20th ATF2 Project Meeting

14-15 March 2017

CERN, Geneva

Demonstration of active orbit feedforward based on ground motion in ATF2

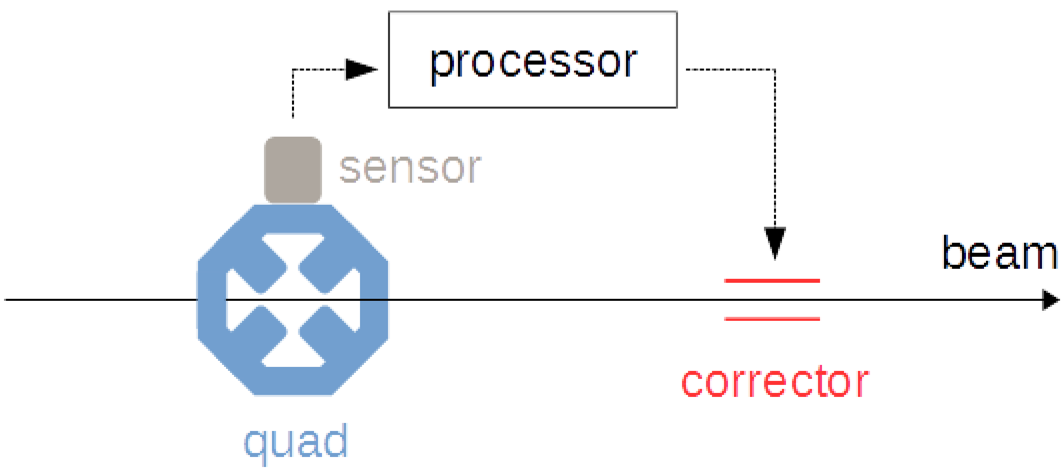
Douglas BETT

Outline

- Introduction
- Description of system
- Latest results
- Conclusions, outlook & summary

Ground motion feed-forward

- Similar concept to orbit feedback but uses **seismometers** instead of BPMs to drive the correction



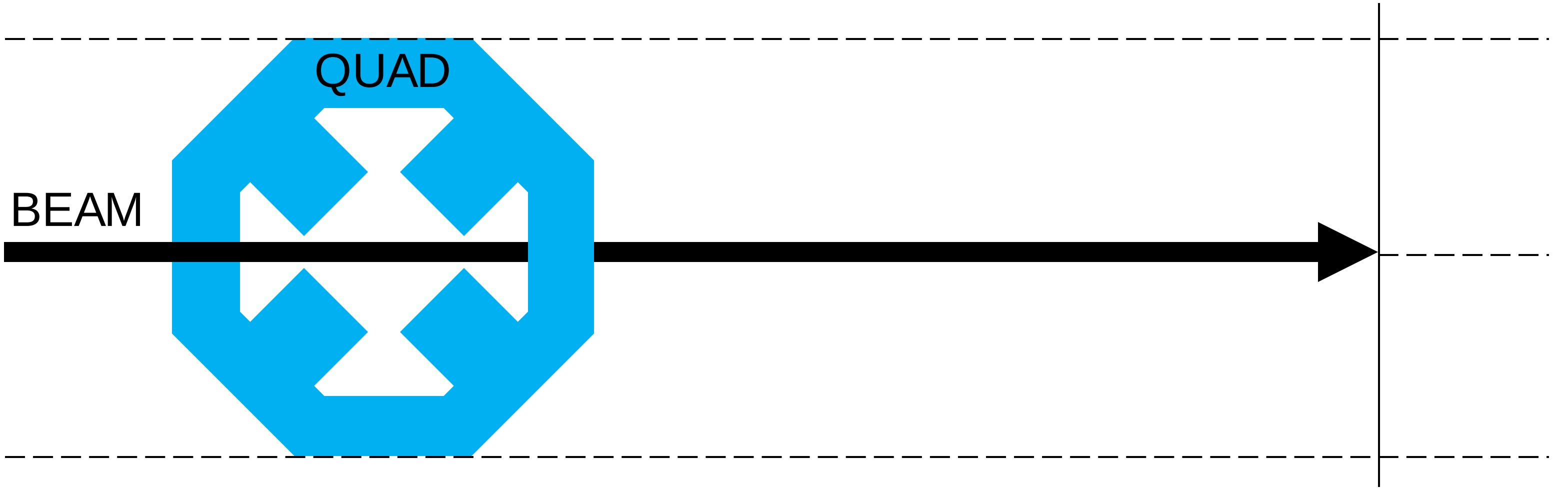
ADVANTAGES

Cheaper than active stabilization systems.

