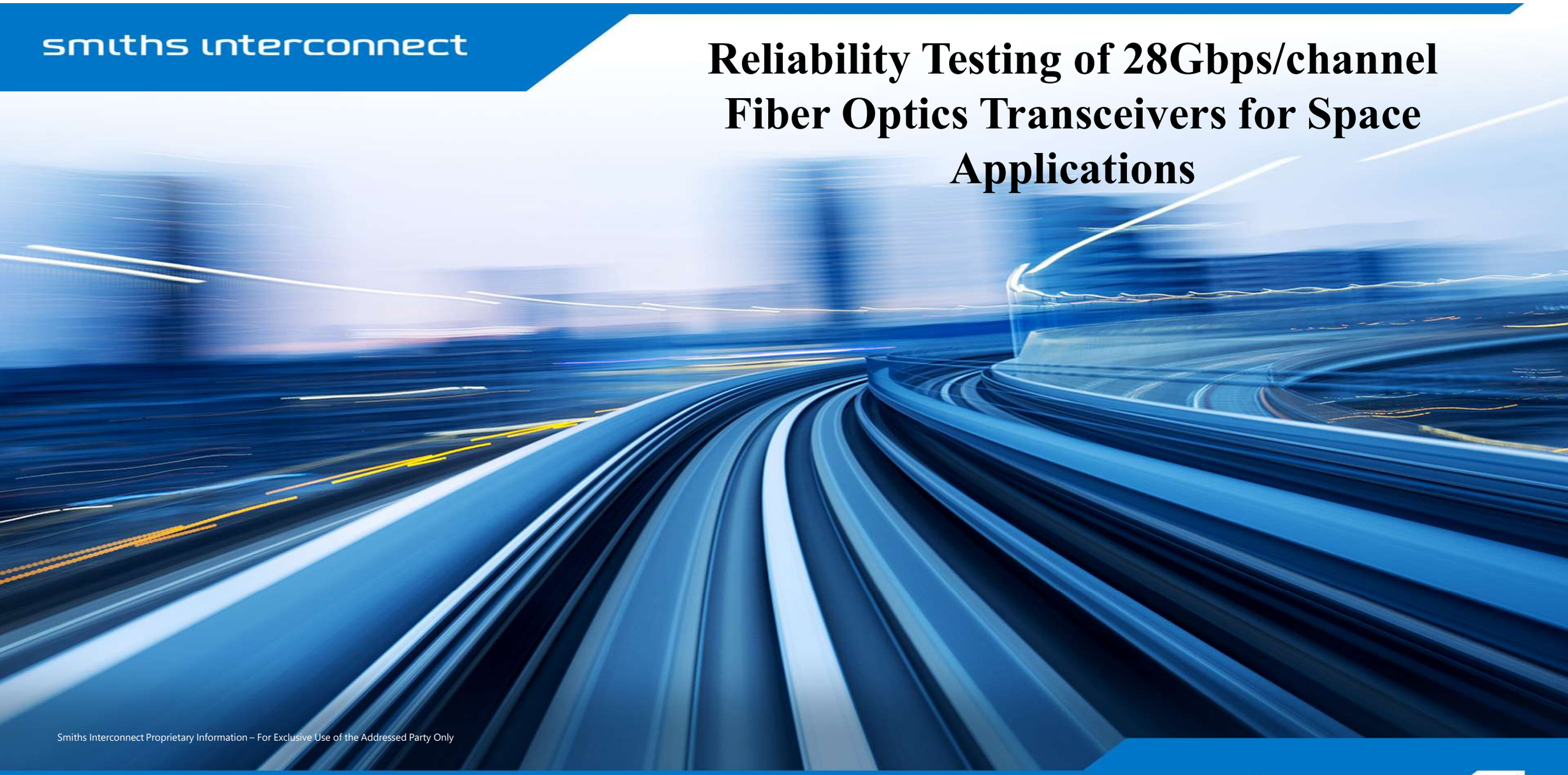
smiths interconnect

Reliability Testing of 28Gbps/channel Fiber Optics Transceivers for Space Applications



ESCCON 2023

Toulouse/March 7th, 2023

CUTTING-EDGE CONNECTIVITY

Agenda

- How optical modules can make a large volume of data processing possible through fiber optic cable?

Smiths Interconnect Multi-channel parallel optical modules

- Types of optical modules
- Functionality
- Physical characteristics
- Performance
- Compatibility

Space Qualification Tests Results

- **Radiation Tests**
  - Heavy ions
  - Total Ionization Dose (TID)
  - Total Non-ionization Dose (TNID))
- **Mechanical Integrity Tests**
  - Thermal Vacuum (TVAC)
  - Random vibration and mechanical shock
  - Damp Heat
  - Thermal Shock
  - Cold Storage
- **Environmental Tests**
  - Outgassing
  - Decompression

How optical modules can make data-intensive application possible through fiber optic cable?

Parallel multimode optical fiber communications offer the largest data processing capacity compared to any other technology:

- Higher data transfer rate
- Small size and lightweight
- Low power consumption
- Electro-Magnetic Interference (EMI) insensitive
- Best choice of technology for optical data communication

- Optical modules and optical data communications
- **Smith Interconnect manufactures high speed optical modules for space applications.**
  - 28Gbps
  - Up to 12 independent channels
  - Wide range of operating temperature
  - Lightweight (3.0g max)
  - Best for point-to-point data communication up to 100 meters
  - Can be use as mid-board or edge-board mounting configuration
  - Space ready technology
  - Radiation hardened

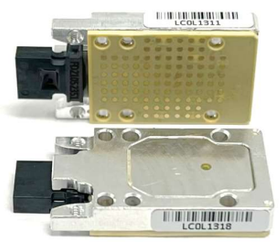
Types of Multi-channel Parallel Optical Modules

1. 12-channel Transmitters (12Tx)

Converting differential electrical input signals to multi-mode optical output signals

2. 12-channel Receivers (12Rx)

Converting multi-mode optical input signals to differential electrical output signals



