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Trillium Horizon 360, a Very Broadband Sensor for Remote Deployments

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Abstract

Dense arrays and portable deployments are typically associated with short-period instruments. Many of these are now switching to broadband seismometers, such as the USGS expansion and recapitalization of the USA regional monitoring networks, CTBTO, and NORSAR. The size, weight and power (SWaP) of the newest broadbands are low enough to enable node-like deployments for new types of remote broadband studies, and shallow burial can provide excellent noise performance on the vertical channel.

In the past, very broadband 360-second instruments could only be deployed in the best-supported observatories because of the environmental operating constraints, logistics, and cost. The Trillium Horizon 360 is a small, environmentally rugged, very broadband instrument that uses only 250 mW of power and weighs only 9.7 kg to optimize operational efficiency compared to other 360-second broadband sensors. Its bandwidth is flat to velocity from 360 seconds to 136 Hz. Self-noise is below the NLNM from 200 seconds to 10 Hz. It is designed for direct burial and can be submerged to 10 m water depth. It is magnetically shielded and can be polar rated to -50 C. A fully gimbaled ocean bottom version is also now available. We describe some of the new experiments and arrays, both onshore and offshore, that could benefit from the availability of this sensor.

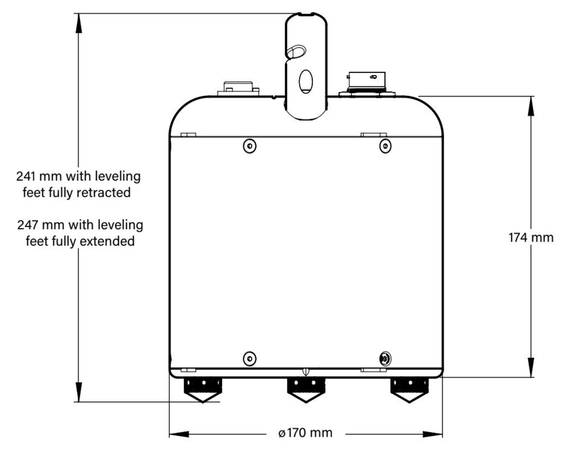
Specifications

The appearance and dimensions of the Trillium Horizon 360 are shown here. It is the smallest seismometer available in this class of performance. Its stainless steel case and geophysical connector are designed for direct burial in any environment, including continuous immersion with freeze/thaw cycles. It is also suitable for vault installation, with a moulded plastic insulating cover available. In addition, a polar rated low temperature version is available.