Correct frequencies out of limits for orbit feedback systems.

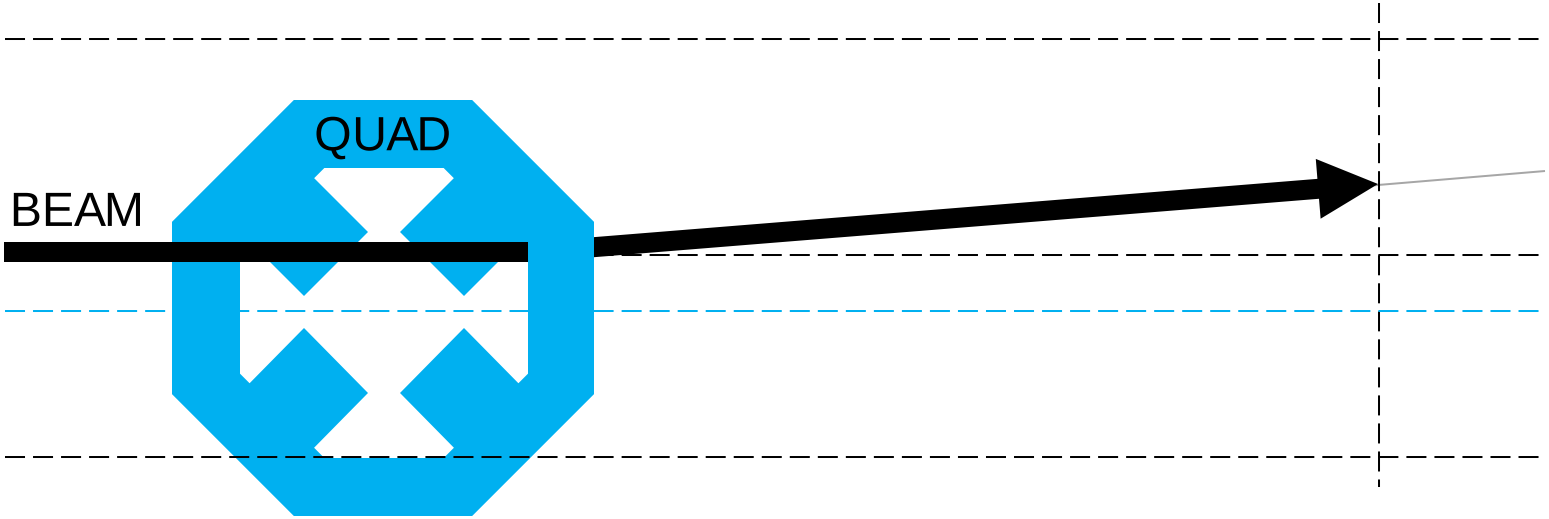
Concept

Quad in nominal location → beam in nominal location



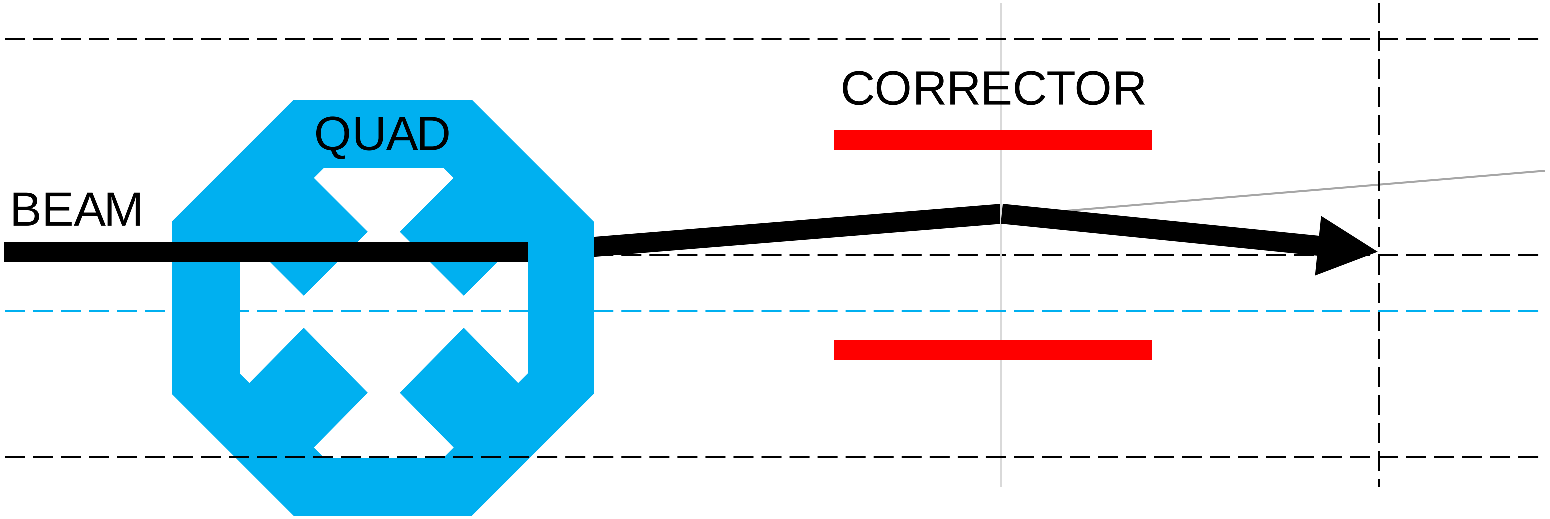
Concept (II)

