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Qualification of Nanometrics Trillium 120QA seismometers and Centaur CTR4-3A digitizer for the IMS

2018-10-24

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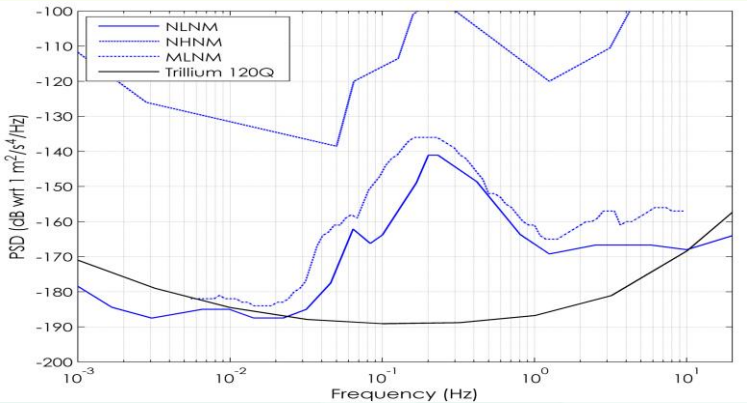
Background

- Canadian stations in the IMS network have used Guralp CMG-3T sensors, GD2 (in house designed) digitizers and Small PC authenticators
- Equipment at end-of-life: 20 years old
- National network undergoing replacement
  - Chose Nanometrics Trillium 120/QA sensors, and Centaur digitizers through a competitive process
  - Sensible to use same equipment at Canadian IMS stations for commonality, serviceability
  - Nanometrics designed an IMS specific version of Centaur digitizer
- Present
  - Characteristics of the sensor and digitizer
  - Results of evaluation of the digitizer conducted at Sandia
  - Side-by-side performance comparisons in stations AS17 (Inuvik) and AS16 (Resolute)
  - First experience with full install (see Tuesday talk: *Recapitalization of T-phase hydroacoustic station HA02*)

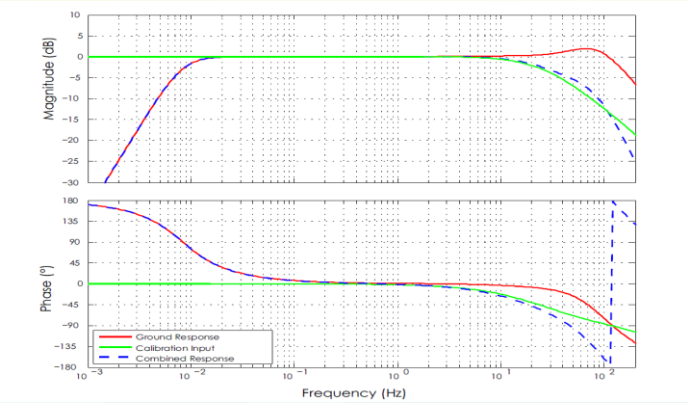
Trillium 120/QA Sensor

- Characteristics
  - Symmetric triaxial, *uvw* or *xyz* output
  - Manual/automatic remote mass centering, real-time mass centre report
  - Remote accessible “Digital Bubble Level”
  - Variants for posthole and direct burial (Horizon)
- NRCan has satisfactorily installed about 100 systems in last three years with very good performance and reliability

Trillium 120/QA Performance



Trillium 120/QA self noise vs frequency



Trillium 120/QA frequency response: Amplitude (top) and Phase (bottom)

- Self noise below the NHLM up to 10 Hz and good at low frequencies
- Within requirements for a sensor for IMS

- Response flat in range 120s to 150Hz(-3db)

Centaur Digitizer

Characteristics

- High performance seismic digitizer with features for IMS support
- 3-channel/24 bit digitizers (6 channel non-IMS)
- Input range settable 1-40V_{pp}
- Sample rates 1 -5000sps
- Compatible with broadband and short period sensors as well as microbarometers
- Versatile sensor calibration capability
  - sine wave, PRB, custom sequence in ".wav" format
- Timing using GPS as well as NTP and PTP protocols

IMS Special Features

- CD1.1 support data/status fields
- Hardware authentication/signing built into device – no supplemental devices required
- Tamper detection:
  - digitizer housing open switch
  - two external switch connections (e.g. vault door)
- Weather station interface
  - Compatible with Gill GMX500 via serial connection
  - 1 sps: Pressure, Temperature, Wind speed/direction