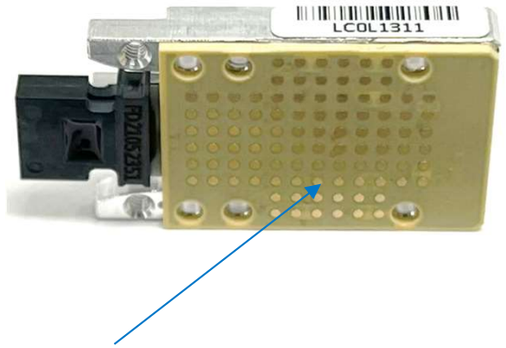
3. 4-channel Transceivers (4TRx)

4-channel transmit and 4-channel receive in the same packaging

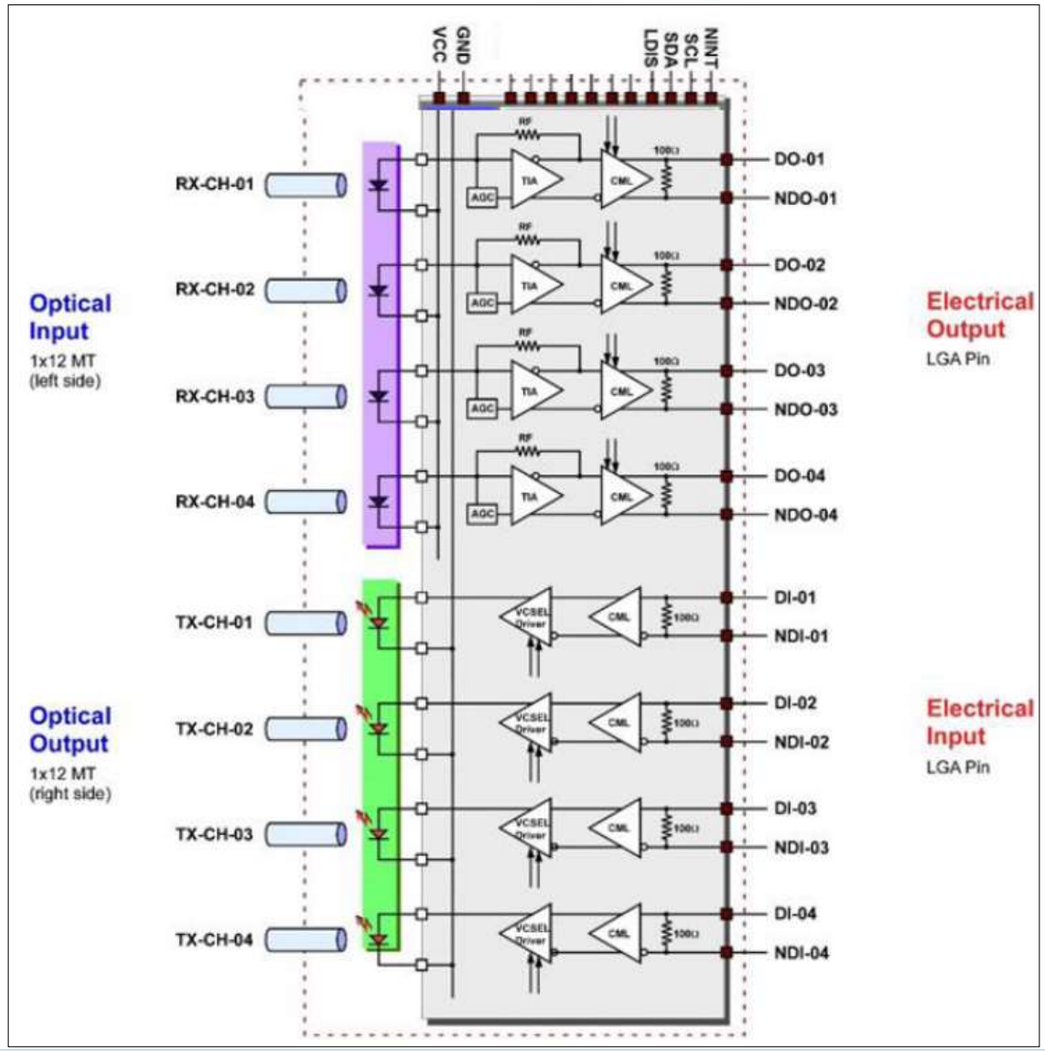
Converting differential electrical input signals to optical output signals and differential electrical input signals to optical output signals

Functionality

- **Signal converters**
- **28Gbps / channel**
- **4TRx is full-duplex**
- **12Tx and 12Rx are half-duplex**

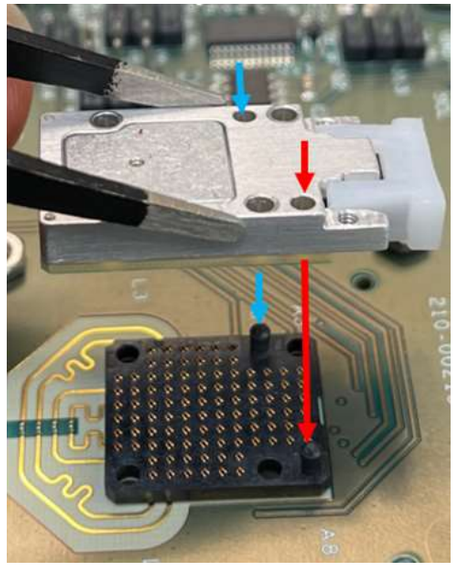


- **Electrical interfaces are 96-contact Land Grid Array (LGA) based on Common Mode Logic (CML)**
- **Optical interface is based on industry standard mechanically transferable (MT) type connector up to 12-channel with fiber graded-index of 50µm core and 125µm silica glass cladding diameter.**
- **Low power consumption: 0.314 watts per channel (12TX-12RX optical link)**



Physical characteristics

- 4TRx Module size: 28.38 x 14.1 x 4.40 mm
  - Plus the interposer height of 1.55 mm
- Weight: 3 grams
- 12Tx and 12Rx have almost the same dimensions and weight as the 4TRx modules.