Displacing quad results in dipole kick → beam moved



Concept (III)

Use corrector to bring beam back to nominal location

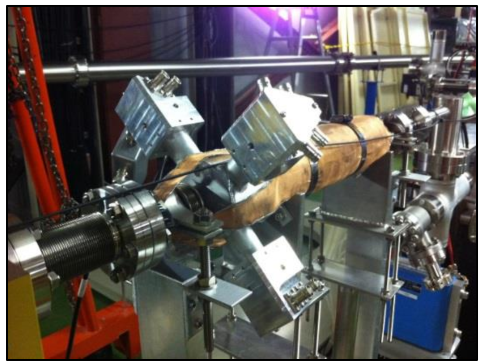


Feed-forward hardware

seismometers

FONT hardware

stripline kicker



drive pulse

kicker amplifier

trigger

drive pulse

FONT5 board

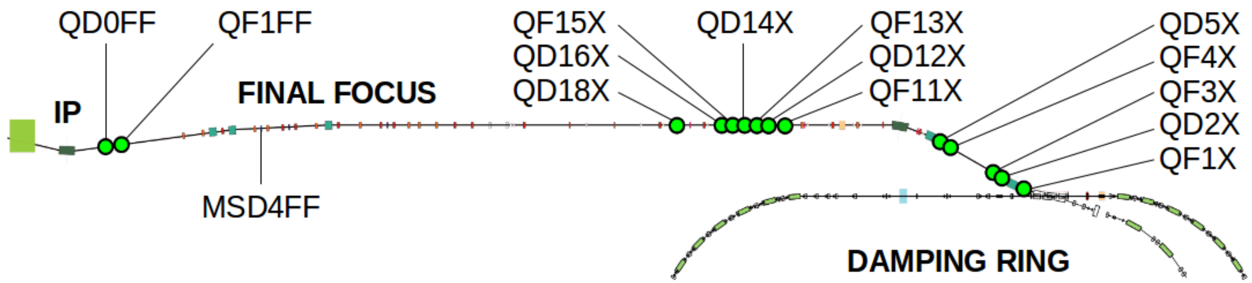
feed-forward correction value
(dedicated digital link)

velocity signal

CompactRIO
(local control room)

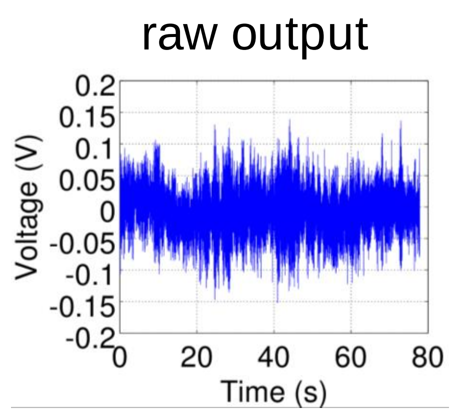
trigger

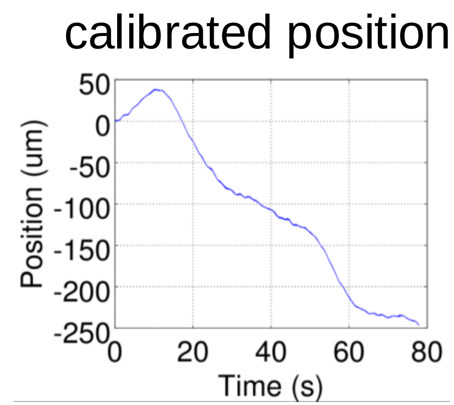
Feed-forward hardware (II)



