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Results from an Ultra Broad Band Borehole seismometer with flat response over 5 decades of frequency is presented

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Introduction

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Detecting small underground nuclear explosions depends on the ability of a seismometer to record high frequencies, as well as on its sensitivity. ALPHA broad band borehole sensor fills this need and improves detection thresholds by spanning *5 decades* of seismic frequencies.

None of the inertial broad band seismometers based on the forced feedback principle, which are currently offered by any manufacturer, are designed to cover ground motions at high frequencies.

Most broad band sensors offered today have their upper -3 dB point either at 50 or 100 Hz, with two exceptions, where it lies at 150 Hz. However, in these sensors which claim to have response up to 150 Hz, the response plots show that the responses are not flat with complex phase response differing from sensor to sensor.

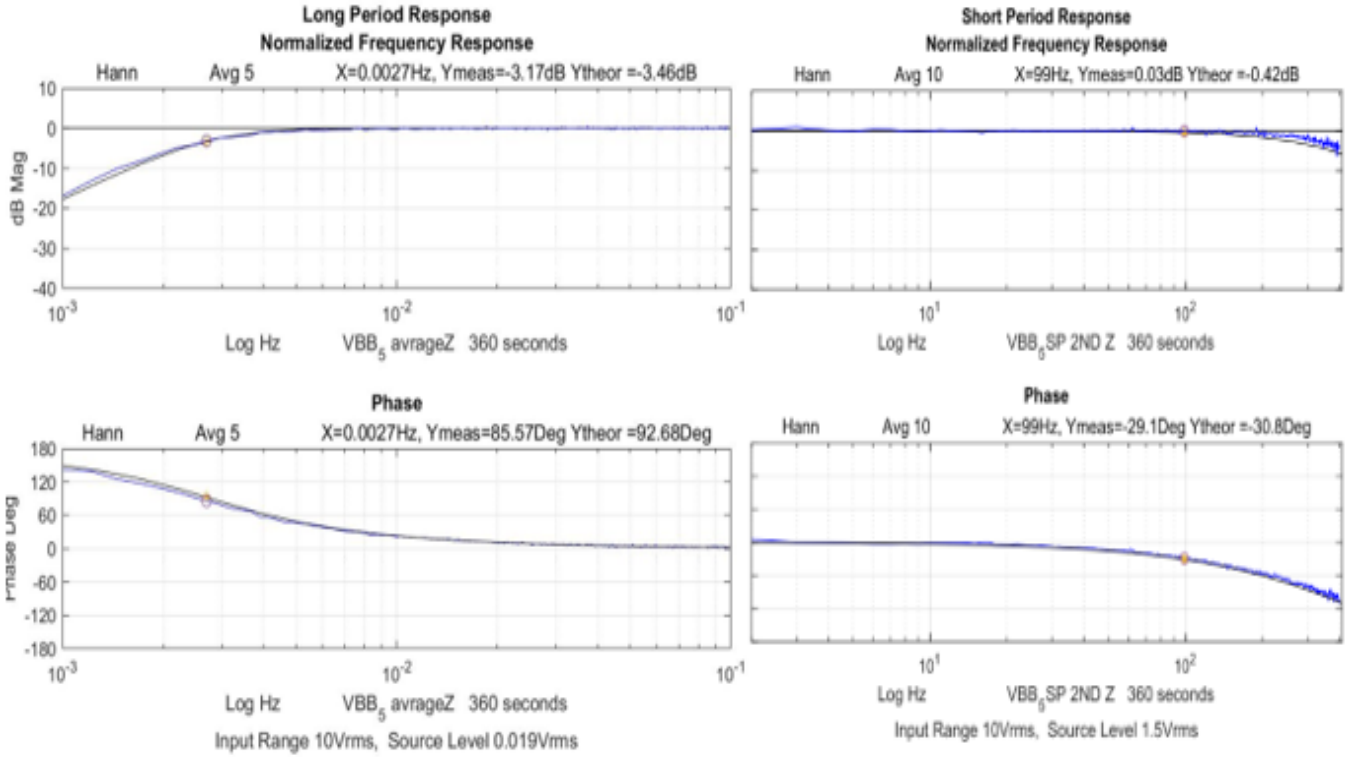

Figure 3: Response of the new sensor to the signal input into the feedback transducer in both amplitude (top panel) and phase (bottom panel). The x-axes are in "log Hz". The 3dB-points are at 2.7 mHz and 270 Hz. The response of the sensor is flat over 5 decades in between.