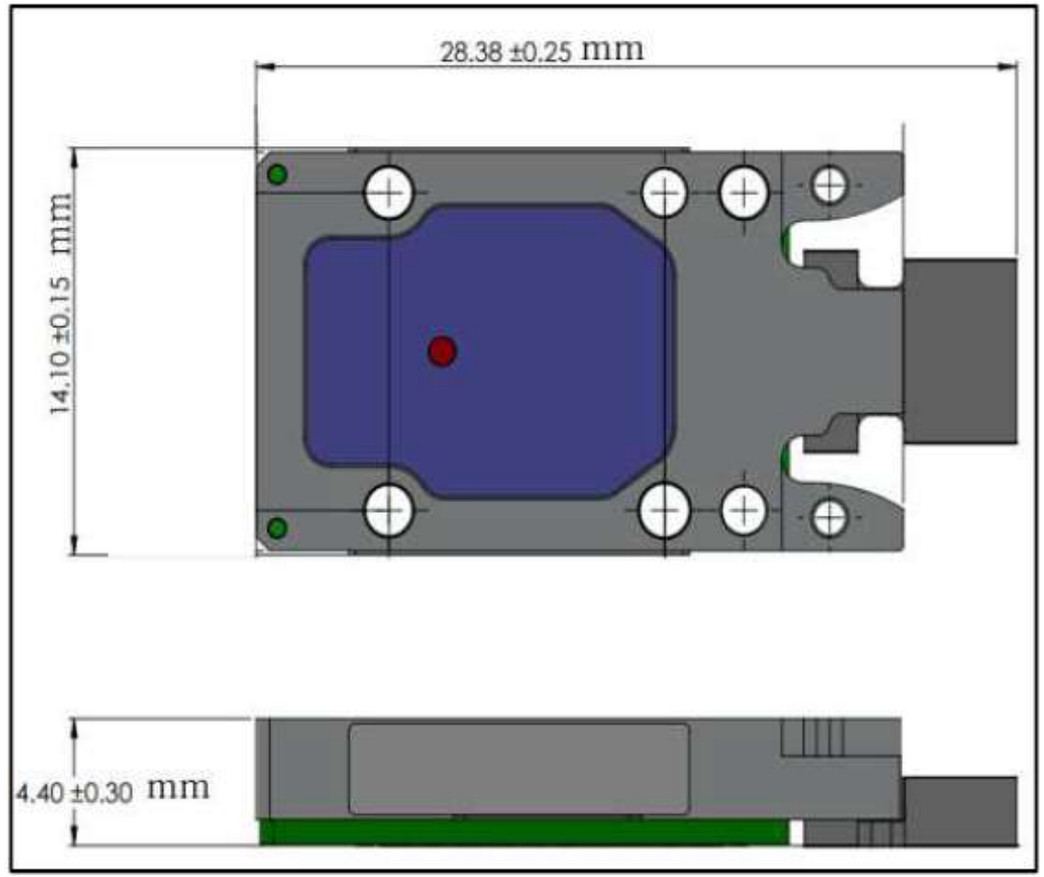


Fig. 4. Transceiver Dimensions

Performance

- **Table 1 presents the key specifications for 28G 12TX and 12RX optical performance.**

TABLE 1. Transceiver Optical Performance

Parameter	Min	Typ	Max	Unit
Bit rate	1	25.78125	28.05	Gbps
Link budget margin	7			dB
Transmitter				
Avg optical power (per channel) at 25°C	2			dBm
Extinction ratio		5		dB
Center wavelength	840	850	860	nm
Receiver				
Sensitivity (per channel) at 25°C for BER 1E-09	-5			dBm
Optical power saturation limit	10			dBm
Peak sensitivity wavelength	840	850	860	nm

Compatibility

The *Space*ABLE 28 optical modules features:

- Industry standard 1x12 (MT) optical interface
- Link distance up to 70 meters with OM3 and 100 meters with OM4 fibers
- 850nm wavelength multimode light emitted from a vertical-cavity surface-emitting laser (VCSEL)
- 12 differential CML inputs or outputs
- Asynchronous channel operation
- Mid-board and edge-board mount configurations

