VLS "New Space" encoders – rugged, high-performance technology for the modern commercial space industry

Introduction

In the early decades of space operations, components used in launch systems and payloads were held to strict specifications developed by the European Space Agency (ESA), the military, and NASA. Meeting requirements often involved high levels of customization, high costs, and long lead times. For the large government agencies, military organizations, and defense contractors that dominated the market, this wasn't a problem. With limited launch schedules and large budgets, they made the economics work.

Today, things have changed. The past decade has seen the emergence of a thriving commercial space industry. Launch frequencies in this new space economy have skyrocketed – 2004 saw 54 orbital launches, while 2023 saw nearly 130 orbital launches in the commercial sector, alone. At the end of 2023, there were over 8000 satellites in orbit. Schedules are tight and budgets are tighter, which means that the old space model for components no longer works. The players in the new space industry need a more efficient approach.

Instead of highly customized devices, the solution is to use quality commercial off-the-shelf (COTS) components capable of operating reliably in low Earth orbit (LEO). Netzer's new VLS family of space-qualified encoders provides a perfect example of this new design and procurement model. Our VLS encoders are high-performance, compact, robust feedback devices built to survive the toughest industrial environments – now modified for space applications. They're economical, and available direct from our factory in volume and with minimal lead-times. VLS encoders – feedback for new space applications.

The challenges of the space environment

The space environment presents a host of challenges. Although competition has driven down pricing, the cost of launching mass into orbit is still several thousand dollars per kilogram. Space components need to minimize size and weight. They should also be designed to control outgassing, because this can contaminate sensitive surfaces such as optics, detectors, and solar arrays. They should minimize power consumption. Above all, they must be reliable – maintenance in orbit is impossible.

The requirement for reliability is part of why early space components were so expensive and over specified. The punishment begins with launch, which exposes components to high levels of shock and vibration for extended durations. If the application is not temperature controlled, devices must survive extreme temperature variations. But the biggest issue is radiation, particularly above the Earth's atmosphere. The high levels of radiation present even in LEO can damage hardware and induce software errors, so radiation tolerance is essential.

For purposes of testing and specifications, this exposure to energetic particles can be classed as follows:

- Continuous radiation exposure: an ongoing stream of protons and electrons from the solar wind and cosmic background radiation
- Single event effects (SEEs): damage from exposure to a single highly energetic particle

Components intended for orbital payloads or reusable launch systems must survive this bombardment for extended periods of time without any reduction of performance or operational failure.

Netzer's VLS family of space-qualified encoders

The VLS family of space-qualified capacitive encoders consists of absolute rotary encoders ready to meet the requirements of the space environment.

- High-performance: VLS encoders deliver high-resolution digital or analog output with angular resolutions as high as 21 bits and accuracies as good as ±0.001°.
- Lightweight and compact
- Robust: VLS capacitive encoders are hollow floating-shaft devices with no bearings or other contacts. They meet the MIL-STD-810F specification for vibration and have been tested to shock loads of up to 100g for 10 ms.
- Space qualified: Rated to withstand orbital radiation conditions, as well as high EMI, RFI, and magnetic fields
- Temperature insensitive: Able to tolerate extreme thermal swings
- Vacuum compatible: Specialty coatings minimize outgassing for vacuum levels of10^{-5} torr
- Economical: Because VLS encoders are modified COTS devices, they are available at a much more reasonable cost than traditional purpose-built space-qualified encoders. Most systems require multiple encoders, making this cost difference a significant benefit.
- Available: VLS encoders are based on modified COTS designs, so we can provide them in high volume and with rapid turnaround.

It's not enough to just state benefits, however. VLS encoders have undergone rigorous testing to prove their characteristics.

Proof of performance

Because components are exposed to two separate types of radiation in orbit, testing took place at two different facilities, governed by different protocols.

Continuous exposure testing

We started by evaluating the performance of the encoders in the presence of continuous radiation at the ESA's European Space Research and Technology Centre (ESTEC; Noordwijk, the Netherlands). The devices were tested per ESCC 22900 and ESA procedure TEC-QEC/PR001, using ESTEC's Cobalt-60 (Co-60) gamma ray source.

The testing involved four encoders, plus an additional reference encoder that was not irradiated. The procedure called for an initial functional test to establish a pre-radiation baseline, then four separate exposures to increase total dose. Functional testing was performed after each exposure, and the total integrated doses (TIDs) and total accumulated TIDs recorded (see Figure 1).