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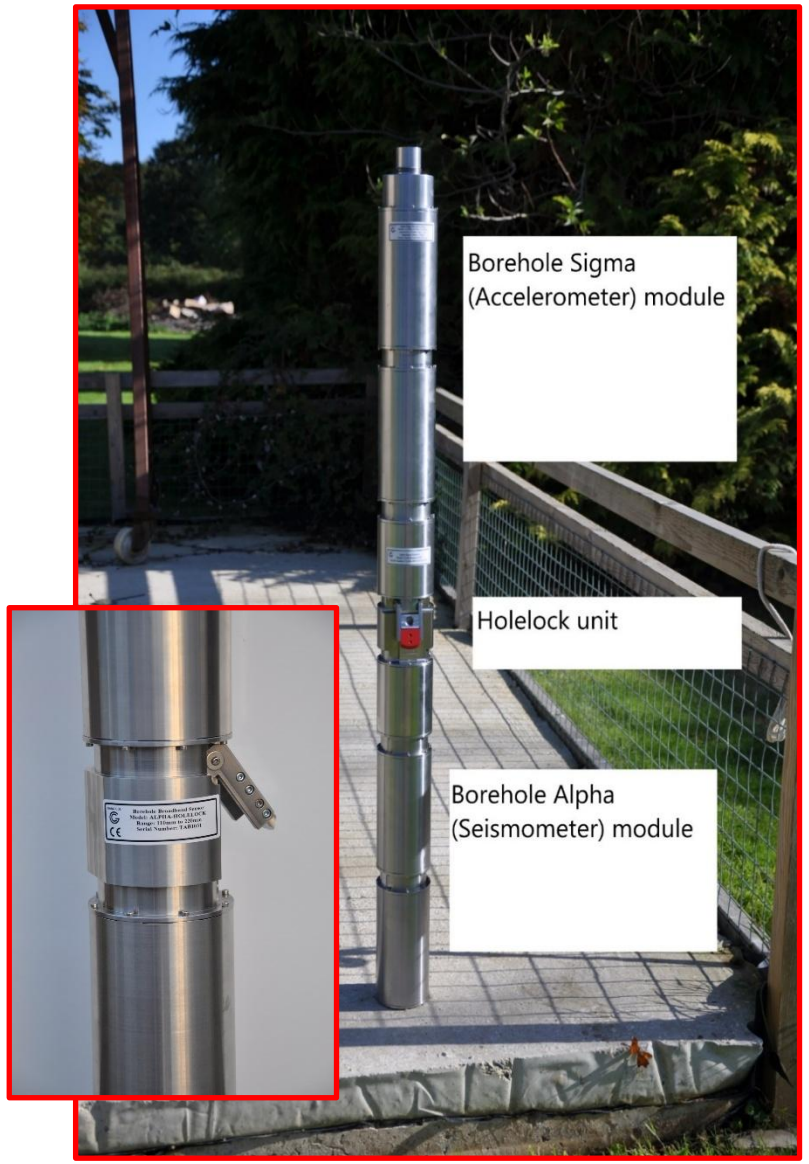
Realization:

The developed ALPHA broad band sensor record ground motions in frequency range of more than 5 decades from 2.7milli Hz (360 sec) to at least 270 Hz.

We have achieved this by applying the following design principles:

- The boom dimensions of the inertial frame of reference have been carefully chosen so as the to be balanced with increased boom efficiency.
- The spring-boom fixing point dimensions was increased from previous C.M Guralp designs with modified spring clamping mechanism to reduce temperature effects and to provide precise clamping point of the triangular spring, commonly known as the “constant stress or C spring” spring
- The designed spring material (proprietary material) has reduced Hysteresis properties, and the heat treatment of the spring material has been changed to provide smaller long-term creep than the available material in the market.
- The spurious modes of the suspension system have been reduced and pushed outside the sensor detection bandwidth above 500 Hz
- Total three component sensor weight has been reduced to 20 kg, and each component Z, N/S and E/W components are separated from each other with rigid “O” ringed Bulkheads. The overall diameter of the borehole sensor is only 89 mm.



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Realization:

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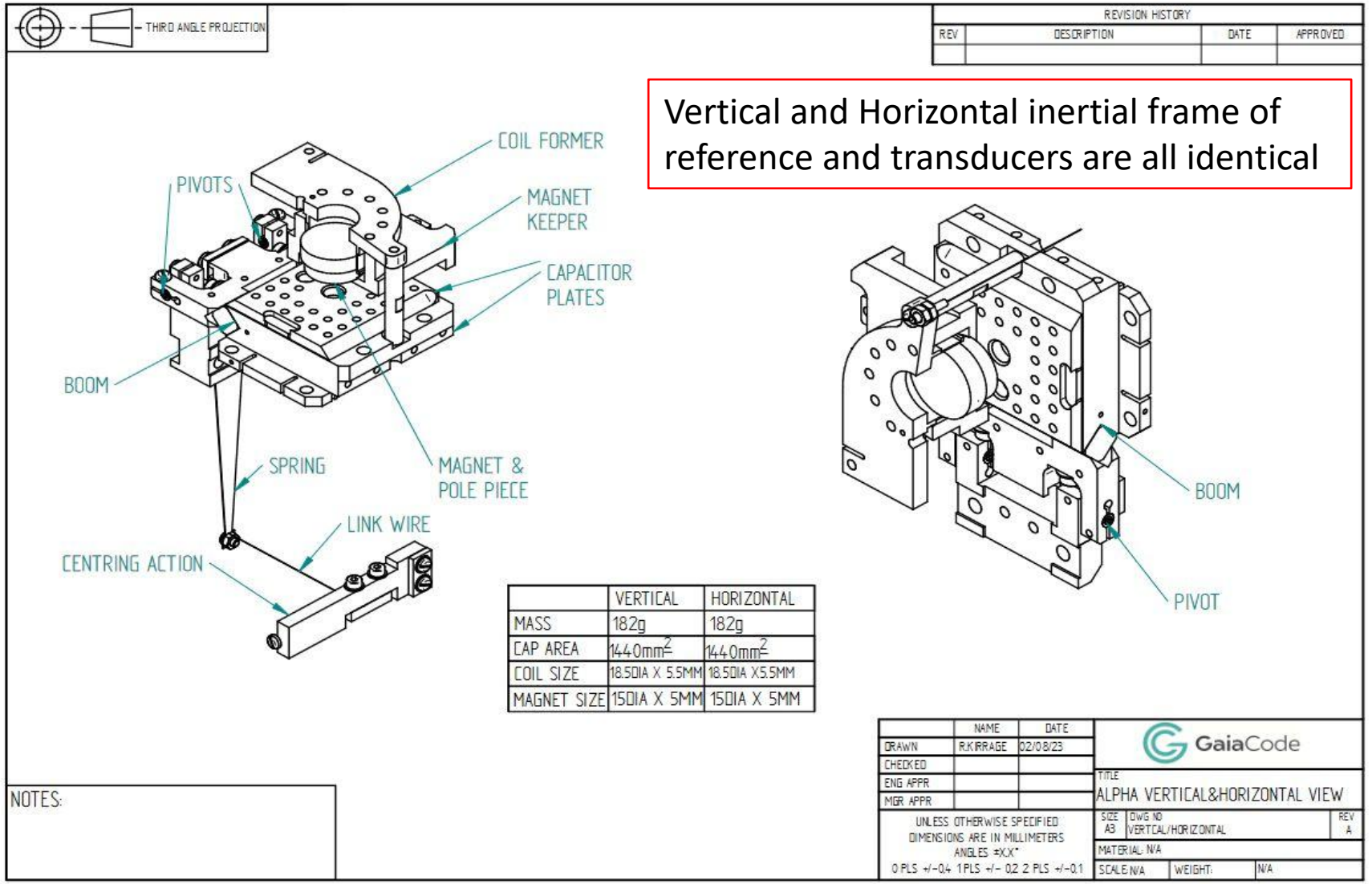
- The feedback electronics have a different topology compared to classical feedback velocity sensor which ensures that the frequency response of the sensor within the feedback loop is flat up to 270 Hz. (-3dB Point).
- If required, the newly adopted Feedback topology allows to generate different sensor frequency responses.
- The sensors modules are calibrated and cross axis sensitivity of each Component individually adjusted. (A new improved method is used to calibrate and adjust the vertical component sensor cross axis rejection)