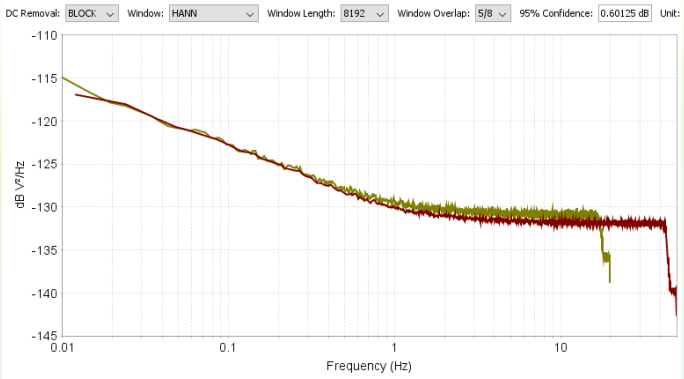
Digitizer Evaluation

- Centaur digitizer was evaluated by Sandia in April 2018 in presence of observers from CTBTO, Nanometrics, NRCan
- See Sandia Report *SAND2018-11442*, from which much of the following is taken
- PTS, based on this has stated: *Following the IMS/ED review of the finalized evaluation report for the Nanometrics Centaur digitizer, we confirm its acceptance for IMS-wide use.*

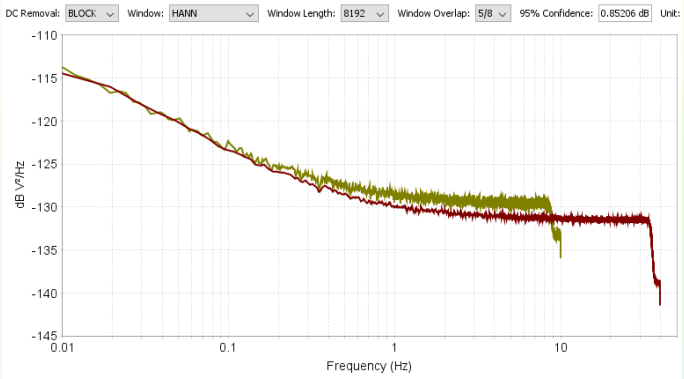
Digitizer Evaluation

- Selected Test Results
  - Power Consumption: measured as 2.5-2.6W; less than manufacturer's specification
  - AC full scale: Fully resolve signals at or about their rated values for all settings
  - Sensor compatibility successfully checked with
    - Nanometrics T240, Kinemetrics STS-2 seismometers
    - MB2005 and MB3a infrasound sensors
  - Dynamic Range
    - At 100Hz dynamic range is 130dB for a 40x gain, 138.4dB at unity gain

Digitizer Self-Noise



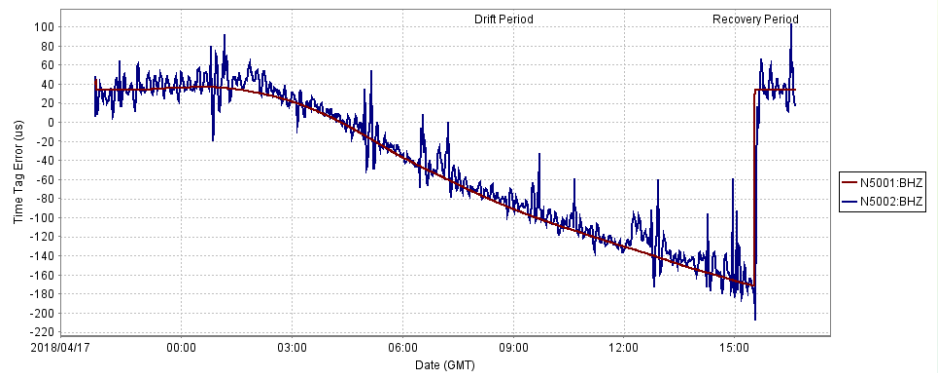
Self noise power spectra Z channel 40sps and 100 sps



Self noise power spectra Z channel 20sps and 80 sps

- Input terminated (50 Ω) self noise tests on two units at various sampling frequencies
- Report remarks: *Higher sampling rates exhibit lower spectral noise levels than lower sampling rates, indicating that the Centaur has very low electronic noise and that the dominant noise source at high frequency is consistent with quantization noise being distributed over a wider frequency pass-band.*
- At unity gain, noise free bits of 23.5 bits at 40Hz and 23.3 bits at 100Hz
- Temperature related self noise: No change in self noise observed over -10 to 40C

