basic specification:
  - test methods & methodology & general requirements & evaluation
  - ⇒ applicable to all EEE components
- Generic specification:
  - requirements for screening, periodic or LAT and qualification testing
  - ⇒ dedicated to individual families of components
- Detail specification:
  - performance, maximum ratings, variants
  - physical dimensions, functional diagram & pin out,
  - deviations from the Generic Specification
  - proposed by manufacturers
  - ⇒ dedicated to individual components

Specifications for photonic components 1/

- Discrete optoelectronics: LED, photodiode, phototransistor, packaged in ceramic or TO can
  - Generic specification ESCC 5000 for discrete semiconductor components is applicable
  - Several ancillaries specifications are related: ESCC 2045000, 2055000, 2095000, 2135000, 2145000, 2265000
  - Detail ESCC 5403/001 Issue 2 Nov 2015: Photodiode, based on Type AE9493

Specifications for photonic components 2/

- Laser diodes
  - Basic specification ESCC 23202 Issue 1 October 2014: Validation and Lot Acceptance Testing, Guidelines for Laser Diodes.
  - Basic specification ESCC 23201 Issue 1 January 2014: Evaluation Test Programme Guidelines for Laser Diode Modules.

- Optical connectors
  - Ancillary specification ESCC 2263010 Issue 3 Sept 2013: Evaluation test programme for optical fibre connector sets
  - Generic specification to be consolidated before submission to PSWG
  - Detail specifications for AVIM and mini-AVIM to be adapted to the generic specification when it is approved

Specifications for photonic components 3/

- CCD and CMOS Image Sensors
  - Basic ESCC 25000 Issue 2 January 2014: Basic Specification for Electro-Optical Test Methods for Charge Coupled Devices
  - Generic ESCC 9020 Issue 3 Nov 2013: Generic Specification for Charge Coupled Devices Silicon Photosensitive
  - Basic ESCC 2139020 Issue 3 Nov 2013: Terms Definitions Abbreviations Symbols and Units for Charge Coupled Devices
  - Detail ESCC 9610/004 Issue 2 Apr 2014: Charge Coupled Devices, Silicon, Photosensitive, Advanced Inverted Mode Sensor, Back Illuminated, 740 X 514 Image Area, Frame Transfer, based on Type CCD55-20
  - Detail ESCC 9610/005 Issue 2 Apr 2014: Charge Coupled Devices, Silicon, Photosensitive, Front Illuminated, 512 X 512 Image Area, Frame Transfer, based on Type CCD57-10

What is meant by Qualification?

The term Qualification is commonly used in many situations. You can find components that get:

- an Approval on a case by case basis which is an individual and limited authorisation for one (or a few) specific project applications, based on a given mission profile
- a full ESCC Qualification which is a general and long term authorisation for use in space and independent of the type of mission
  - Components are part of the ESCC QPL (Qualified Parts List)
  - Components are available at manufacturer as space grade
  - For some specific missions (e.g. radiation, cryogenic applications …) extra reliability assessment may be necessary
  - ESCC is the European “organism” for space qualification, others space agencies provide Qualification with their standards, see DLA for instance http://www.landandmaritime.dla.mil/Programs/QmlQpl/

ECSS standards

1. ECSS is the European Cooperation for Space Standardization
   - Initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities
   - http://ecss.nl/
   - to download any documents, this is necessary to register!

2. Aim is to provide the **philosophy of testing** not the tests methods.

3. Three ECSS panels:
   - Engineering, ECSS-E-serie
   - Management, ECSS-M-serie
   - Product Assurance, ECSS-Q-serie

ECSS standards for photonic components

There is no specific standard for photonic components

Those standards are used for EEE & photonics components:

- ECSS-Q-ST-60C Rev2: Space product assurance for EEE components
- ECSS-Q-ST-60-05C Rev.1: Generic requirements for hybrids
- ECSS-Q-ST-70-02C: Thermal vacuum outgassing test for the screening of space materials
- ECSS-Q-ST-30-11C Rev 1: Space product assurance, Derating for EEE components

There is a TM applicable to the splices: ECSS-Q-TM-70-51A: Termination of optical fibres

Criteria for choosing a photonic component for space application

Engineering requirements

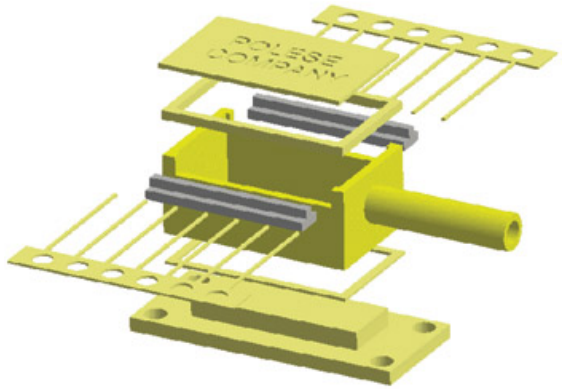
- Performances
- Package:
  - Interface definition
  - Thermal management
- Testing methods/methodology

Mission requirements

- AIT, Ground storage, Launch and In-orbit environment definition
- Product assurance requirements
- Quality assurance

Management requirements

- Availability on the market at the required quantities
- Cost & lead time
- Availability of interlocutor at manufacturer



Procuring and approving use of photonic component: testing flow

C.A.