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Location of 200-meter-deep Alpha Borehole and Surface ALPHA Broad Band sensor Installation

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Location of the borehole ALPHA sensor.

Top cover for Borehole casing to reduce Borehole Wind Noise

Location of the surface ALPHA sensor, inside the Grey enclosure.

Not wind- or water-proof.

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Result from 200-meter-deep installation of ALPHA BOREHOLE sensor in comparison to surface ALPHA broad band sensor

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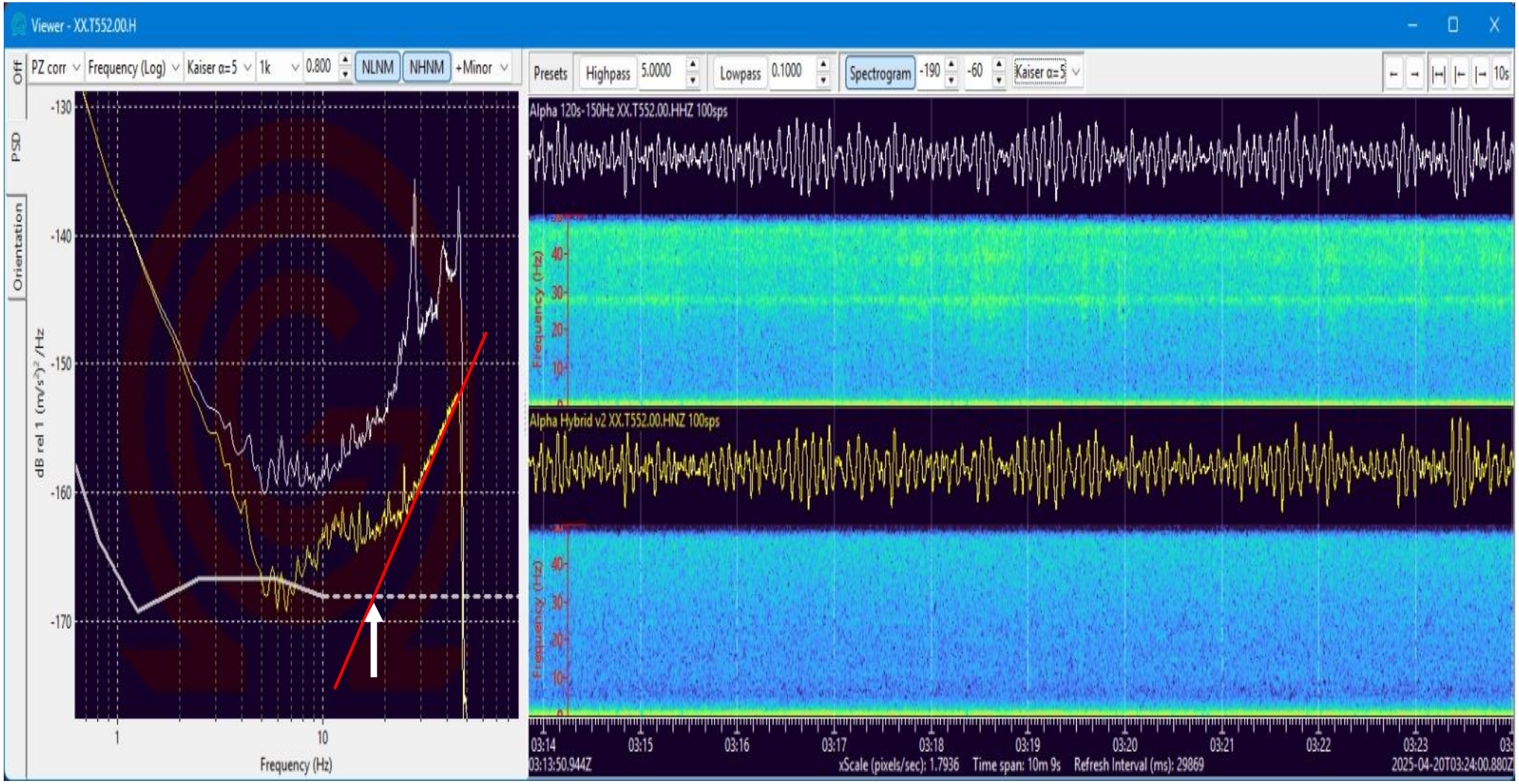

Borehole Three component sensor Noise level, **Yellow Trace**

The white trace is the surface sensor

The sensor High frequency Noise level crosses the New Low noise Model around 18 to 20 Hz .