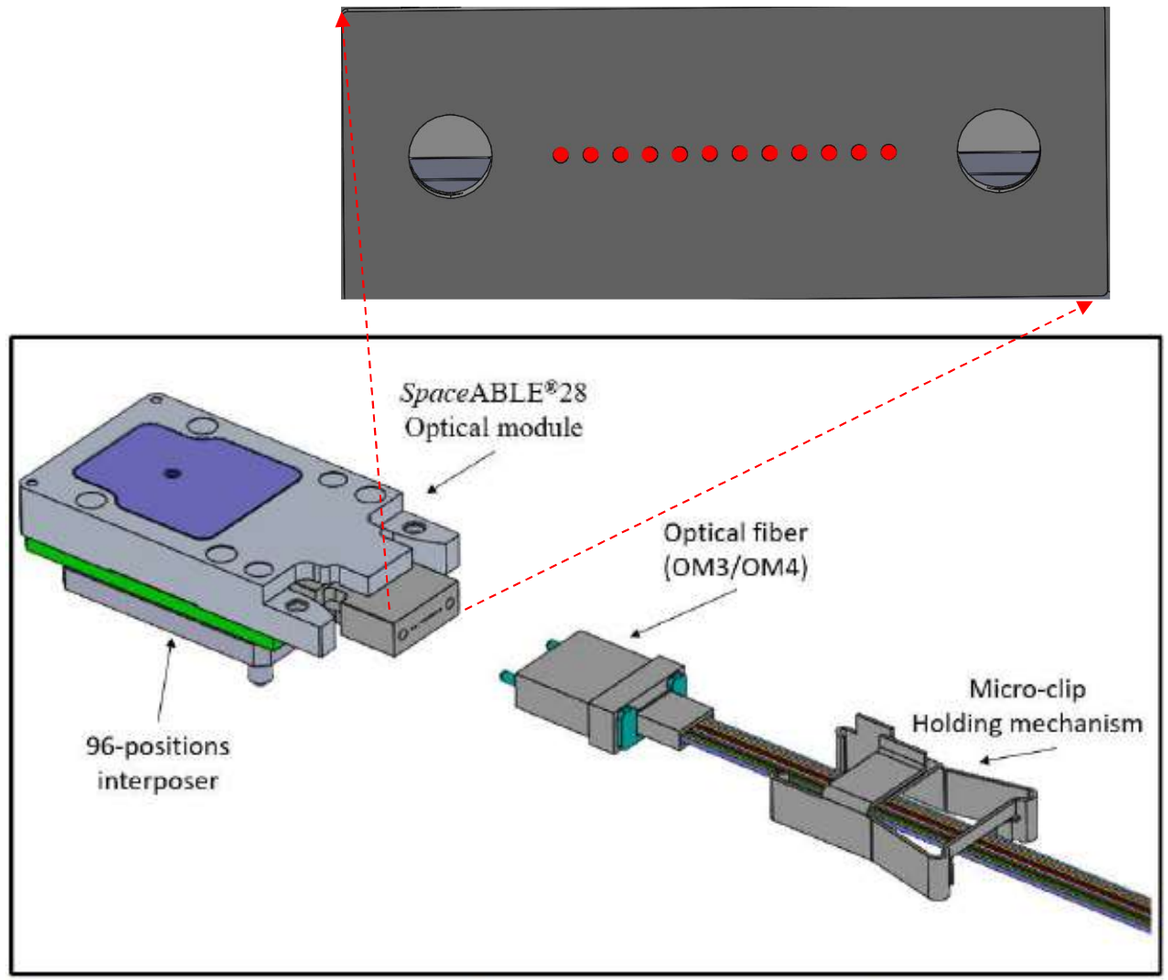


Fig. 3. Transceiver Optical Connection to Optical Fiber

Space Qualification Tests : Heavy Ion

Heavy ion radiation causes **Single Event Effects** (SEE) on microelectronics in the space environment which results in microcircuit to malfunction by inducing soft errors or complete burnout of the device. Optical must qualify for this space environment test.

Heavy ions radiation tests

Based on ECSS 25100; Issue (2)standard (2) and for real-time SEE measurement during heavy ions radiation.

Optical modules were tested live at +25C and +85C case temperatures with pseudo-random binary sequence bit pattern (PRBS-31) at 25.8715Gbps running through all channels.

Testing for three types of SEE

1. **SEFI** (Single Event Functional Interrupts): The device under radiation loses functionality and goes to reset mode.
2. **SEL** (Single Event Latch-up): This is when the device under radiation malfunctions by going under another high-current consumption state.
3. **SEU**: Single Event Upsets: The device under radiation is affected by heavy ions and causes soft errors in data communication.

Space Qualification Tests Results

(Heavy Ions Radiation continue …)

Power consumption of one optical module during heavy ions radiation

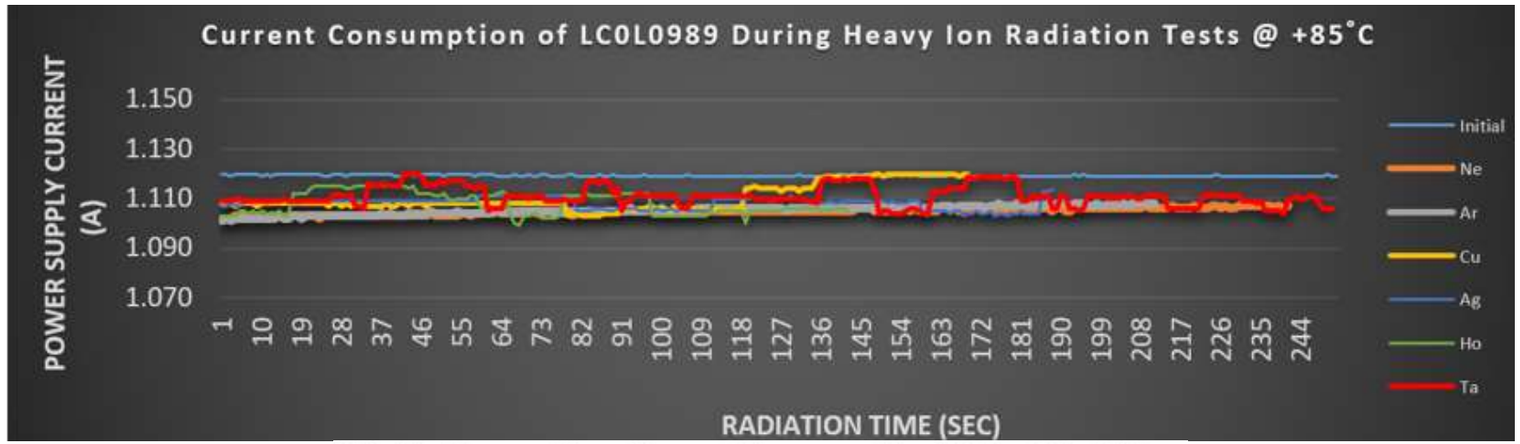


Fig. 7. Transceiver Power Consumption Under Radiation

Heavy Ions Radiation SEE Results

The SEU rate calculation is done using Petersen's Figure of Merit (FOM)

Product	SEL	SEFI	SEU Event/Day (LEO)	SEU Event/Day (GEO)
12Tx	No SEL	No SEFI	2.66E-3	2.13E-2
12Rx	No SEL	No SEFI	1.89E-1	1.52
4TRx	No SEL	No SEFI	7.75E-2	9.65E-3

Heavy Ions Radiation Tests Results

Table 6 represent typical example of SpaceAble 28G product's BER live monitoring under radiation by heavy Ions BER.