Procure several parts from several manufacturers:

- Perform a performance assessment
- Perform a construction analysis + some pre-evaluation tests

⇒ select the manufacturer based on the compared results

EVAL

Procure enough parts from the selected manufacturer to:

- Perform an Evaluation testing

⇒ lessons learnt and improvement of the built / design for flight models

QUALIF

Procure FM from the selected manufacturer to:

- Get the FM + spares + attritions
- Perform the Lot Acceptance Tests (or periodic testing)

⇒ Delivery shall happen after the LAT results are available

Procuring and approving use of photonic component: QA flow

C.A.

- Collect the mission environment and the applicable PA requirements
- Discuss with the manufacturer to expected failures modes and on QA matters
- Collect lessons learnt from previous projects and known issues
- Define the tests for construction analysis
- Review and analyse the tests reports
- Participate to the approval of the manufacturer selection

EVAL

- Participate to write the draft procurement specification, including evaluation tests sequence, screening tests, qualification sequence, delivered documentation, acceptance reviews
- Review and approve the draft PID (product identification document) written by the manufacturer,
- Review the Evaluation test plan and approve the Evaluation test reports

QUALIF

Before manufacturing starts:

- Review and approve the updated PID written by the manufacturer
- Participate to write the updated procurement specification

During manufacturing:

- Performs the customer inspections: precap / postcap, customer buy-off
- Review the screening tests results and check for lot rejection criteria
- Review the Lot Acceptance Tests plan and approve the LAT reports
- Participate the incoming inspection at reception

PID = guarantee the representativeness of tested devices (design, materials, processes, tests methods and criteria)

Procuring and approving use of photonic component: PA flow

C.A.

- Provide the mission environment and the applicable PA requirements

ECSS-Q-ST-60C Rev.2
21 October 2013

EVAL

- Approve the procurement specification, Evaluation test plan, Qualification test plan, Radiation test plan, all summarised in the PAD (Part Approval Document) = as-design PAD approval
- Participate to the Non Conformance review Boards

QUALIF

- Approve the PAD (Part Approval Document) = as-built PAD approval
- Participate to the Non Conformance review Boards
- Review the incoming construction analysis

PAD not signed = part not approved to be used

Topics to be discussed with the component manufacturer

The formal review of the manufacturer processes is the **PID review**.

But some items have to be discussed with the manufacturer in advance:

Design

- Space friendly materials
  - no pure tin,
  - low outgassing epoxies,
  - materials compatible with each others (corrosion)

Testing

- Test benches
- Pass / fail criteria
- Yield survey?

Manufacturing

- Batch size
- Bake materials prior use
- List of reworks and the repairs allowed
- Storage during manufacturing
- Traceability

Quality

- Incoming inspection? Criteria?
- Step subcontracted? How is this controlled?
- Qualification of operators
- Quality inspections vs “self control”

Procurement specification content: advices

The procurement specification will define all aspects of the component.

- Performances: spectral characteristics, noise, stability
- Design: chips, package, add-on, fibre if any, interface definition
- Operation: input/output power, operating temperatures, wavelength, modulation, consumption, etc **end of life**
- Environment: specify the lifetime, radiations levels, mechanical stress, thermal stress, humidity exposure on ground, and storage duration to assess the hermeticity
- Manufacturing: single batch approach for all sub parts, screening definition for chips, add-on, fibre, define the allowed reworks, low outgassing materials
- Testing: evaluation and qualification plan, test methods, screening definition,
- Quality and Product Assurance: focus on reliability and traceability, define the customers reviews as early as possible, the list of documents to be delivered, how the hardware is accepted for delivery, criteria for batch rejection

PAD

Table D-1: PAD sheet

PROJECT:..... Doc n°:..... Prepared by: .....
Issue:..... Date:.....

Approval requested by:.....
Family:..... Fcode [ ] Group:..... Gcode [ ]
Component Number:.....
Commercial Equivalent Designation:.....
Manufacturer/ Country:.....
Technology/Characteristics (value or range of values with tolerance, voltage, package etc): .....
Pure tin free (Y/N) [ ]
Generic specification:.....
Detail specification:..... Issue:..... Rev.:..... variant:.....
Specification amendment: ..... Issue:..... Rev.:..... variant:.....
Quality level:..... Procurement by:.....

APPROVAL STATUS

EPPL Part 1/2 listed (1/2/N) [ ]
ESCC QPL or EQML listed. (Y/N) [ ]
MIL QPL or QML listed (Y/N) [ ] If yes: QPL/QML Reference:.....
Other approvals/former usage .....
Evaluation programme required (Y/N) [ ]
If yes reference of the Evaluation Programme:.....

PROCUREMENT INSPECTIONS and TESTS

Precap (Y/N) [ ]
Lot acceptance:
ESCC LAT/LVT level or subgroup [ ]
MIL QCI/TCI group [ ]
Buy-off (Y/N) [ ]
DPA (Y/N) [ ] if yes: sample size .....

Complementary tests .....

RADIATION HARDNESS DATA

Radiation Hardness Assurance Plan applicable (Y/N)[ ]
Doc. Ref.: .....

Total Dose Effects:
Evaluation Test Data (report) reference: .....

Single Event Effects: SEL/SEU/SET/SEFI/SEB/SEGR/others: *(cross out when non applicable)*
Evaluation Test Data (report) reference: .....

RVT required (Y/N)[ ]

REMARKS

Approval customer ..... Date .....

Approval first-level supplier ..... Date .....

EEE Space product assurance

ECSS-Q-ST-60C Rev.2
21 October 2013

Space product assurance

Electrical, electronic and electromechanical (EEE) components

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

PA-QA support on photonics @esa

Thank you for your attention

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