The RED Line is the theoretical noise model of the sensor.

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Result from 200-meter-deep borehole comparing to EKA post hole sensors and Surface ALPHA broad band sensor

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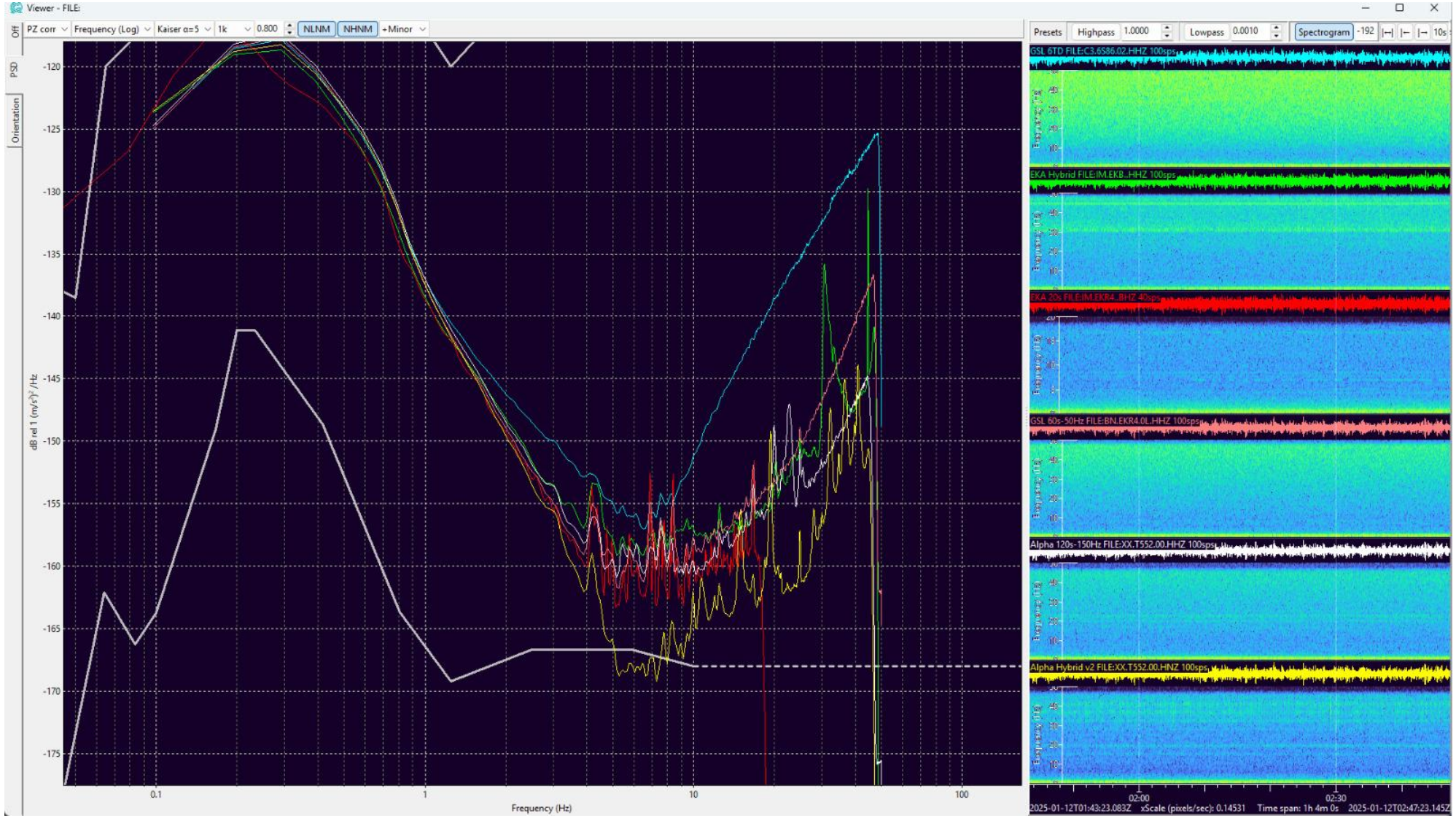

Yellow: Borehole sensor

Green: Surface ALPHA broad band

Red: EKA posthole

Blue: CMG-6TD

EKA station detection capability can be enhanced with if borehole-ALPHA sensors were to be used.
The provided power spectral density plots clearly prove the improved detection, signal to noise level of the borehole station.

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Results from 200-meter-deep Borehole Alpha sensor