Digitizer Time Tagging



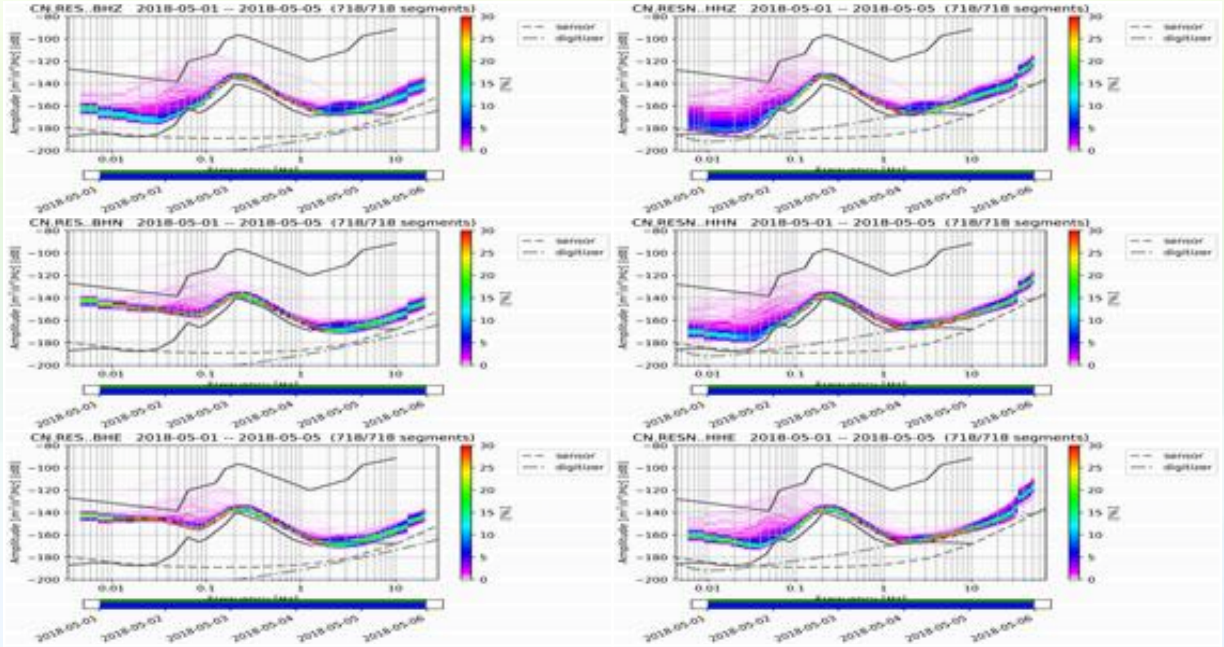
Timing drift with time source removed (this example for PTP), and recovery

- Timing can be GPS, NTP, or PTP
- Accuracy 2.4µs with GPS
- Drift 15.548 µs/hr with GPS and 15.873 µs/hr with PTP
- Recovery from drift within 2 minutes (GPS)