- BER is real-time error acquisition during all selected heavy ions.
- BER of channel 1 and 4 increased gradually for every ion.
- BER of channel 2 and 4 spike during BER logging which is an indication a burst of errors caused by radiation, but the DUT fully recovered within 1 second.
- None of the DUT exhibited SEL. All of the devices under radiation remained fully functional and had very stable power consumption (Table 7)

Calculation of SEU rate is based on Petersen's Figure of Merit (FOM) using Devices 4TRx, 12Tx, 12Rx shielded (200Mils) and unshielded (100Mils)

Results

- 4TRx SEU rates (unshielded) on GEO and LEO are 28.3 and 3.52 events per year respectively
- 12Tx SEU rates (unshielded) on GEO and LEO orbits are 0.97 and 7.79 event per year respectively
- 12Rx SEU rates (unshielded) on GEO and LEO orbits are 6.9 and 554 per year respectively

TID & TNID Results

TID

Total Ionization Dose (TID) test **from Cobalt-60 gamma ray radiation** are to emulate the presence and the impact of such radiation on high–speed opto-electronics circuits when used for space applications including intra-satellite communications.

- Tests based on ESCC22900 Issue 5 Standard
- Eight units are prepared for TID radiation four biased and four unbiased while exposed to radiation.
- Both biased and unbiased units results in errors in some channels after first step of radiation, but the error cleared after annealing.
- Increase number of errors shows the affect of total ionization of irradiation on optical modules and proving the units survived Cobald-60 irradiation without any permanent damage.

TNID

The purpose of Total Non-Ionization Dose (TNID) radiation test **is to confirm the radiation hardness level in a proton** radiation environment. TNID radiation tests are needed to emulate the presence and impact of such radiation on high-speed opto-electronics circuits when used for space applications and intra-satellite communications.

- All DUTs are tested before and after TNID radiation as initial and final tests.
- According to the data , all units DUTs have passed the performance test and total non-ionization dose test without any permanent damage or performance degradation.

Environmental Test Results

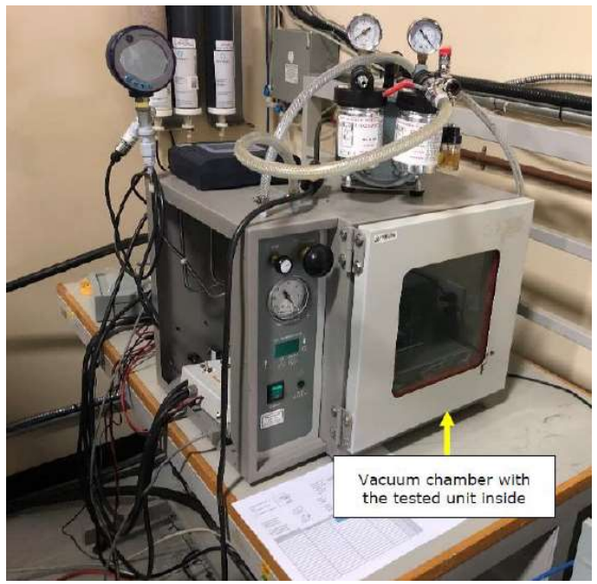
Outgassing

- **Standard: ECSS-Q-ST-70-02C**
- **Recovered Mass Loss (RML) < 1.00%**
- **Collected Volatile Condensable Material (CVCM) < 0.10%.**

1X	1.55 mm 96pos 13743 Interposer			3X	SLX04P528532102			3X	SLT12P928533002		
	TML %	RML %	CVCM %		TML %	RML %	CVCM %		TML %	RML %	CVCM %
Cup 1	0.077	0.052	0.002	Cup 1	0.215	0.189	0.031	Cup 1	0.158	0.124	0.029
Cup 2	0.073	0.052	0.003	Cup 2	0.206	0.179	0.044	Cup 2	0.136	0.094	0.018
Cup 3	0.064	0.051	IR plate	Cup 3	0.204	0.177	IR plate	Cup 3	0.123	0.085	IR plate
Average	**0.071**	**0.052**	**0.002**	**Average**	**0.208**	**0.182**	**0.038**	**Average**	**0.139**	**0.101**	**0.024**
Passing Limits	Not defined	< 1.00	<0.10	**Passing Limits**	Not defined	< 1.00	<0.10	**Passing Limits**	Not defined	< 1.00	<0.10

Decompression

Standard: MIL-STD-810G, method 500.5 and test condition III (simulation of going from 8000 to 52000ft in less than 15 seconds).



Thermal Vacuum (TVAC) Test

- **Vacuum less than $5x10^{-5}$hPa**
- **20 temperature cycles from -40°C to 85°C with +/-5°C precision.**
- **5 minutes of dwell time.**
- **Temperature ramp rate of 3°C/min**
- **Live Bit Error Rate (BER) monitoring.**