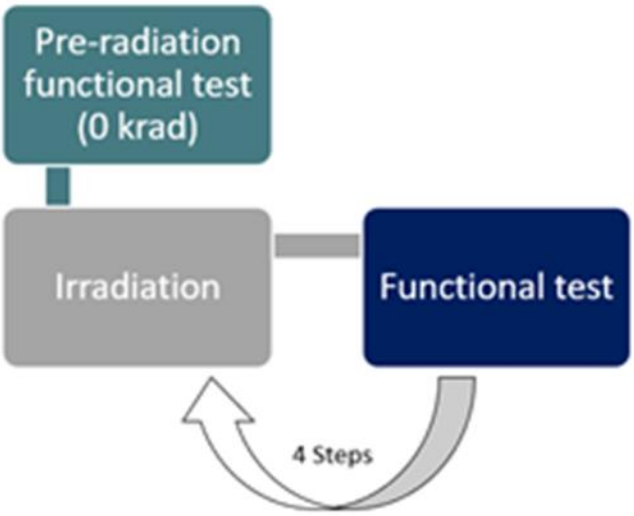

Figure 1 Flow diagram of test procedure

Test set up and irradiation

Per specification, the DUTs were mounted on a Plexiglas holding fixture, along with a dosimeter (see Figure 2).

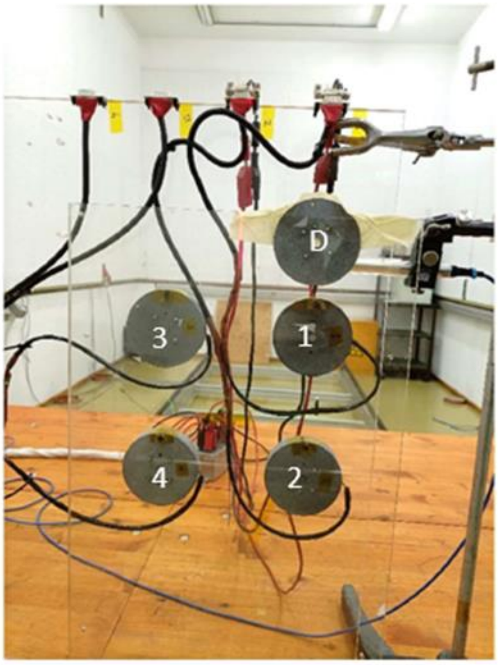

Figure 2 The encoders mounted on the holding fixture, seen from the front; "D" represents the dosimeter

The fixture was mounted on a table in the radiation chamber. Rails on the floor enabled the distance between table and Co-60 source to be adjusted to achieve the desired dosage (see Figure 3).

Figure 3 Set up inside the irradiation chamber showing the Co-60 source and devices under test; the rails on the floor enable the holding fixture to be positioned for the desired radiation levels

The tests involved two encoders that were biased at 5 V with a 100-mA limit, and two devices that were unbiased (see Figure 4). As previously mentioned, an additional reference device was left outside the irradiation chamber and unexposed.

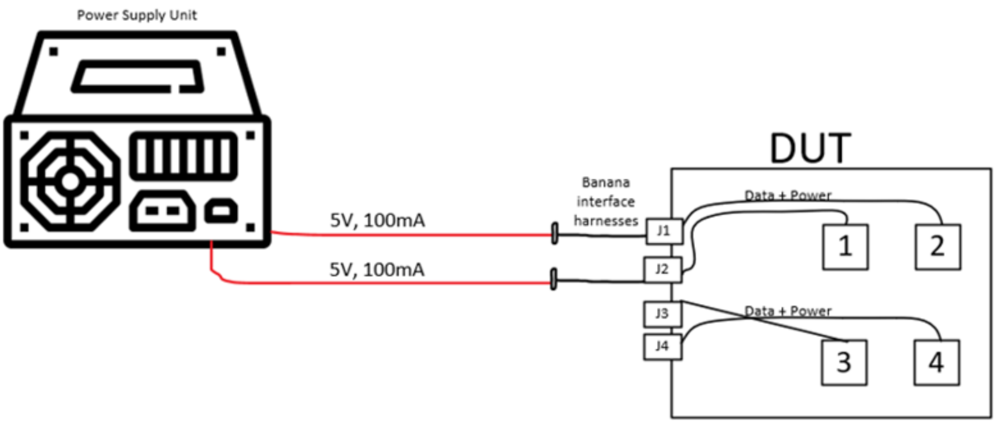

Figure 4 Wiring scheme for DUT irradiation powering

After baseline functional testing, the units underwent four separate exposure periods, as noted in Table 1.