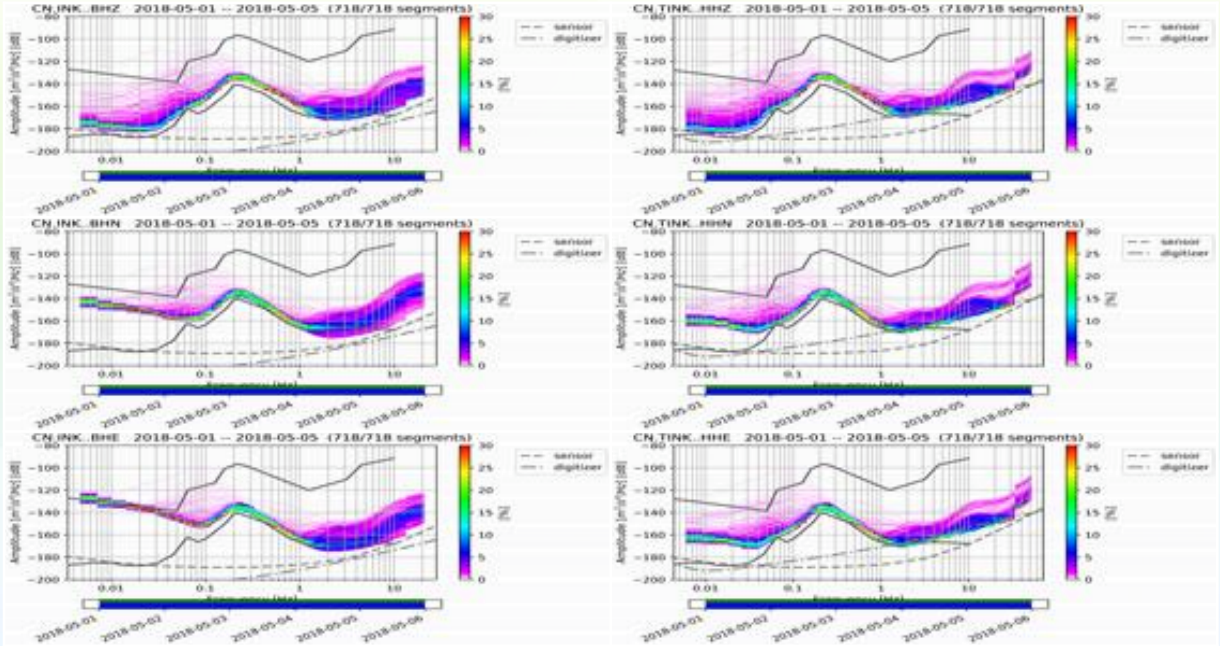
Real World Experience

- Comparisons performed against operating IMS stations in Resolute (AS16) and Inuvik (AS17)
- In winter particularly these are very low noise sites
- This comparison conducted in winter 2017/18 with Trillium 120QA and non-IMS versions of Centaur digitizer
- Look at PSD

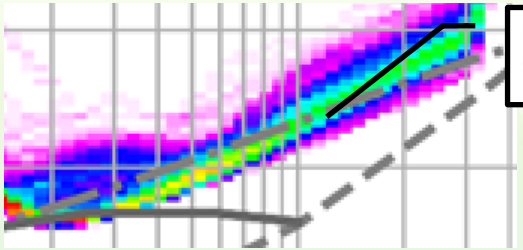
Comparison of PSD IMS RES vs test RESN



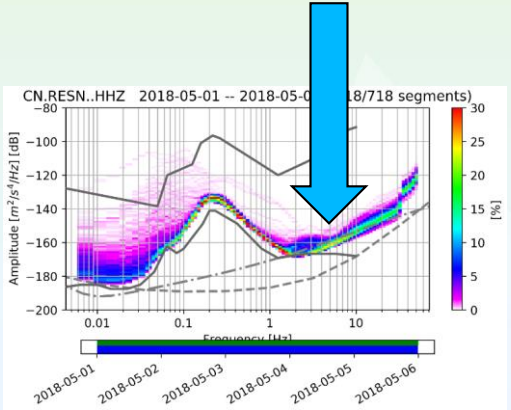
Comparison of PSD IMS INK vs test TINK



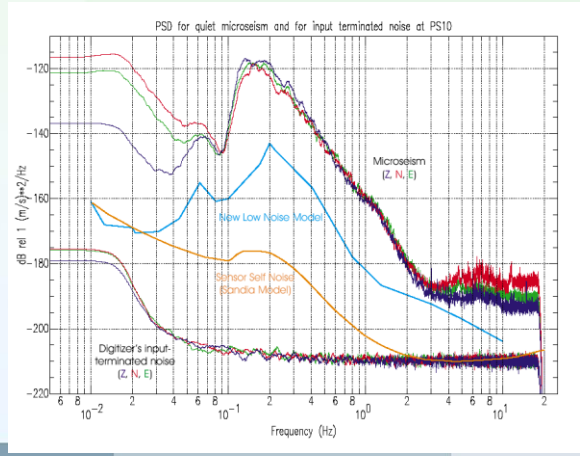
Gain Settings and System Noise



Digitizer Noise (dash dot) is of same order as site noise

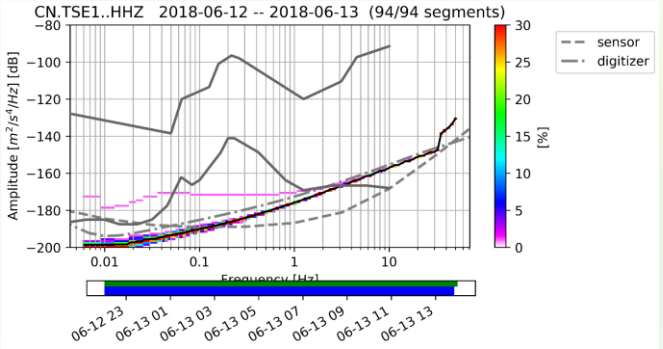


- This is not a good situation and is non compliant with the specification.
- For earlier certifications (PS10 below), digitizer noise and sensor noise are comparable, but PTS allowed as both well below site noise.
- This is not the case here as digitizer noise higher



