Recent Improvements in Very Broadband Seismometer Self-Noise Performance Embodied in the New Trillium 360 GSN Instruments

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ABSTRACT

Nanometrics new Trillium 360 GSN seismometer embodies the culmination of many years of research and technology innovation as well as extensive collaboration with and input from the scientific community interested in very broadband seismometry. Several generations of seismometers with 240 or 360 second corner frequency have demonstrated successive improvements in self-noise at both very low and high frequencies. The most recent development has produced the lowest self-noise of any vault seismometer, and is the only seismometer currently being manufactured that meets the performance requirements of a primary seismometer for the Global Seismographic Network.

Posthole, Borehole and Vault form factors are available and being manufactured and delivered to the GSN. Performance testing of several units of each model type has been carried out at the facilities of GSN participating member institutions to qualify it as a suitable replacement for the STS-1. Field deployment is now proceeding, to upgrade the GSN network with Trillium 360 GSN seismometers.

Here the results of the performance testing are reviewed, interpreted, and compared with other co-located instrument types including the venerable STS-1. We also present the Trillium 360 roadmap, with a smaller low-power version for ocean bottom and portable land deployments in development for 2022.

SPECIFICATIONS

Trillium 360 GSN is able to resolve minimum Earth noise as represented by the Peterson New Low Noise Model at all frequencies as shown in the specification below and supported by test results at multiple sites.

The same sensor technology is available in vault, posthole, and borehole form factors as shown at right. All versions come equipped with a magnetic shield (internal for Vault, external for Posthole and Borehole) that reduces magnetic sensitivity by a factor of 100.

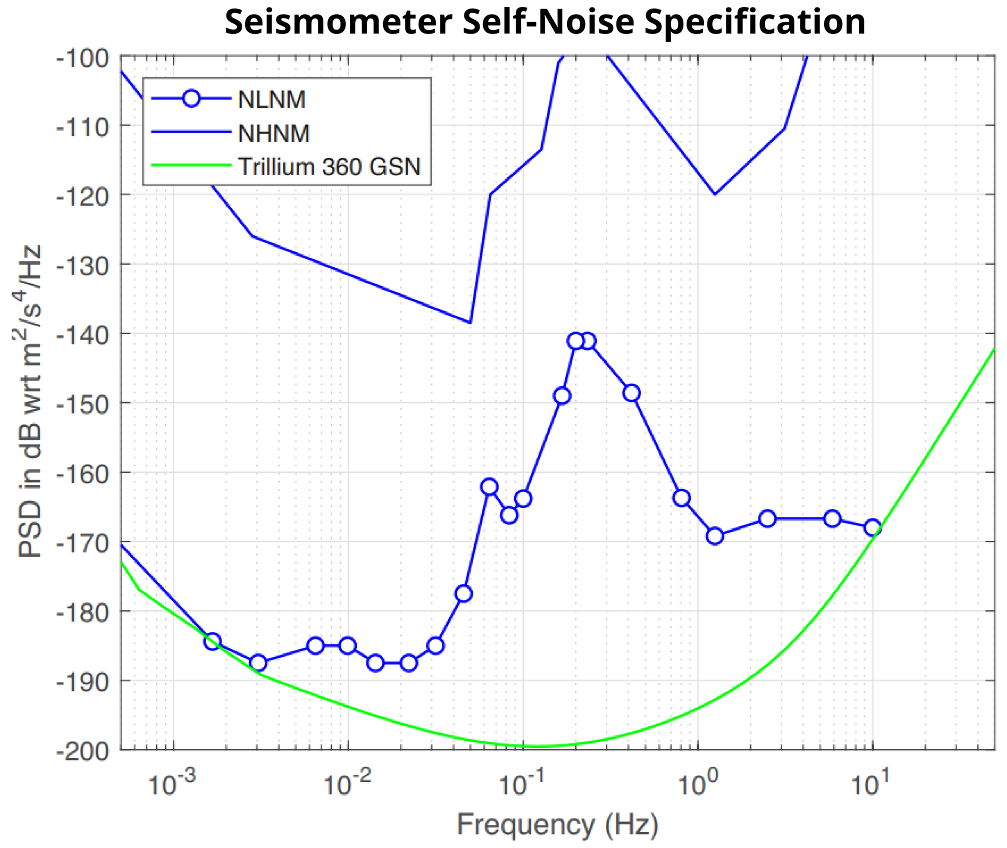
Key specifications for the T360 GSN product line