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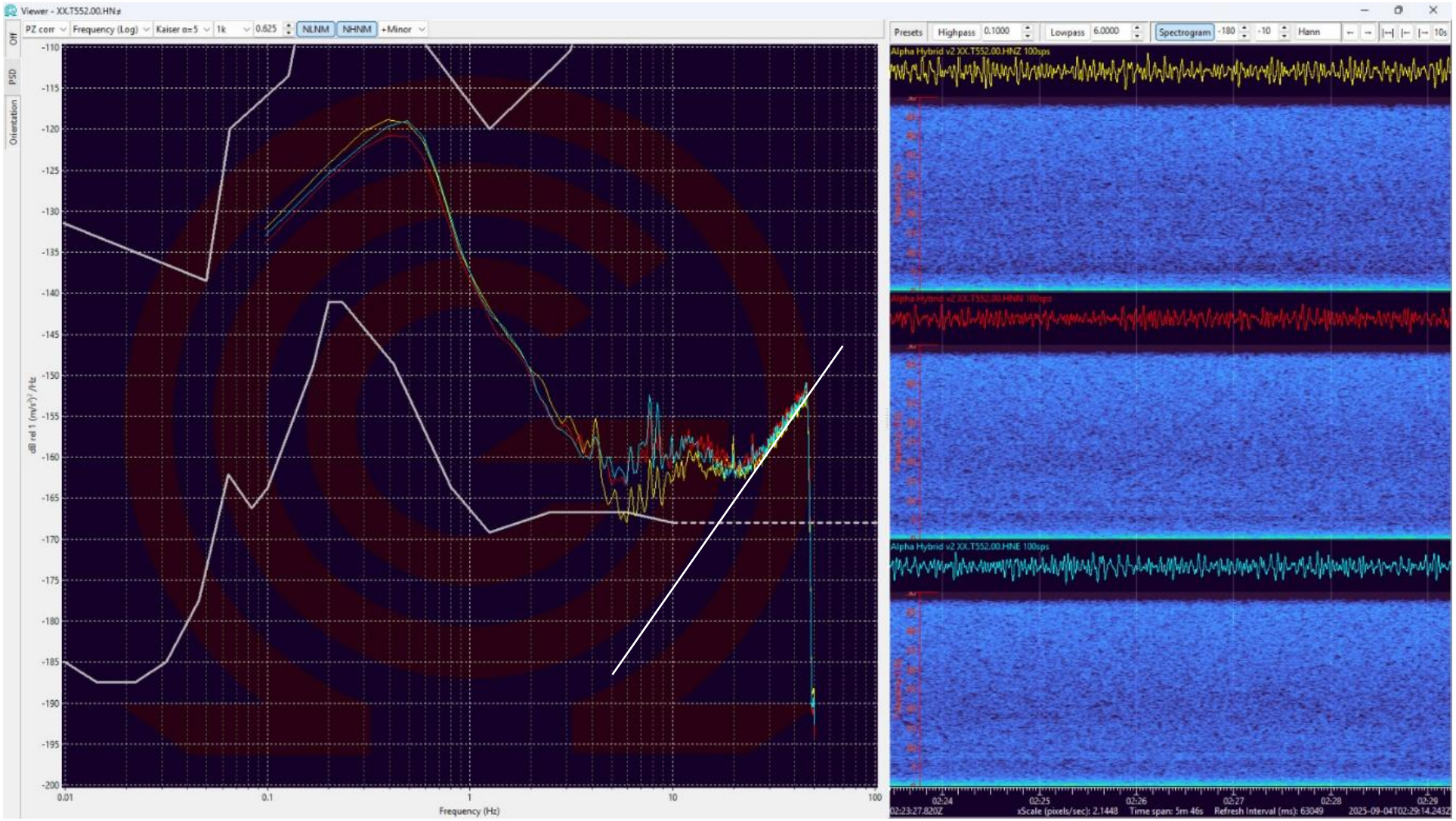

Borehole three component sensor Noise levels.

The sensor *high frequency* Noise level crosses the New Low noise Model around 18 to 20 Hz.

The white Line is the theoretical noise model of ALPHA sensor.

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Result from 200-meter-deep installation of three component ALPHA BOREHOLE sensor in the Long period portion of the seismic-spectrum

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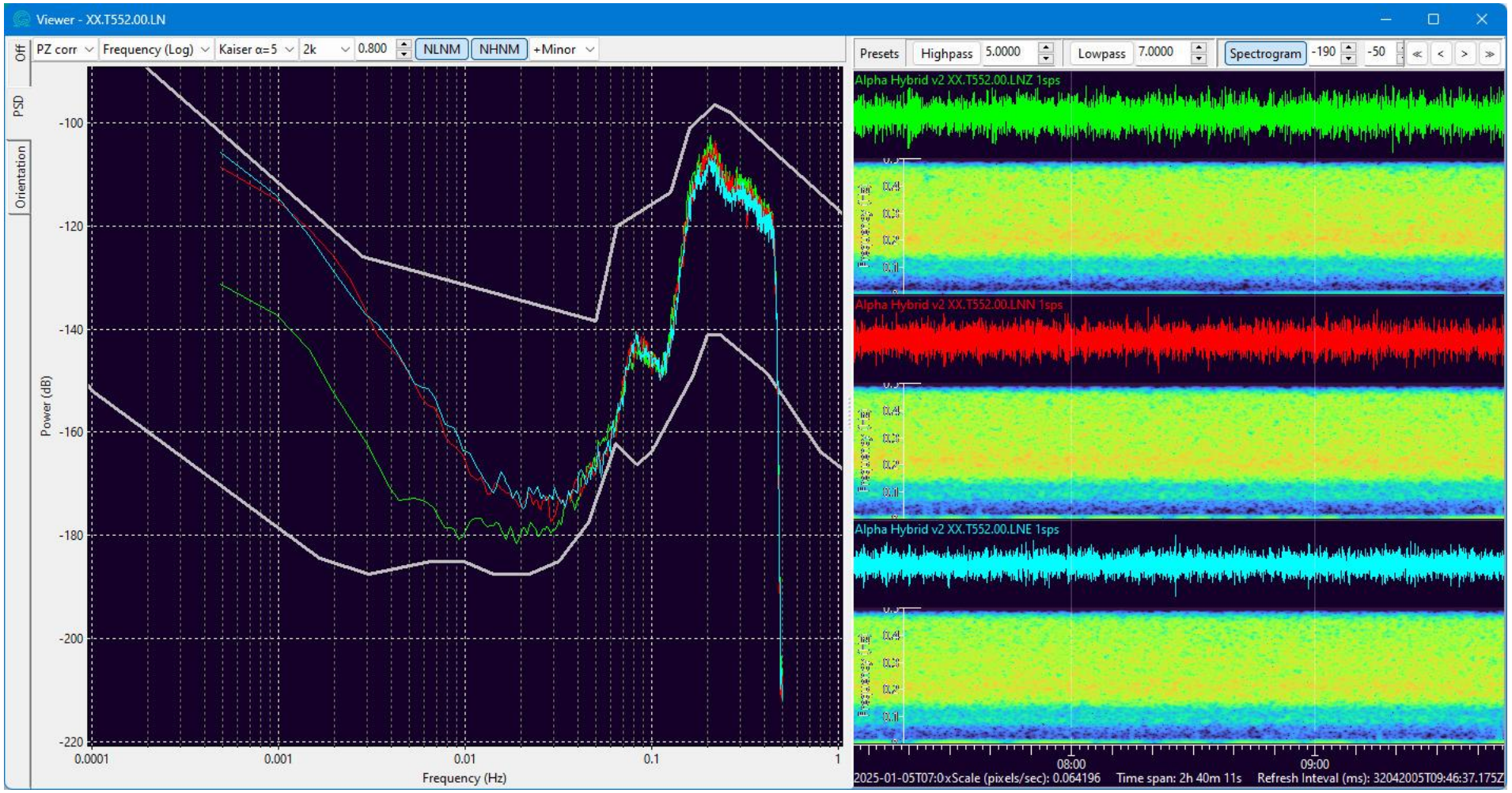