- **PASSING with BER better than E-12**

Figure 11. TVAC Testing Chamber and Test Station

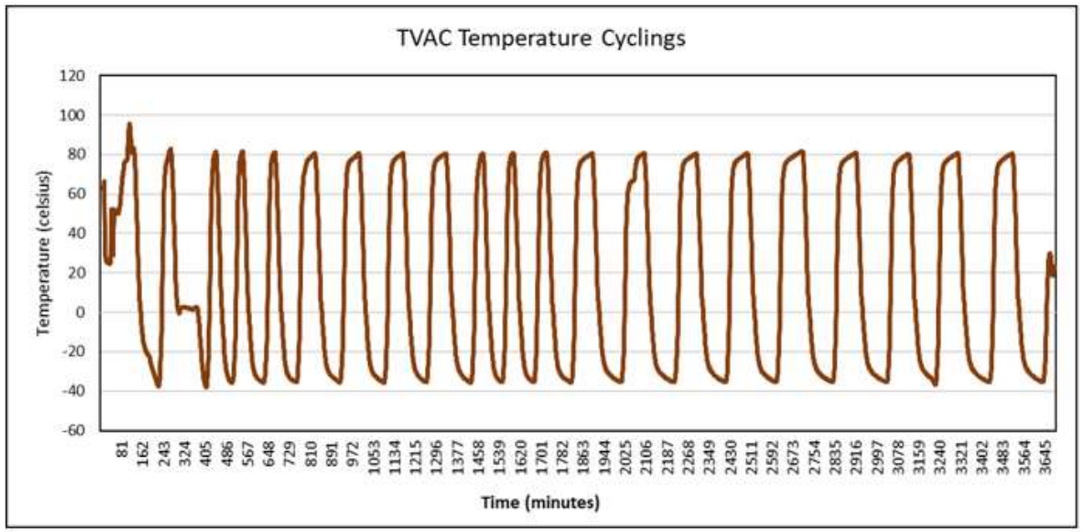


Fig. 13. TVAC Temperature Cycling

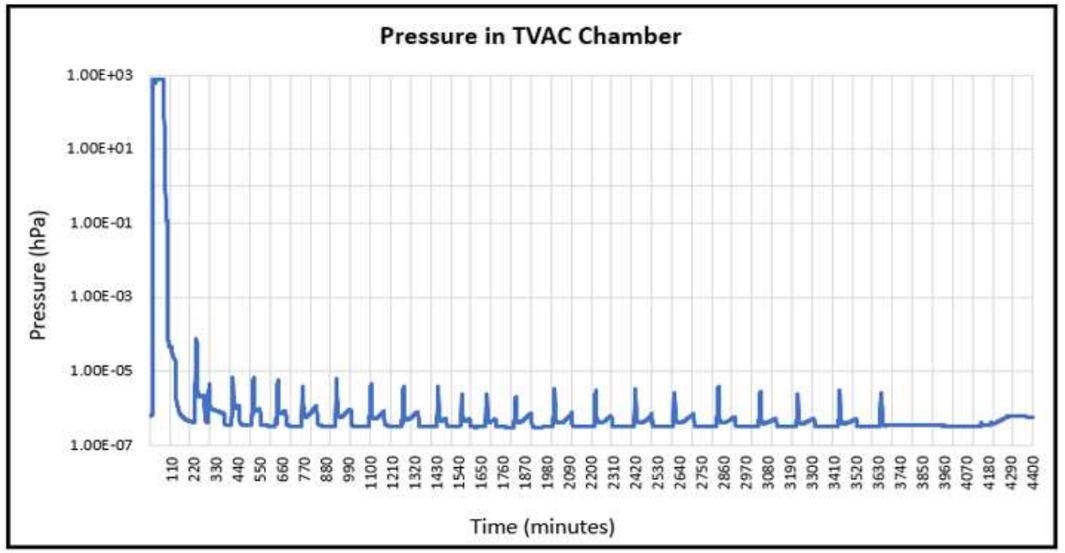


Fig. 12. Vacuum Pressure of TVAC Test

Random vibration and mechanical shock test results (Setups)

The random vibration testing was done in accordance with MIL-STD-883, TM 2007 12 with **28.4 Grms** perpendicular and **27.1 Grms** parallel accelerations.

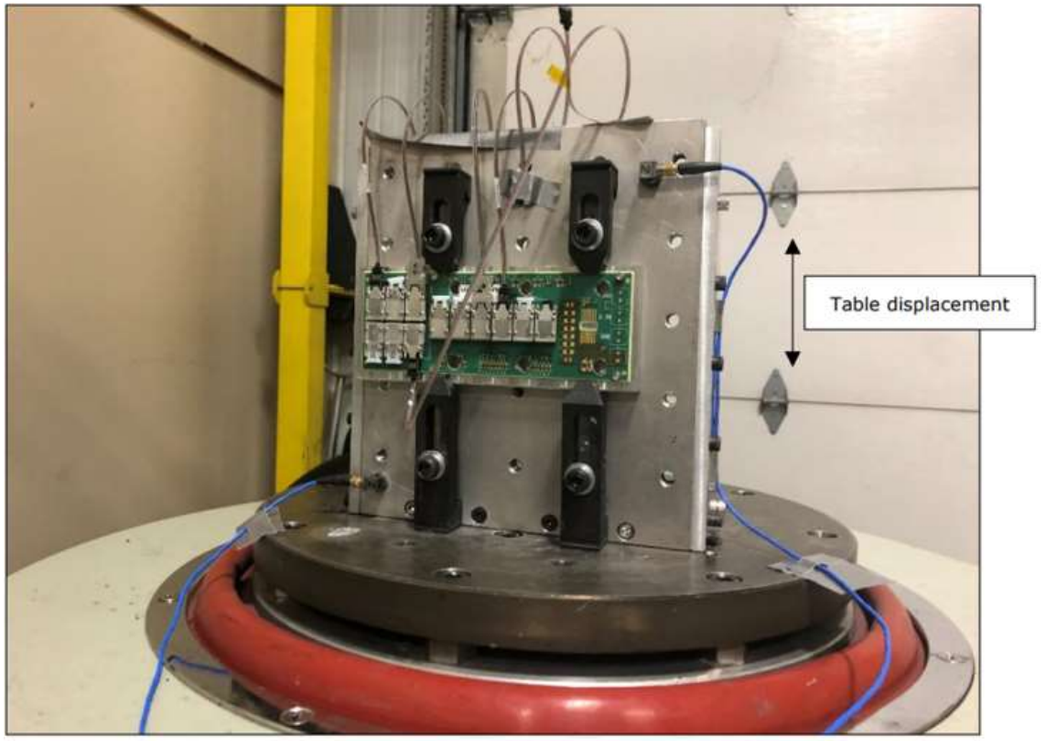


Fig. 14. Random Vibration Test Setup

The mechanical shock testing was done in accordance with MIL-STD-883 TM 2002 with **1500g** acceleration, **0.5ms** pulse width half-sine on all directions.