- Bandwidth 360 seconds to 79 Hz
- Sensitivity 2000 V/(m/s)
- Clip level 10 mm/s
- Magnetic sensitivity <0.03 (m/s^2)/T
- Power consumption 820 mW quiescent

Specific to Posthole and Borehole versions

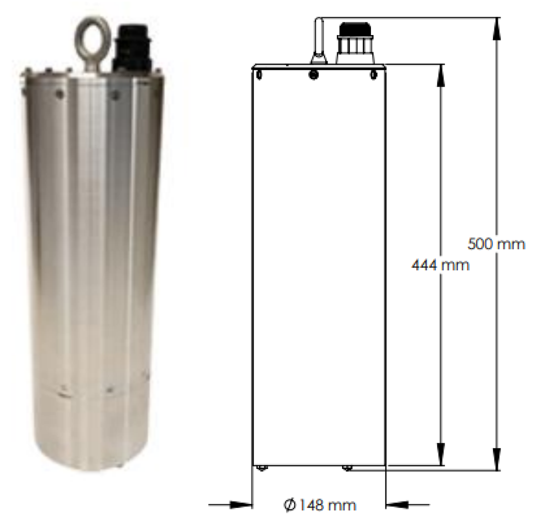
- Internal self leveling with +/-5 degree tilt range
- Marine connector
- 300 m immersion depth rating (30 m for holelock actuator)