Borehole Three component ALPHA Noise level in the Long period.

The long period Noise level of the horizontal component ALPHA modules show background noise close to the Vertical component which is virtually impossible to achieve as surface broad band senor.

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Result from 200-meter-deep Borehole Alpha sensor outputs sampled at 1000 s/s there are No observable spurious Resonances

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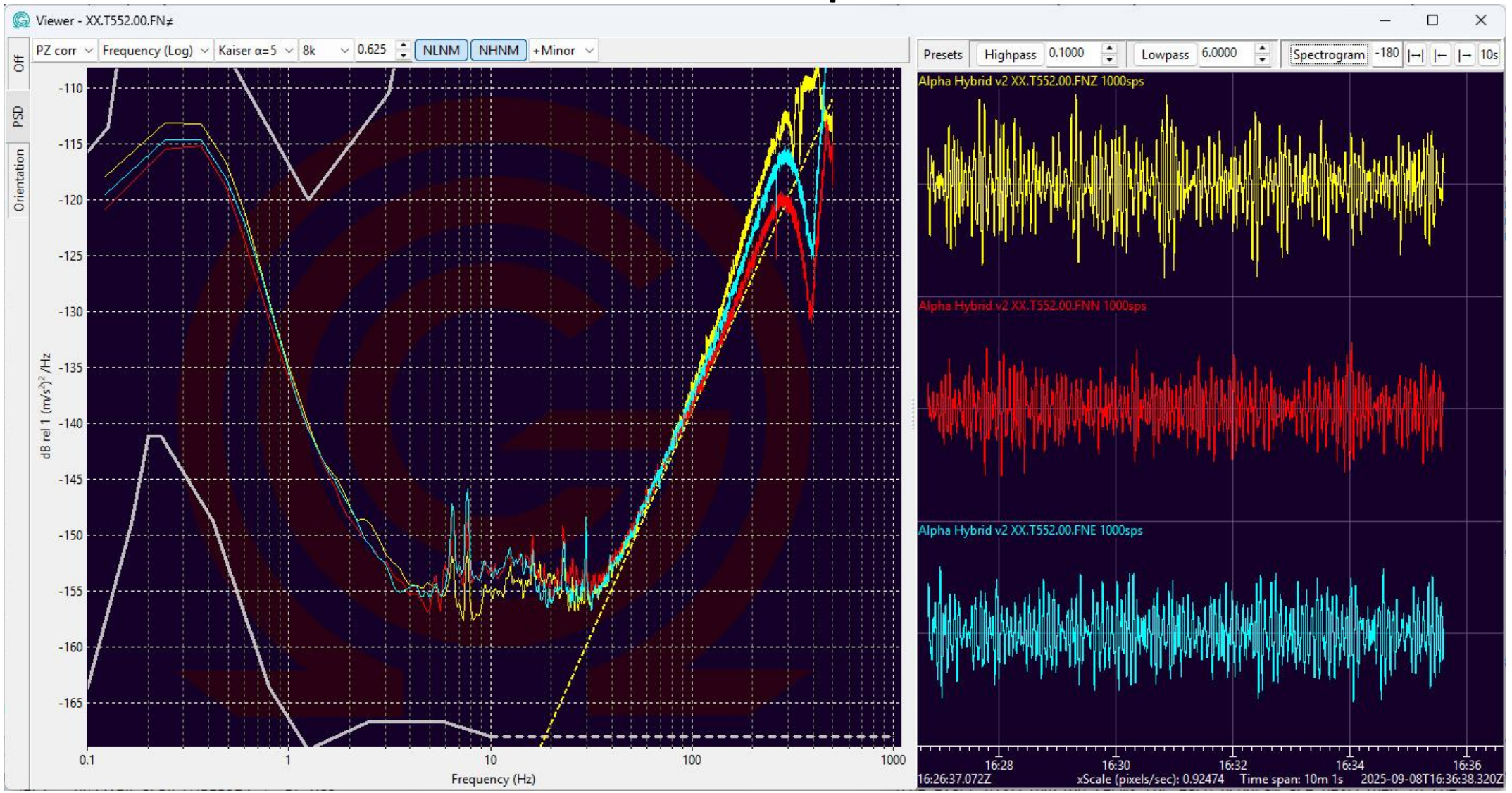

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Result from 200-meter-deep Borehole *vertical* sensor comparing surface ALPHA with the borehole ALPHA broad band sensor