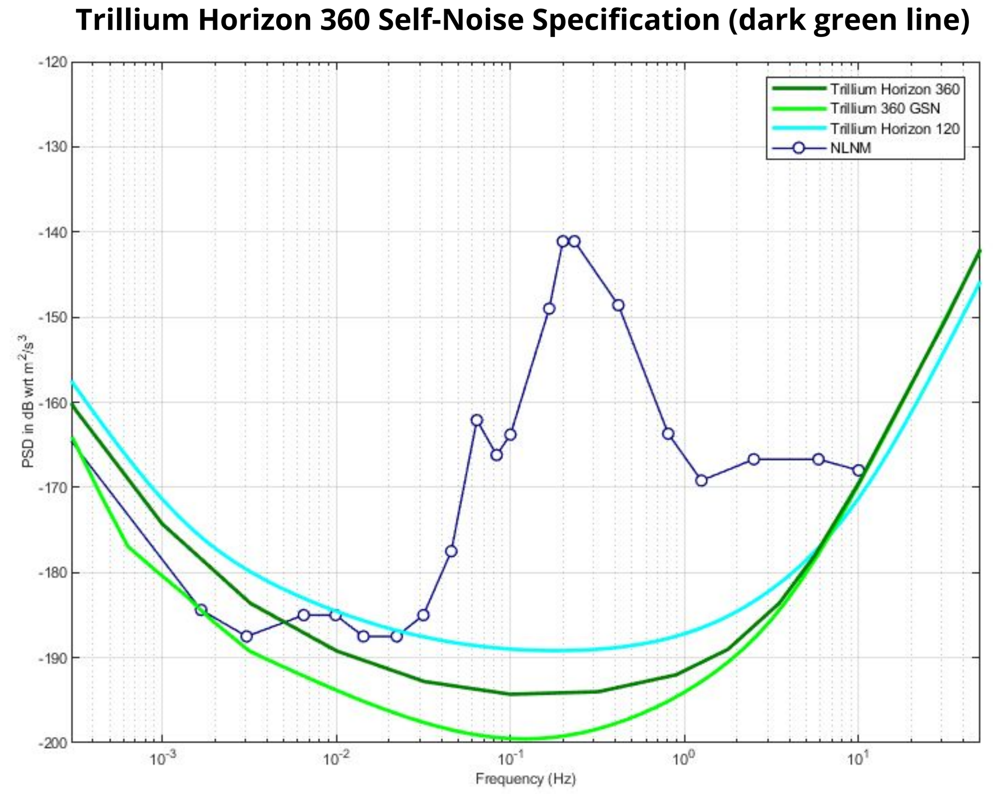
Trillium Horizon 360

The dark green line shows the self-noise performance specification on the acceleration PSD plot below. Self-noise of the Trillium 120 (light blue) and Trillium 360 GSN (light green) are also shown for comparison. There is a trade-off in power consumption versus self-noise performance for the 250 mW Trillium Horizon 360 versus the 820 mW Trillium 360 GSN. Trillium Horizon 360 has lower self-noise than Trillium 120 in the low frequency range below 0.03 Hz (30 seconds). Although horizontal noise may be limited by the site in direct burial deployments, very quiet vertical noise performance should be achievable due to the benefit of insulation by the soil. We will aim to demonstrate this in future field studies.

Key specifications:
- Power consumption 250 mW quiescent
- Bandwidth 360 seconds to 136 Hz
- Sensitivity 2000 V/(m/s)
- Clip level 10 mm/s
- Magnetic sensitivity <0.03 (m/s^2)/T
- Weight 9.7 kg
- Water immersion rated IP68 10 m
- Souriau UTS Hi-Seal connector



Trillium Horizon 360 Self-Noise Specification (dark green line)