Seismometer Self-Noise Specification

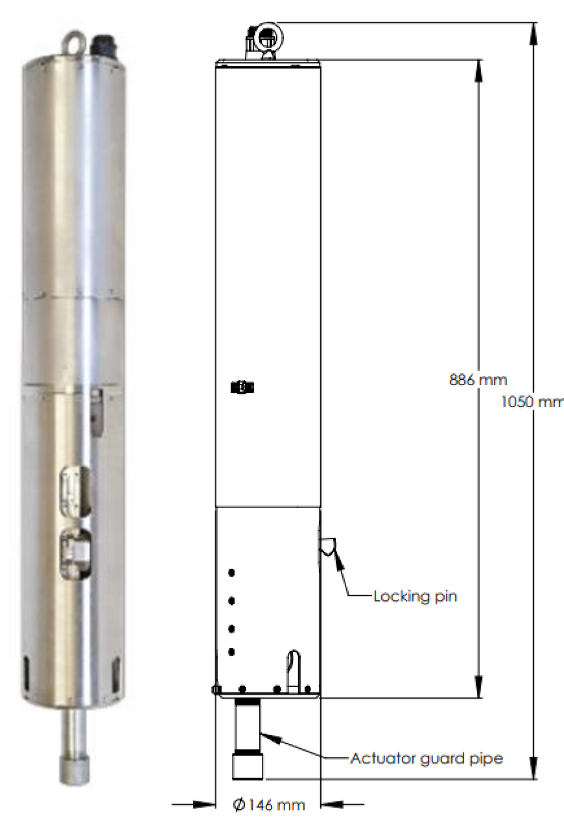


Trillium 360 GSN Vault

Trillium 360 GSN Posthole



Trillium 360 GSN Borehole

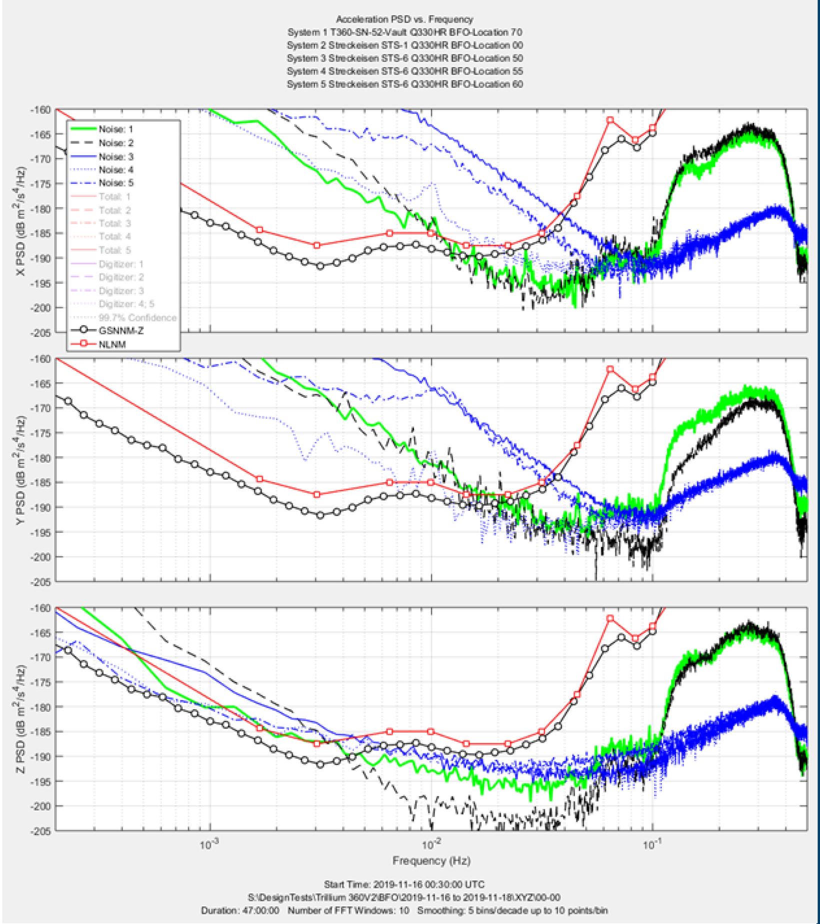


TEST RESULTS

Low frequency noise:
T360 GSN Vault at Black Forest Observatory

The plot at right shows noise for sensors at BFO, calculated by Sleeman coherence using 48 hours of data starting Nov. 16, 2019, from a T360 GSN Vault (green line) and STS-1 (dashed black) co-located on a pier, and three STS-6 (blue lines) sand-installed in shallow postholes nearby in the mine. For clarity, only noise, not total signal is shown here. Noise above 0.1 Hz is affected by non-coherence due to the separation distance of the instruments.

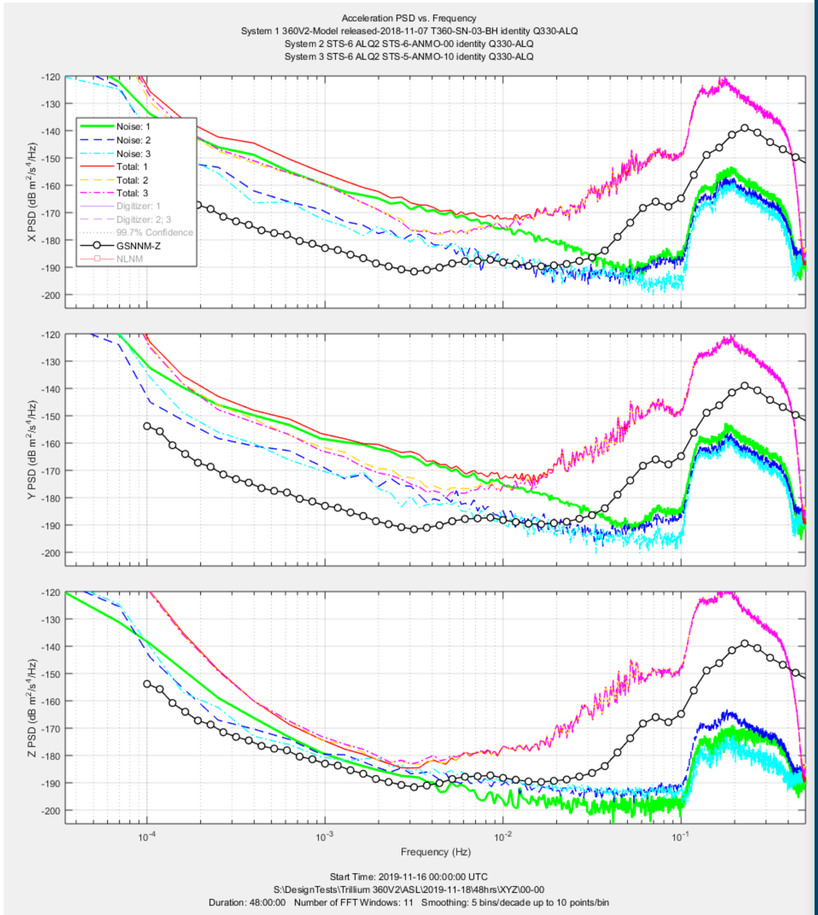
- On X (East), the T360 has the lowest overall noise level.
- On Y (North), T360 noise is similar to the STS-1 on the pier, whereas noise of the STS-6 units in postholes is quite variable.
- On vertical the T360 is at or below the NLNM (red line) and is the only sensor reaching this level at 0.003 Hz where earth background signal is at a minimum. The STS-1 is quietest at 0.01 Hz, and the STS-6s are quietest at 0.0002 Hz, although these differences are less significant because these levels are below earth background signal.