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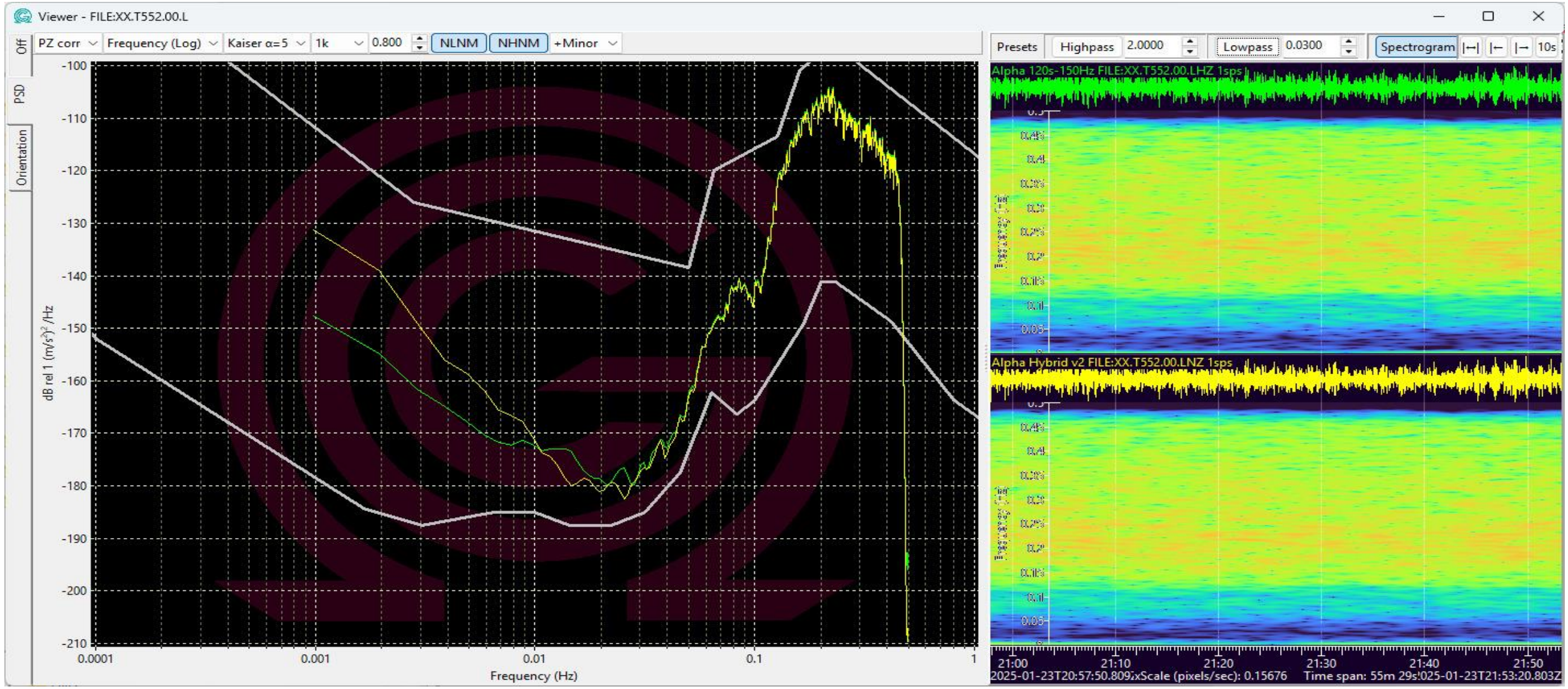

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Result from 200-meter-deep Borehole In the Long period and Compared to collocated surface ALPHA broad band sensor

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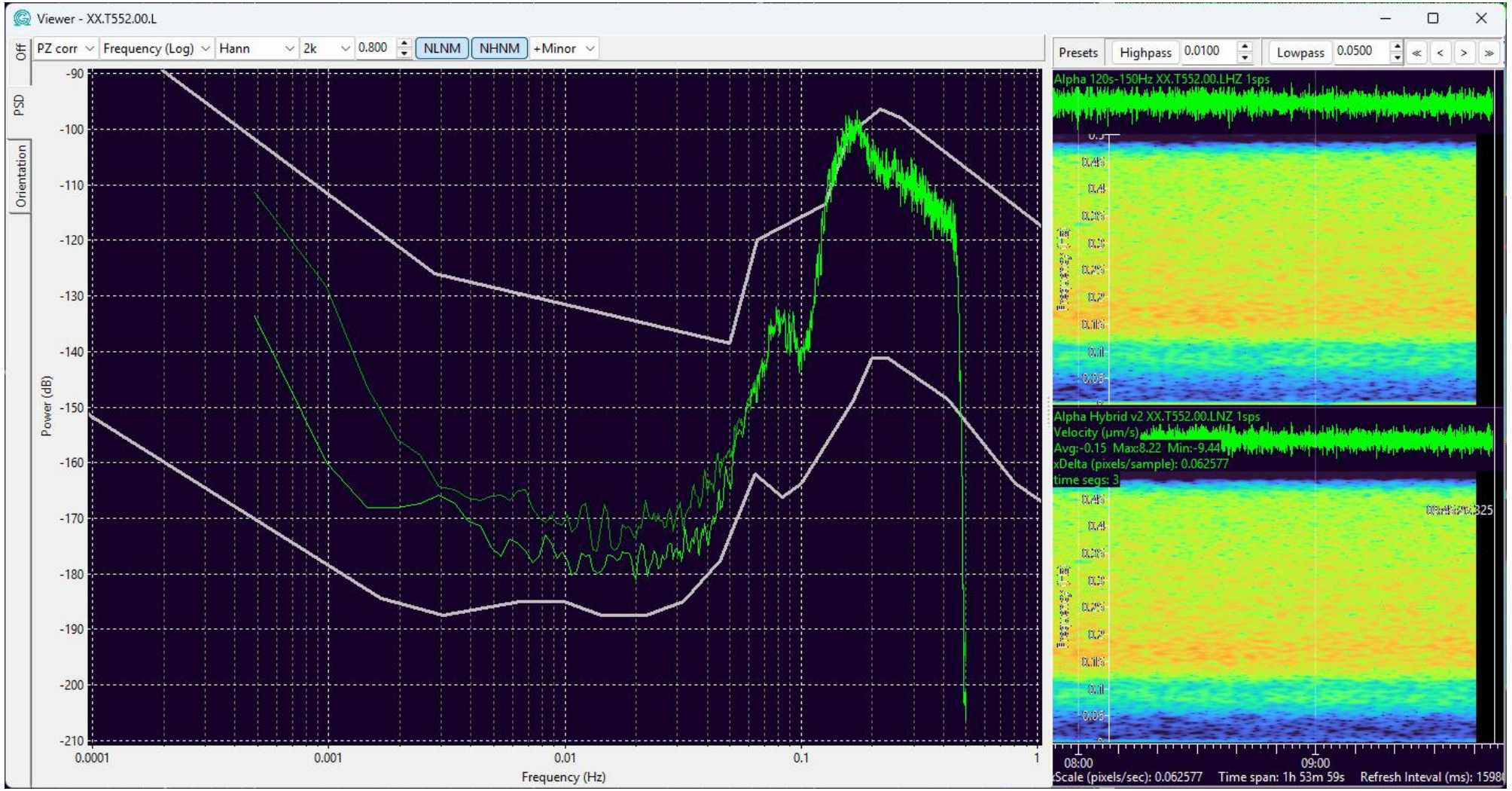