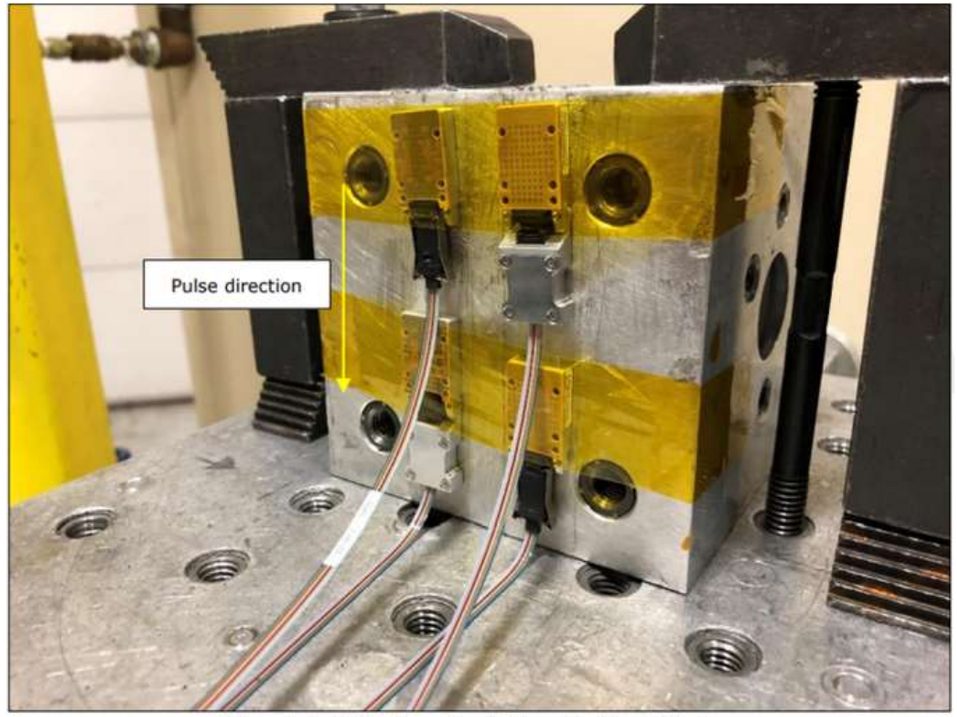


Fig. 15. Mechanical Shock Test Setup

Random vibration and mechanical shock test results: (Electro-Optical Performance Results)