Low frequency noise:
T360 GSN Borehole at Albuquerque Seis. Lab.

The second plot at right shows signals and noise calculated by Sleeman coherence using data from the same time period (Nov 16-17, 2019) for sensors in boreholes at ASL. A T360 GSN Borehole (noise line in green) was installed with a holelock at 52 m depth while an STS-6 (dashed blue line) was sand installed in a nearby hole at 188 m and a custom version STS-5 with 360-second response (light blue line) was sand installed at 92 m depth.

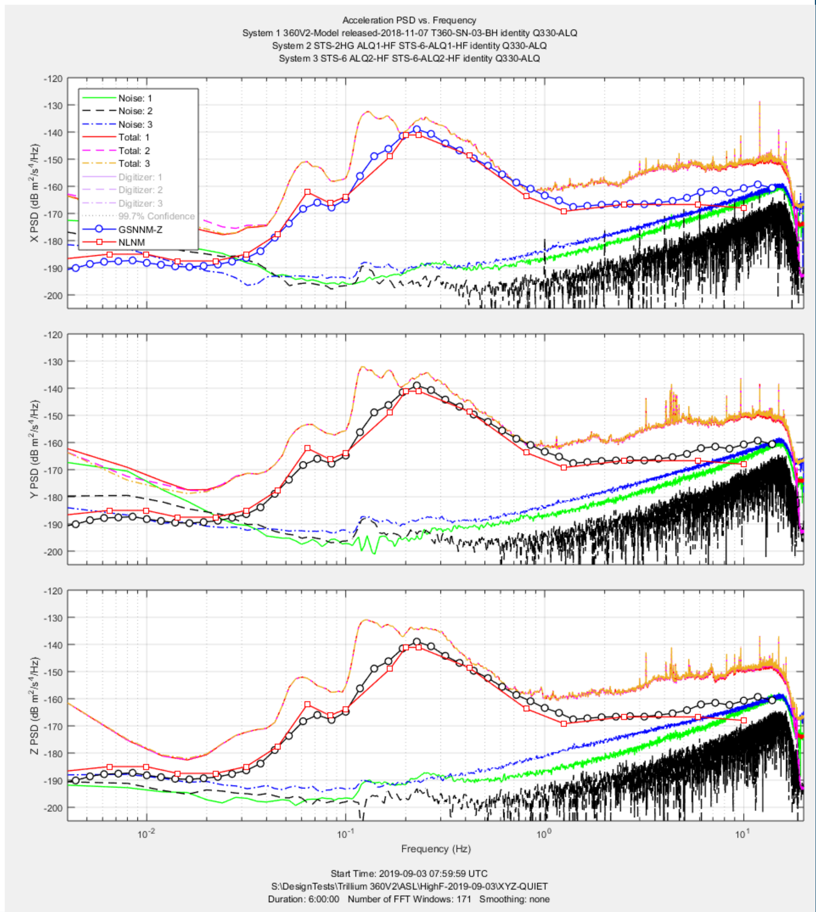
- Horizontal noise of the STS-6 was lower at ASL than at BFO, whereas horizontal noise of the T360 was higher, which illustrates that fact that horizontal noise often depends on details of the installation rather than being inherent to the sensor or the site.
- Vertical noise results in the ASL boreholes were very similar to the BFO vault for both the T360 and STS-6. Again, noncoherent noise of the T360 was lower above 0.001 Hz and noise of the STS-6 was lower at 0.0002 Hz. The difference in total signal was minimal except in the range of 0.0005 to 0.005 Hz, where the T360 was quieter.



High frequency noise:
T360 GSN Vault at Albuquerque Seis. Lab.

The third plot at right shows signals and noise at high frequencies calculated by Sleeman coherence for three sensors in the ASL vault. The sensors themselves have similar specs for high frequency noise, but system noise (including the digitizer) depends on the sensitivity of the seismometers. Higher sensitivity produces a larger signal going into the digitizer and reduces the effect of digitizer noise.