Table 1: Conditions of irradiation for test

Irradiation Step	Start Date	Finish Date	TID (krad)	Dose Rate (rad/h)	Accumulated TID (krad)
1	2/5/2023 15:16	3/5/2023 11:29	6.69	331	6.69
2	3/5/2023 12:38	4/5/2023 10:36	7.283	331.4	13.973
3	4/5/2023 12:06	5/5/2023 13:03	8.308	333	22.281
4	5/5/2023 13:42	8/5/2023 9:00	22.29	331.3	44.571

Functional testing

For functional testing, each encoder was connected to a Netzer NanoMic interface unit in operational mode (20-bit resolution, SSi protocol). The unit sends a bitstream to the oscilloscope in RS-422 format (see Figure 5).

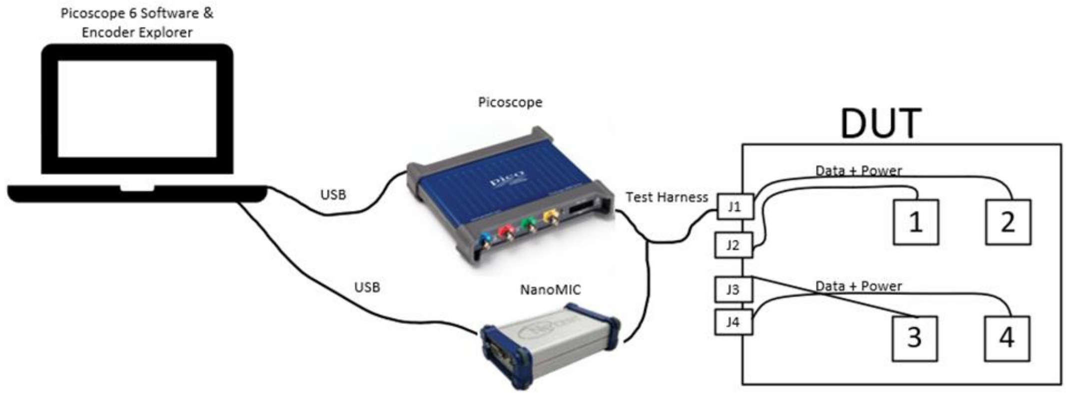

Figure 5 Wiring set up for functional testing

The following data was captured at baseline for each encoder, and then again after each irradiation step. For comparison, the reference encoder was also evaluated.

Parameters evaluated:

- Scope fine sine (mV)
- Scope fine cos (mV)
- Radius (mV)
- Offset sine fine (mV)

- Offset fine cos (mV)
- Offset coarse sine (mV)
- Offset coarse cos (mV)
- Electric angle
- Jitter max (counts)
- Jitter min (counts)
- Jitter counts (counts)

Netzer's Electric Encoder Explorer V6.0 software is used to analyze the data for variations in slope, voltage levels, noise, etc.

Continuous exposure testing results

The analysis shows that all encoders maintain functionality throughout the full irradiation cycle, with no observable degradation or anomalies in angle output or communication (see Figure 6). The slope rate, voltage levels and noise are consistent across all tests, before and after irradiation.

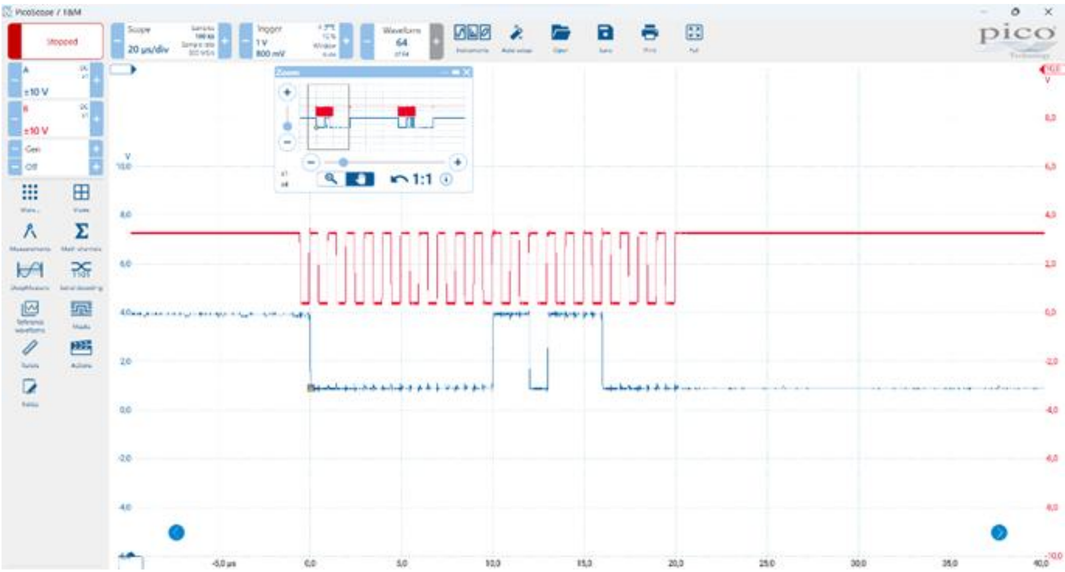

Figure 6 Encoder 1, 22.281 krad, RS422 Traces (red: clock+, blue: data+)