SEISMOMETERS

- 14 Güralp Systems model CMG-6T
- Frequency response: 0.2 – 100 Hz
- Measure velocity in horizontal and vertical axes
- Best results when mounted on quads

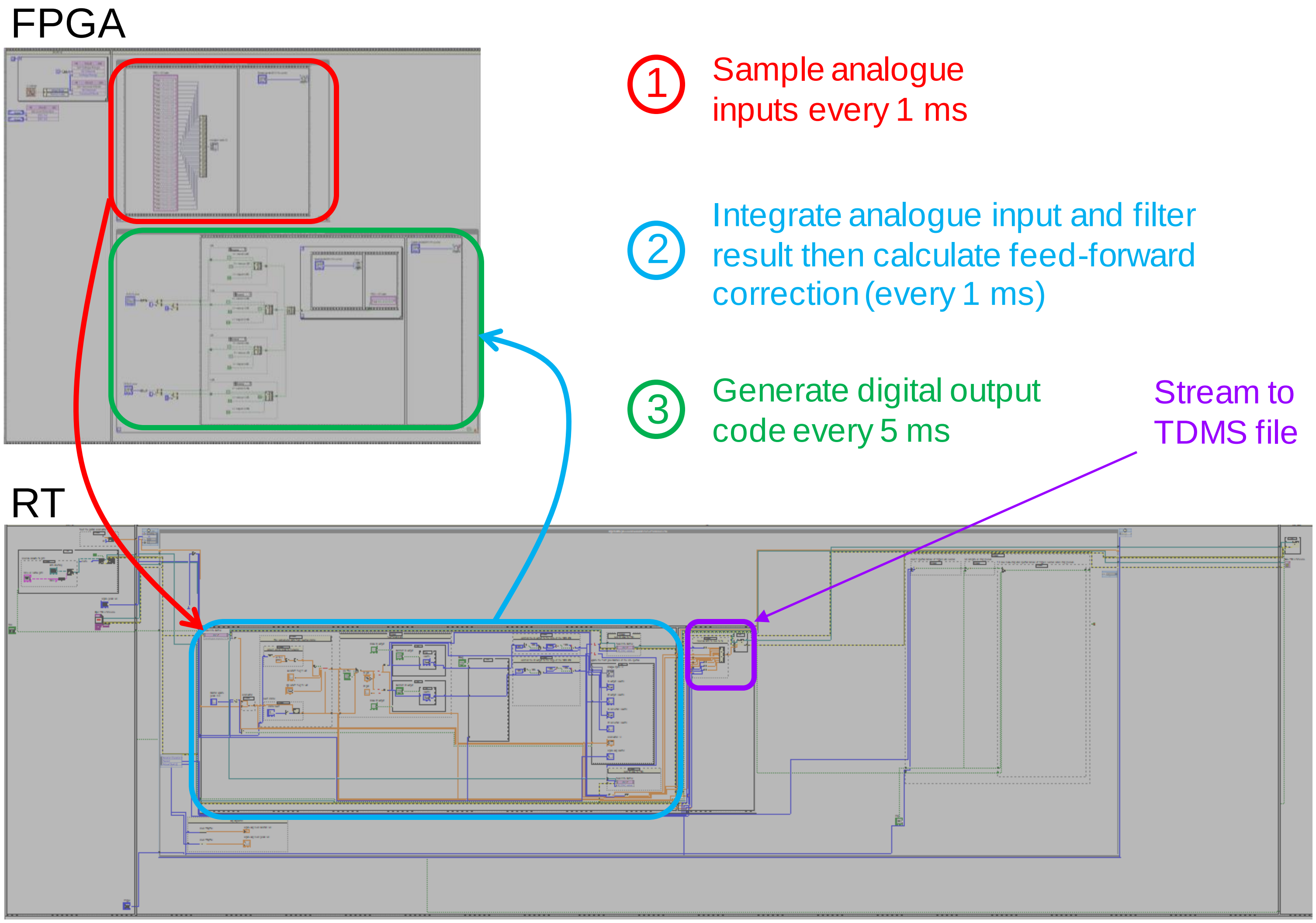




FEED-FORWARD PROCESSOR

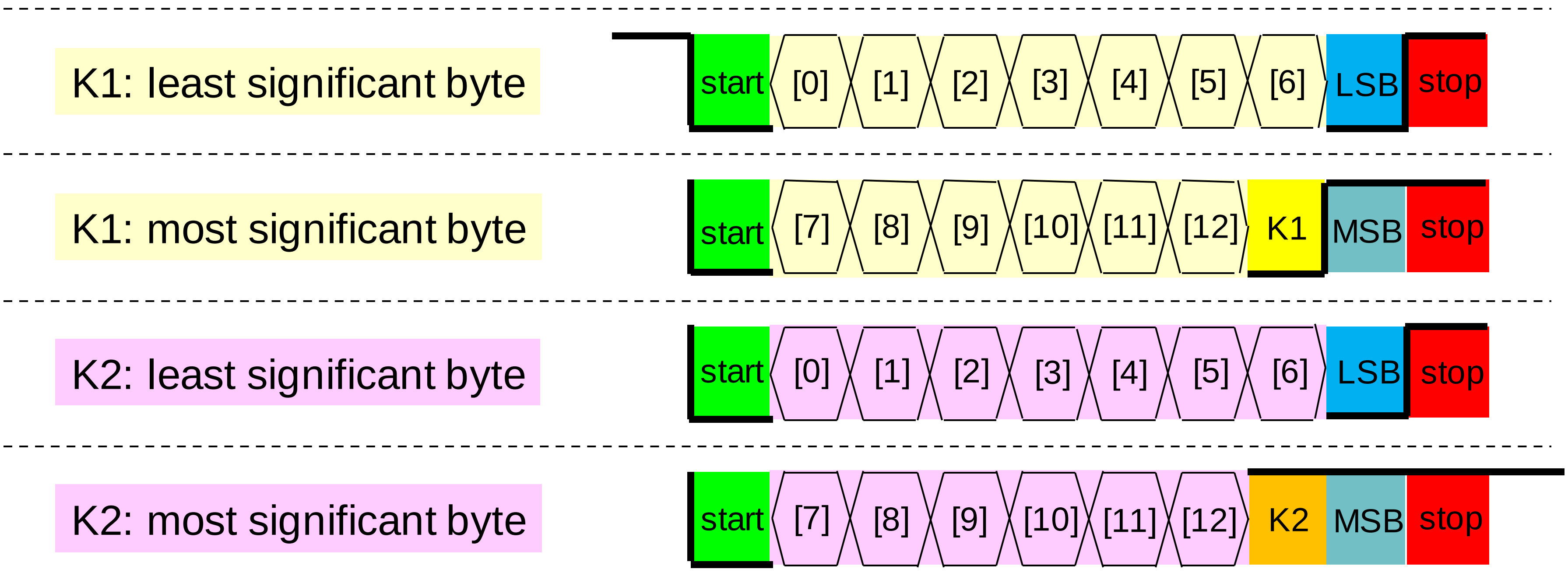
- National Instruments CompactRIO-9064 real-time controller chassis running real-time LabVIEW
- Contains Artix-7 FPGA and following IO modules: 9205 (analogue input), 9401 (digital I/O), 9263 (analogue output)