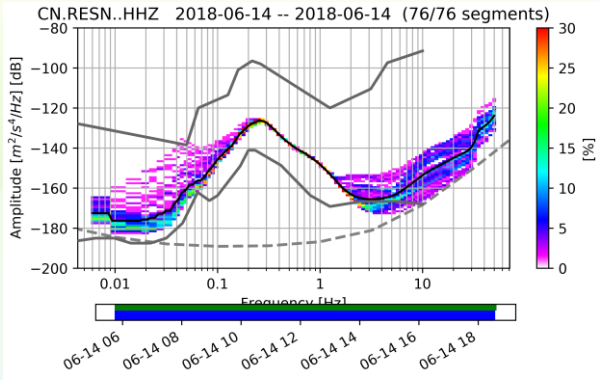
Check Real Input Terminated Noise

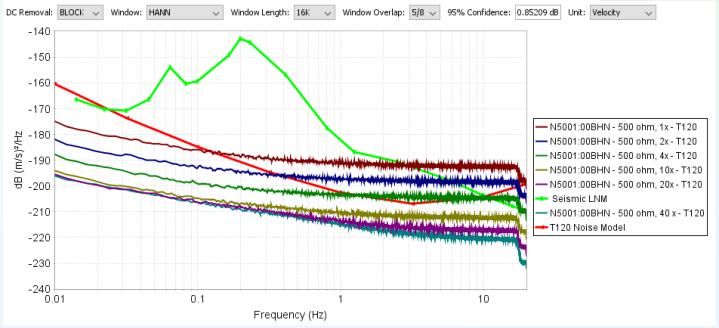
- Previous plots show a noise model
- Look at real system (TSE1) in the vault at Ottawa with terminator
- Measured noise slightly better than model, but consistent
- Confirm that with unity gain digitizer noise can be above NLNM



Change Digitizer Gain

- Trillium sensitivity is 1202.5 V/(m/s)
- Centaur standard unity gain (40Vpp) 4.81E8 cnt/(m/s)
- Change to gain of 10 (4Vpp) , 4.81E9 cnt/(m/s)
- Now 10 dB below sensor, but still well below site noise
- Behaviour is borne out in Sandia testing as well



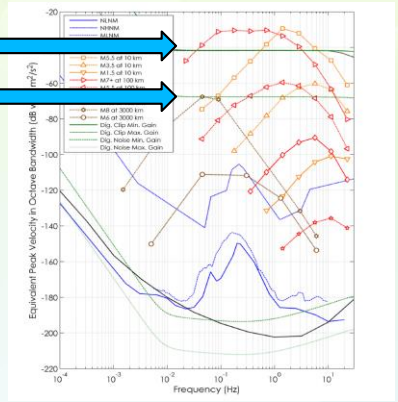


Configuration for Earthquake Monitoring

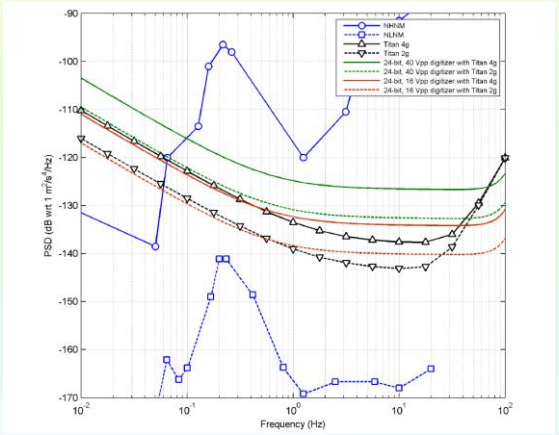
- Stations serve both to support IMS and measure earthquake characteristics
- Gain change would result in clipping for large events at a lower level
  - Clip at 40Vpp 20.97V, at 4Vpp 2.1V
- Supplement station with an accelerometer (Titan) on its own digitizer
- Trillium and Titan ranges overlap providing full coverage

Clip at 40Vpp

Clip at 1Vpp



Trillium clip levels



Titan noise floor levels

Summary / Next Steps

- Nanometrics has successfully developed a modern set of instrumentation suitable for IMS use
- Digitizer evaluation successfully completed at Sandia and digitizers accepted for IMS use by the PTS
- Comparisons with at existing sites have positive results
- Remains to finalize calibration procedures
- Initial field deployments at Canadian stations underway