Single event effect (SEE) testing

SEE testing (testing tolerance of highly energetic single particles) took place at the Paul-Scherrer Institute (PSI; Villingen, Switzerland). The task was to evaluate the performance of the encoders.

Test set up and irradiation

In keeping with the new-space philosophy, the tests followed the proton board-level test method (PBTM).[1] The encoders were mounted on a plywood holding fixture with the boards exposed (see Figure 7).

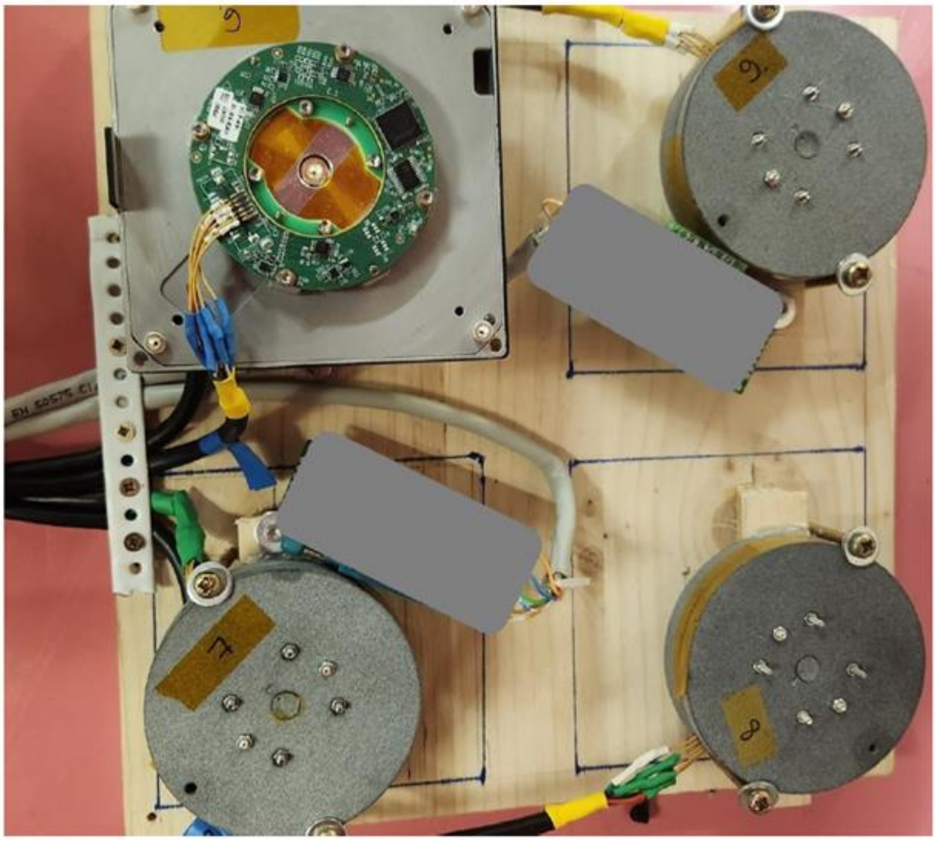

Figure 7 The wooden holding fixture for encoders, 6, 7, 8, and 9; the blue squares represent the irradiation area for each DUT.

The proton beam was set at a constant flux of 9.5E7 protons/cm²/s, which scales linearly with time to yield an equivalent effective dose. The board-encoders on the holding fixture were exposed serially to a 200 MeV proton stream (see Figure 8).