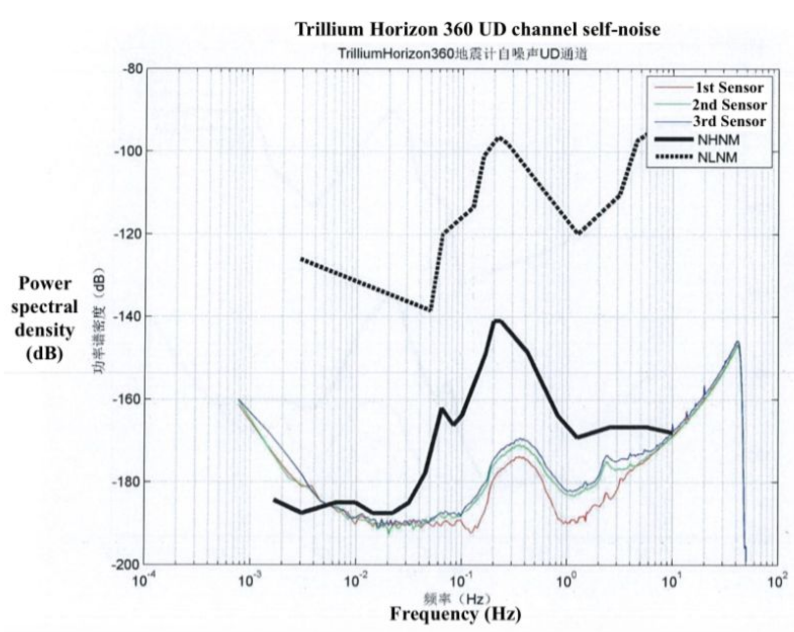


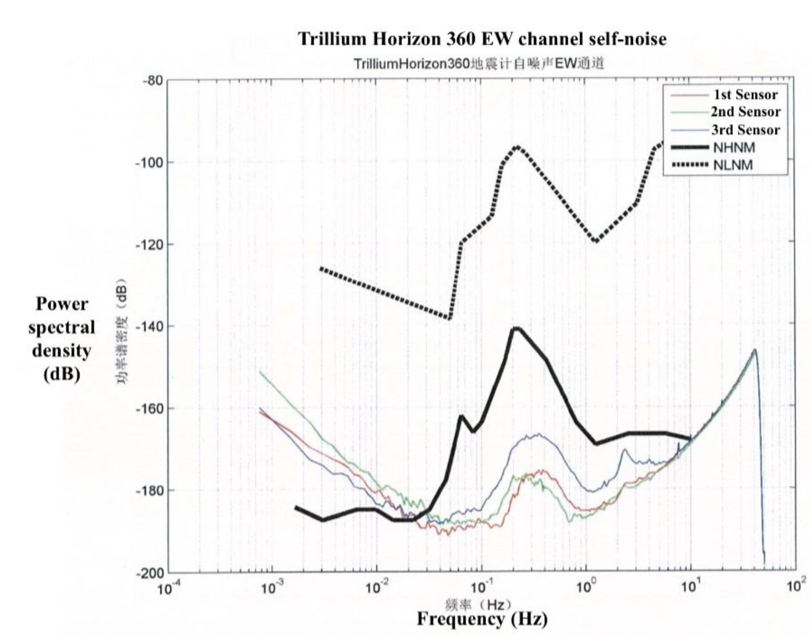
Noise Test Results

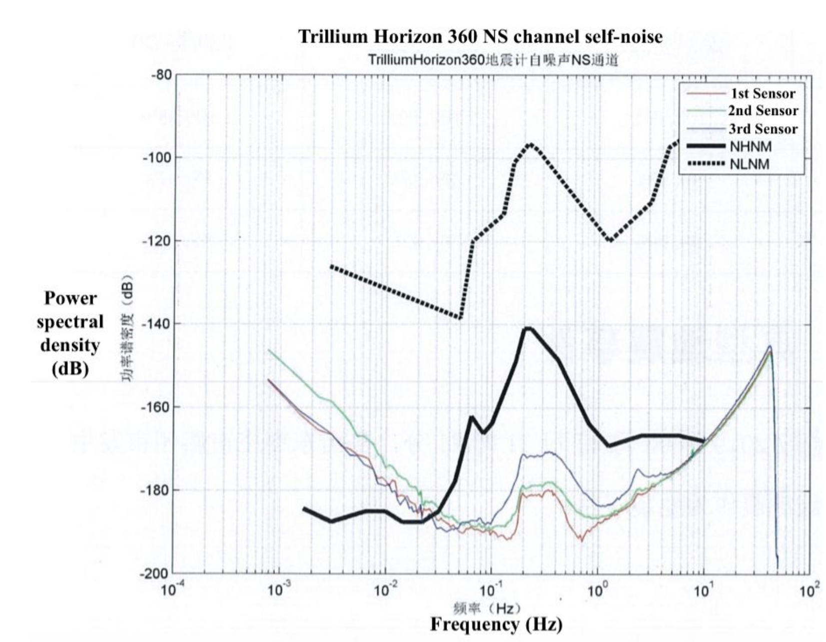
China Earthquake Administration

These three plots show the results of noise testing by the Sleeman coherence method for three Trillium Horizon 360 seismometers deployed in a quiet vault by the First Monitoring and Application Center of the China Earthquake Authority in 2019. (This is an earlier version of this seismometer design with similar performance but higher power consumption than the current version.)

- On the vertical (UD) channel shown at right, all three seismometers consistently meet the self-noise specification, corresponding to the dark green line in the previous plot at the lower right. (The peaks at 0.3 and 2 Hz are not self-noise of the seismometer, they are typical artifacts of the Sleeman test method, showing a residual fraction of the background seismic signal, which is non-coherent because the seismometers are not precisely co-located or aligned in the same direction.)
- Noise performance of the horizontal channels (EW and NS) shown below is similar to the vertical, except that the non-coherent noise is about 10 dB higher at low frequencies. This is also due to a typical limitation of the test method, in that horizontals show higher signal at low frequencies due to tilt, which is not entirely coherent between different sensors at the same site.