- STS-6 (noise line in blue) has the lowest sensitivity (1200 V/m/s) and therefore the highest system noise, primarily due to the Q330 HR digitizer at its gain 1 (40 Vpp) setting.
- Trillium 360 (noise line in green) with 2000 V/(m/s) sensitivity has digitizer noise proportionally lower (-5 dB).
- STS-2 High Gain (noise line in black) with 20,000 V/(m/s) shows the lowest noise, not limited by the digitizer.



ONGOING DEVELOPMENT

Nanometrics is currently prototyping a low power version of Trillium 360 technology for remote or portable deployments. This will be available in the "Horizon" form factor for direct burial or vault use, and in a pressure vessel with internal gimbal for ocean bottom deployment.

There is a trade-off in power consumption versus noise performance as shown in the noise comparison plot at right, with the low power Horizon 360 spec shown in dark green above the T360 GSN spec shown in light green. The Trillium 120 noise spec is also shown for comparison.

The low power T360 has lower noise than T120 in the low earthquake band of 0.003 to 0.03 Hz (30 to 300 seconds). Although horizontal noise may be limited by the installation in temporary deployments, low vertical noise performance should be achievable when the installation is temperature stable, such as in a buried deployment or a covered OBS. We will aim to demonstrate this in future field studies.

Key specifications for low power T360

- Power consumption **<300 mW** quiescent
- Bandwidth 360 seconds to 108 Hz
- Sensitivity 2000 V/(m/s)
- Clip level 10 mm/s
- Magnetic sensitivity <0.03 (m/s^2)/T

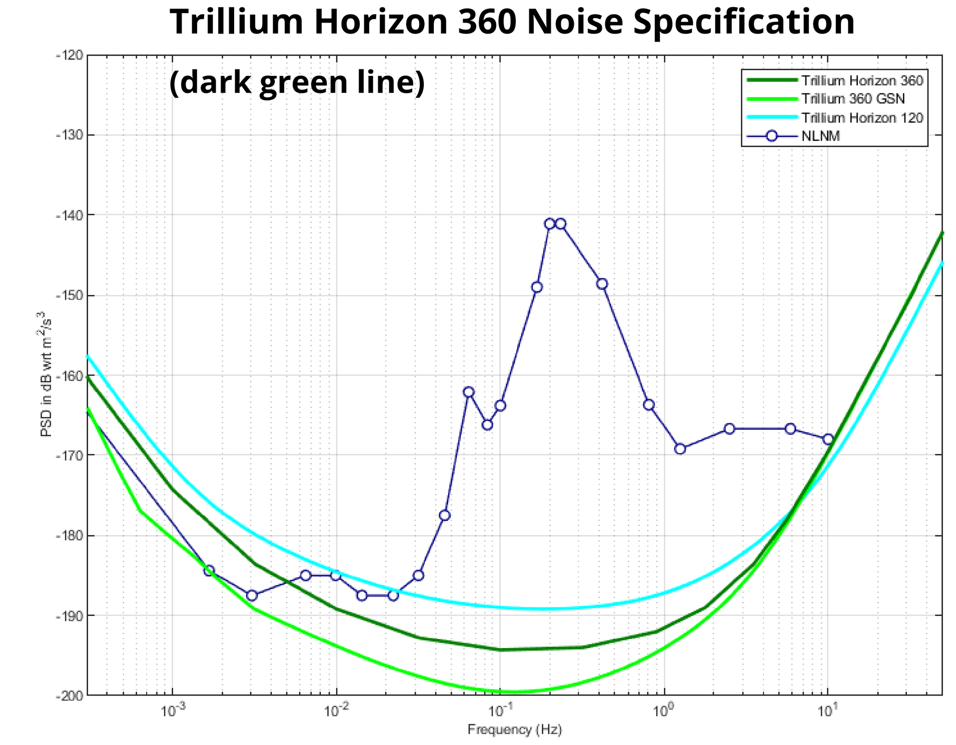
Specific to Trillium Horizon 360

- Weight 5.3 kg
- Water immersion rated IP68 10 m

Specific to Trillium 360 OBS

- Depth rated to 6000 m
- 16-pin Subconn micro-circular connector
- Gimbal autoleveling +/-50 degrees X and Y
- Level on command or on schedule
- Records and reports SOH including tilt of case and sensor, internal humidity, internal vacuum pressure, and temperature

Trillium Horizon 360 Noise Specification



Trillium Horizon 360

Trillium 360 OBS

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