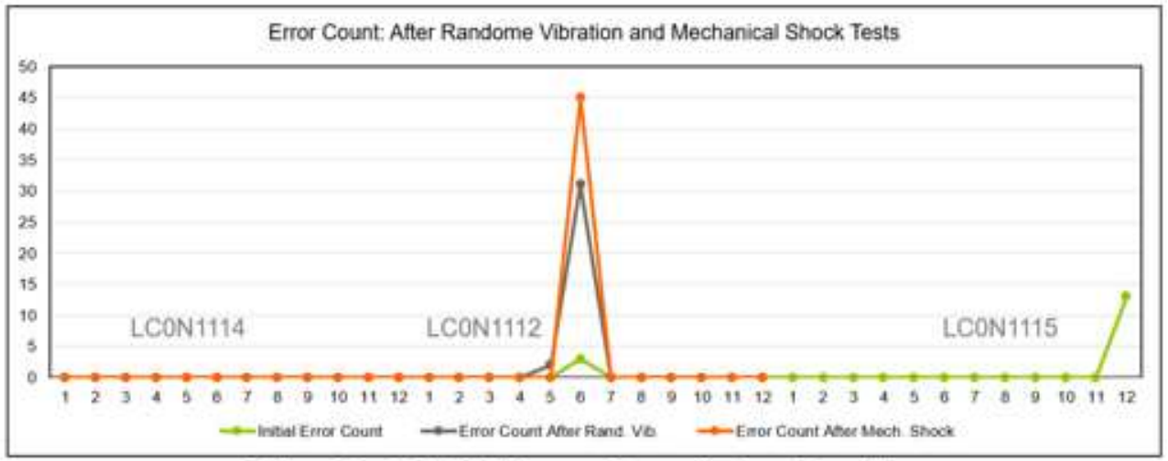


Fig. 18. 12RX Error Count Test Results

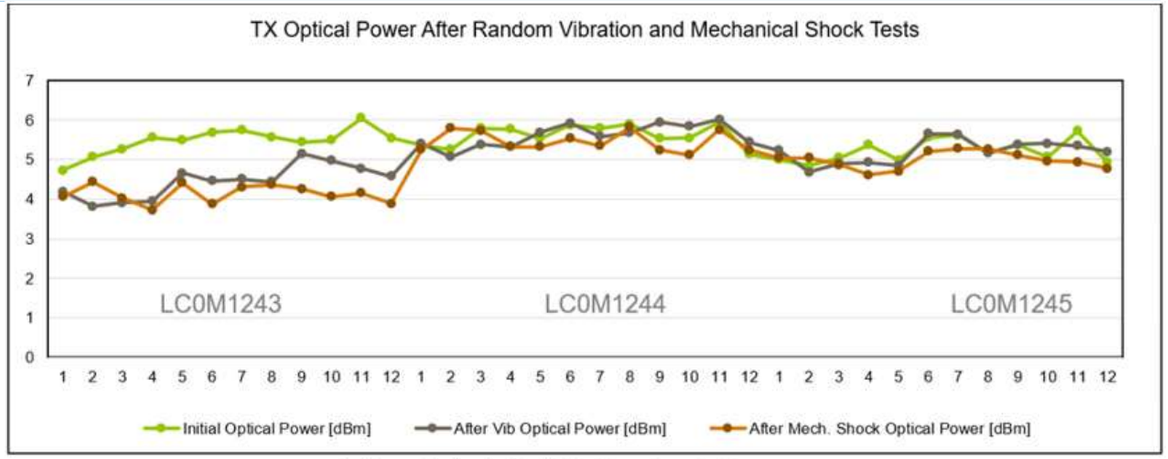


Fig. 16. 12TX Optical Power

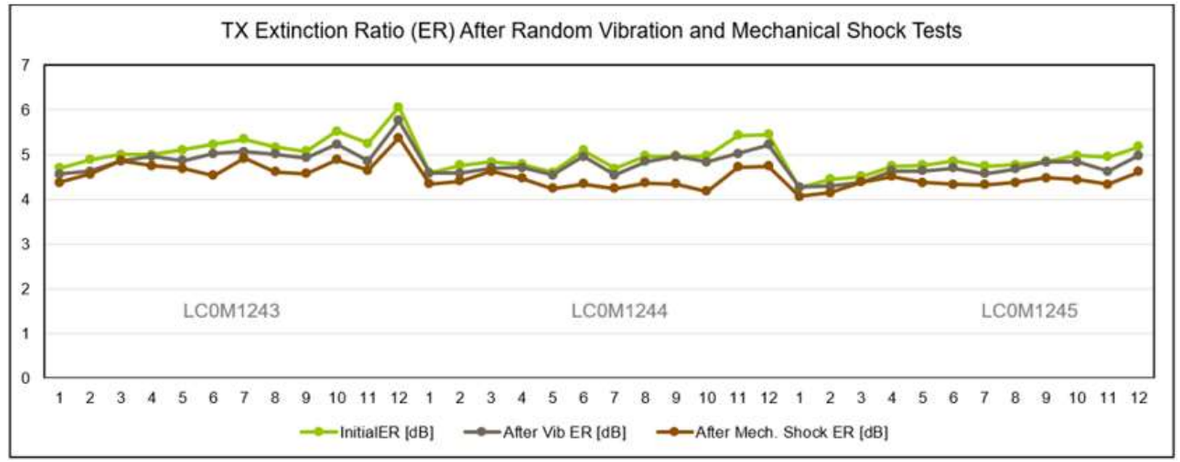


Fig. 17. 12TX Extinction Ratio

No significant performance degradation after random vibration and mechanical shock tests

1000 Thermal Cycling

- **Test Protocol:**

- Ref. Standard: **MIL-883K, Method 1010.9**
- Low Temp: -40 ±3°C
- High Temp: +85 ±3°C
- Ramp rate: 10°C/min (minimum)
- Number of cycles: 1000

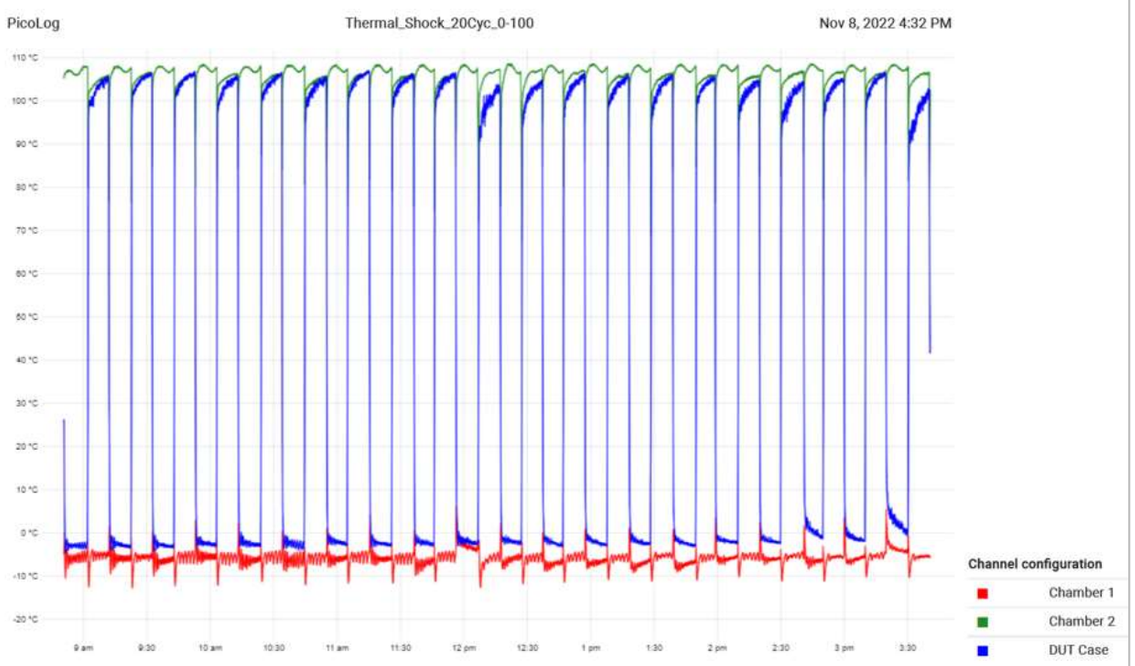
- Overall, the average optical power (AOP) degraded by **0.08** dB after 1000 temperature cycling.
- Worst AOP increase was measured at **1.22** dB on channel 11 of LC0M3237

- On average, the Extinction Ratio (ER) value is dropped by **0.03** dB after 1000 temperature cycling.
- Worst ER drop was measured at **0.58** dB on channel 2 of LC0M3237

Thermal Shock and Cold Storage

Thermal Shock

Number of cycles	20
Temperature	0°C to 100°C
Dwell time	10 minutes
Transient time	< 5 seconds



Cold Storage

- **Standard**: MIL-STD-810G, Method 502.5
- **Temperature**: -57°C
- **Duration**: 168 hours
- **Ramp Rate**: 1C/min

Damp Heat

- **Standard**: MIL-STD-202G, Method 103
- **Temperature**: +85°C
- **Relative Humidity:** +85°C
- **Duration**: 500 hours

Conclusion

- SINT is the leading manufacturer of embedded high-speed transceivers (10G-28G) for harsh environment including military and space markets (radiation hardened).
- The parts **are available as Commercial Off-the-Shelf (COTS) product**.
- Optical communication through fiber optic for **intra-satellite applications** is an absolute requirement.
- Space qualified optical modules using parallel optics over OM3/OM4 multimode fiber provides **the best data transfer service for space optical communication.**
- The space qualified optical modules offer the best performance for any mid-board or edge-board mount configuration and pass both **radiation and environmental** qualification tests.
- First generation of transceivers (10Gbps) are now in service install on GEO (20 years mission) satellites for very high throughput (VHTS) application.
- Reliability tests for SpaceAble 28G 4TRx 12Tx-12Rx have been successfully completed and report (STP2) will be available to our clients.
- In parallel, new generation of satellites are being build by leading vendors based on SpaceAble transceivers (10G & 28G) on board (GEO and LEO missions).

Q&A

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