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PPSD for 28 days in February 2025 of the ALPHA vertical component of the borehole sensor.

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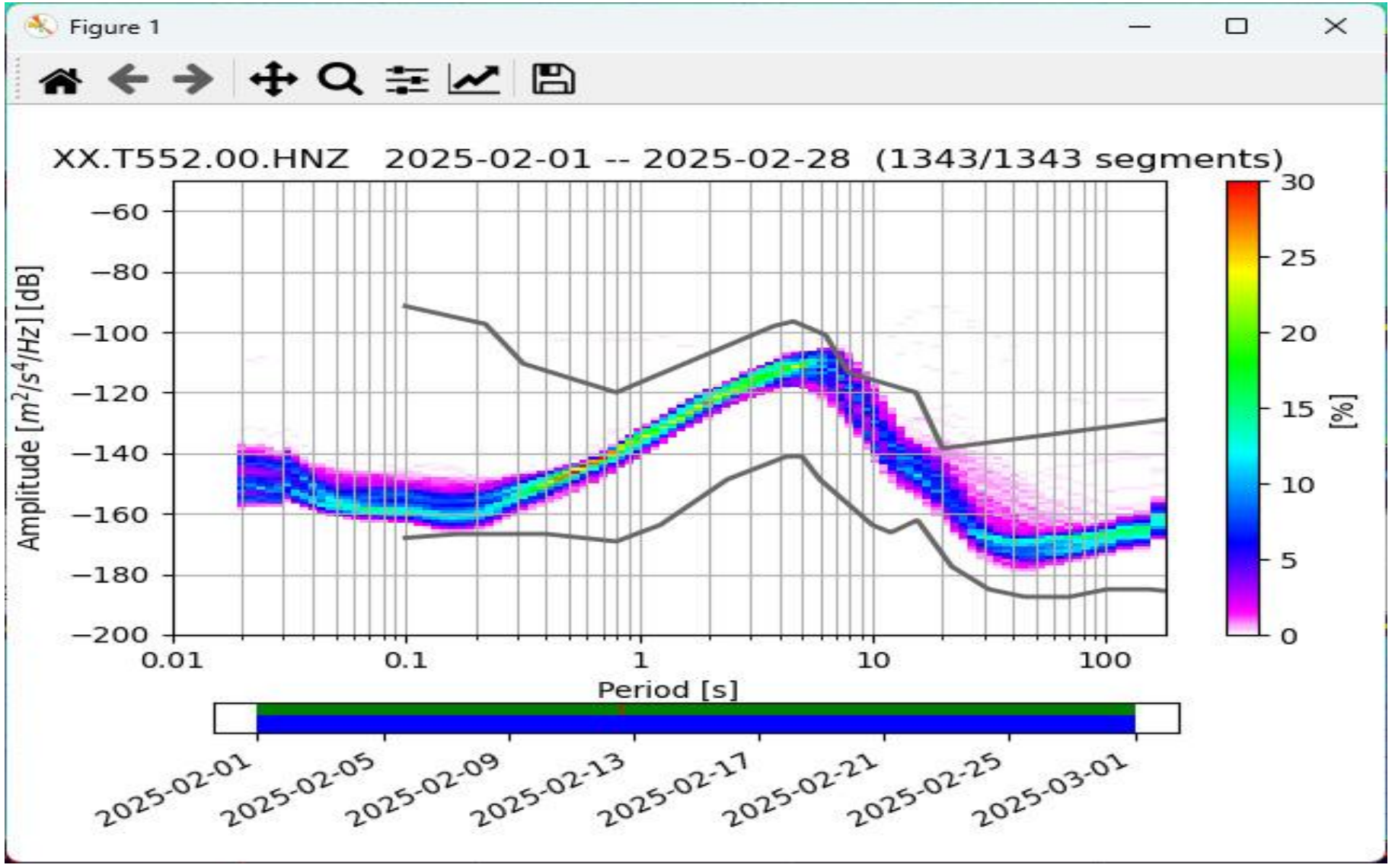

Conclusion

- **ALPHA Broad band sensor achieves a flat frequency response over more than five decades, from 2.7 mHz (360 sec) to 270 Hz and beyond.**

- **Alpha Broad band sensor does not have Spurious modes of resonances up to 500 Hz and beyond.**

- **At 200-meter depth Broad band Borehole sensor noise level is below the Low noise model (NLNM) when compared to EKA-CTBTO station sensors.**