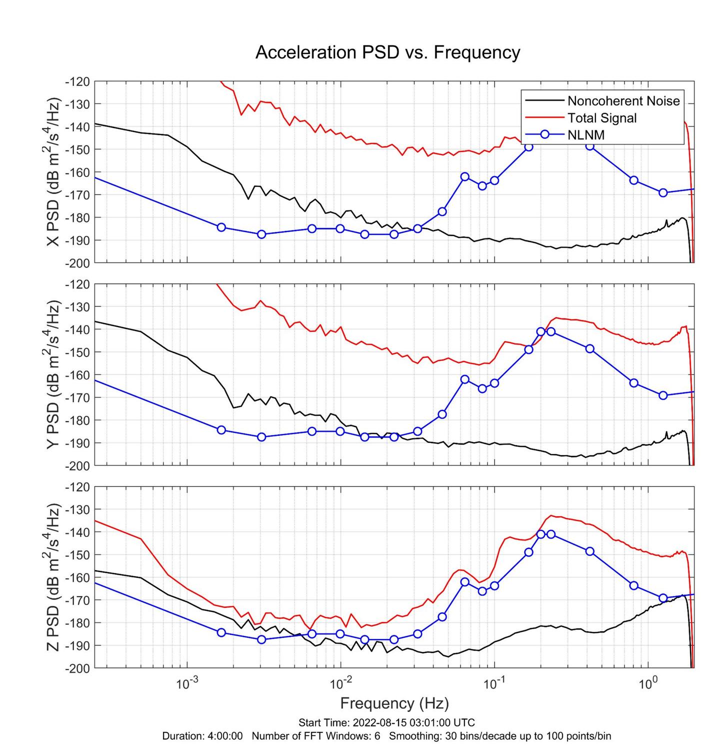






Nanometrics (Ottawa, Canada)

The three-channel plot at left shows the results of noise testing by the Sleeman coherence method of the new low-power version Trillium Horizon 360 seismometer at Nanometrics manufacturing test site in Ottawa, Canada. Noise performance is similar to the CEA test results above and consistent with the self-noise specification at left on the vertical channel at low frequencies.



Trillium 360 OBS

The same low-power Trillium 360 seismometer technology and performance is also available in a self-levelling gimbal and titanium pressure vessel for ocean bottom deployment. The pressure vessel has been successfully tested to 7000 m equivalent pressure at the Woods Hole Oceanographic Institution. (It is conservatively rated to 6000 m to allow for material and manufacturing tolerances.)

Trillium 360 OBS is compatible with the Abalones sled system (sold by Nanometrics under license from Scripps Institution of Oceanography). It comes supplied with a lifting bail to connect to Abalones and tripod feet designed for stable support and easy release on ocean bottom mud or rocky surfaces.

Key specifications:
- Diameter 327 mm
- Height
  - 265 mm pressure vessel
  - 340 mm with tripod and feet as shown
- Weight 26.1 kg in air, 10.5 kg in water
- 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
  - mass positions
  - internal humidity
  - internal vacuum pressure
  - temperature

Potential Applications

Seismic observatory sites with well-developed infrastructure already benefit from very broadband Trillium 360 class instruments. However, such installations are sparse outside developed regions on land and have rarely been attempted in the ocean. Going to more remote sites can provide multiple benefits:
- complete coverage
- lower cultural noise
- data from unique environments such as polar ice, subduction zones, and spreading ridges

We can draw an analogy with a space telescope: there are benefits in going to a more remote environment, and for the investment needed to go there, it makes sense to use the best possible instrument - not only for the sake of the immediate experiment but for any future re-analysis of that data.

Specific applications may include:
- expansion of the GSN network to the sea floor where size and power consumption are key considerations
- polar environments, which are seismically quiet and also require a magnetically shielded sensor
- SZ4D, which can benefit from very broadband instrumentation spanning sea and land
- Prompt elastogravity signals (PEGS), which benefit from stacking across a dense network of VBB sensors

References

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