Feed-forward software



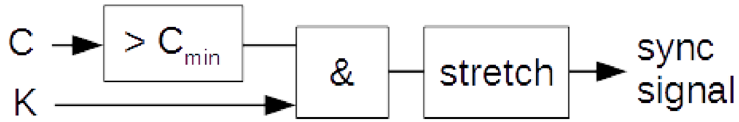
Dedicated digital link

- Send the digital output of the CompactRIO system to the ring clock input of the FONT5 board over RG58 cable
- 4-byte code, baud rate of 1.84 Mbits/second → transmission takes 20 μs



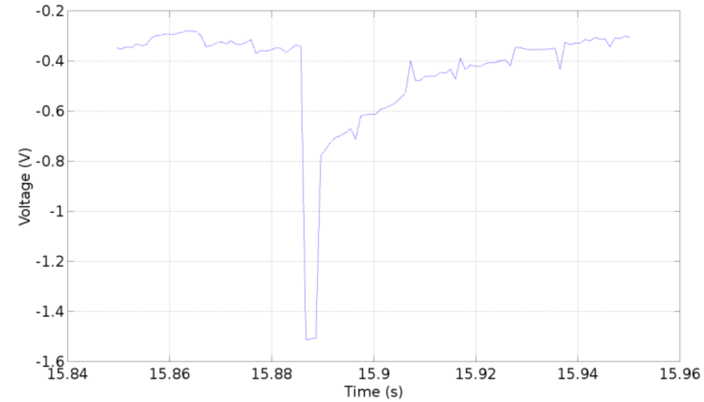
Synchronization signal

- Extra signal digitized by CompactRIO
- Used to synchronize seismometer and BPM data in order to calculate correlations
- Requires careful setup