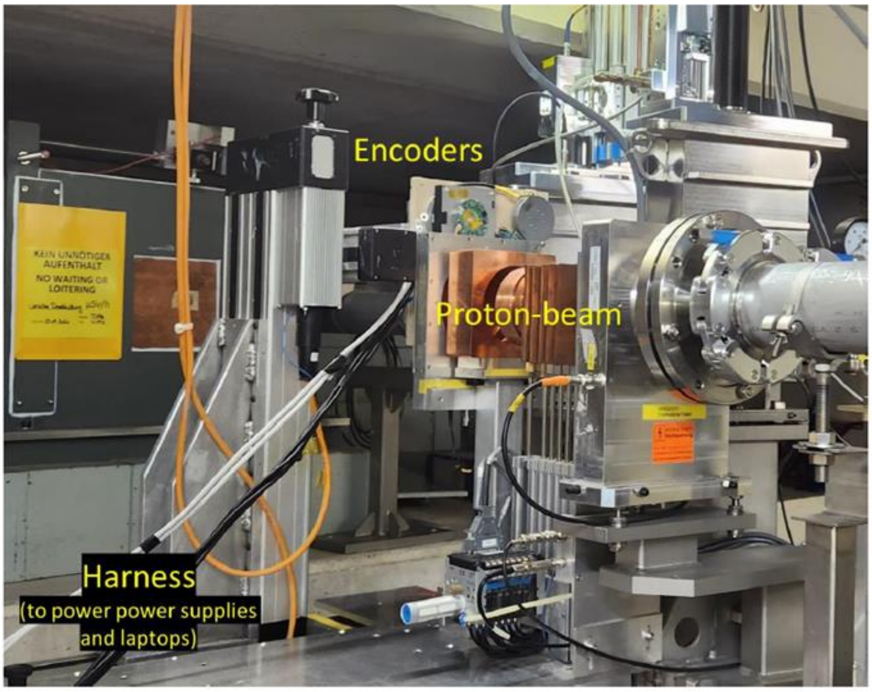

Figure 8 Proton beam SEE irradiation set up

Exposure times were set to 1066 seconds (approximately 18 minutes), equating to a total dose of approximately 5 krad (see Table 2). By the end of the irradiation session, each DUT had been exposed to a proton flux of 1E8 p/cm²/s and a proton fluence of 1E11 p/cm².

Table 2: Proton beam irradiation process

Irradiation step	Device under test	Start time	Stop time
1	Encoder 6	20:32	20:50
2	Encoder 7	21:03	21:21
3	Encoder 8	21:34	21:52
4	Encoder 9	22:08	22:26

SEE testing analysis

Assuming bombardment by a stream of 200 MeV protons with a fluence of 1E10p/cm², we can express the mean time between failures (MTBF) caused by proton-induced SEEs as:

$$MTBF\ in\ days = \frac{1800}{N} \quad [1]$$

where N is the number of SEEs normalized to the fluence 1E10p/cm².

Equation 1 uses the standard value for proton fluence. To provide a more conservative result, this testing used a fluence of 1E11p/cm². Increasing the fluence by an order of magnitude has two implications. First, the exposure time for the test could be reduced from 18 minutes to 1.8 minutes. Second, if the exposure duration remains 18 minutes, then the total counts "*N*" of SEE should be divided by 10.

We can use equation 1 and test data to determine the number of SEE-free days for the DUTs:

$$Number\ of\ SEE - free\ days = \frac{1800}{N} \times \frac{T_{SEE}}{T_e} \quad [2]$$

where T_{SEE} is the duration between events and T_e is the scaled test duration.

SEE test results

The proton-induced irradiation dose did not cause any permanent damage to any of the DUTs. None of the encoders were damaged, even after exposure to a fluence of 1E11p/cm² at 200 MeV. After analysis of the data on all devices, the test team concluded that Netzer VLS encoders are good candidates for LEO and medium Earth orbit (MEO) applications of up to 10 years.

Conclusions

Netzer's VLS family of space-qualified encoders delivers performance competitive with traditional space-qualified encoders at a fraction of the price. Netzer VLS encoders have undergone continuous exposure and SEE testing by independent laboratories to ESA standards. Despite the potentially destructive nature of these tests, the encoders still functioned normally at the end of radiation exposure. The test teams concluded that VLS encoders are radiation tolerant enough to survive up to 10 years in LEO/MEO. Note that the current results applied to the particular devices used in the tests. Although those devices can be considered representative samples, durability can vary slightly from batch to batch. To maximize confidence levels, customers may choose to perform tests on a "component production lot" basis.

Netzer VLS encoders offer other characteristics that make them ideally suited for space applications. They're built to survive the harshest environments, with extreme temperatures and high shock and vibration. They provide absolute feedback in a compact, lightweight form factor. Best of all, they're economical and available in volume, and with short lead times.

The new space industry needs a commercial encoder that can do the job – Netzer's VLS family of space-qualified encoders provides verified performance at a budget-friendly price.

Join the other commercial space organizations who trust Netzer with their feedback needs. Reach out to our application engineers and find out how VLS encoders can help make your next project a success.

contactus@netzerprecision.com

References

1. Board Level Proton Testing Book of Knowledge for NASA Electronic Parts and Packaging Program

Further reading

Space – Netzer Precision Position Sensors