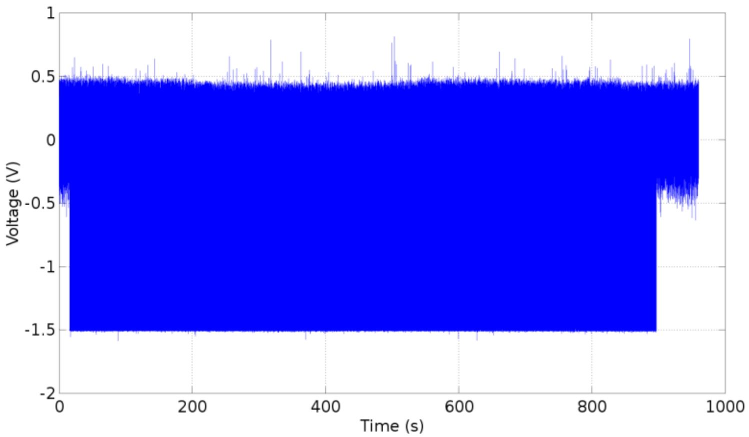


inputs
C – beam charge
K – kicker trigger

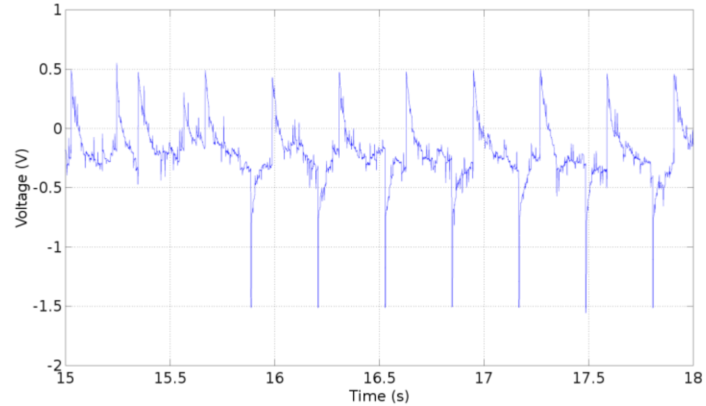
single pulse



whole run

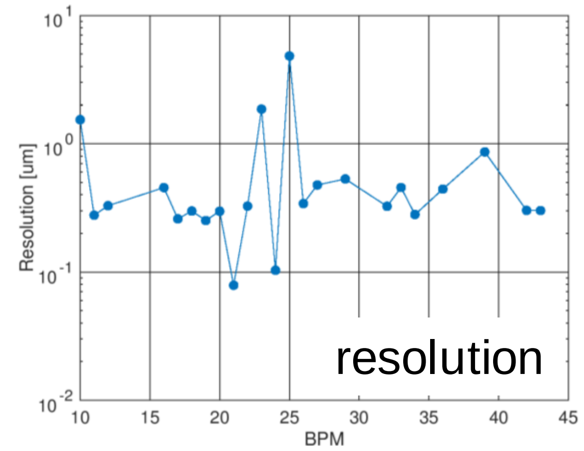


on/off transition

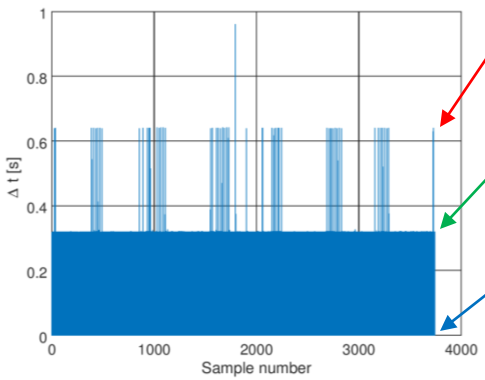


BPM data

- BPM data (x, y, charge) gathered from Flight Simulator at 12.48 Hz
- Use timestamp analysis to identify missing triggers (~5%)
- Use charge signal to identify beam on/off



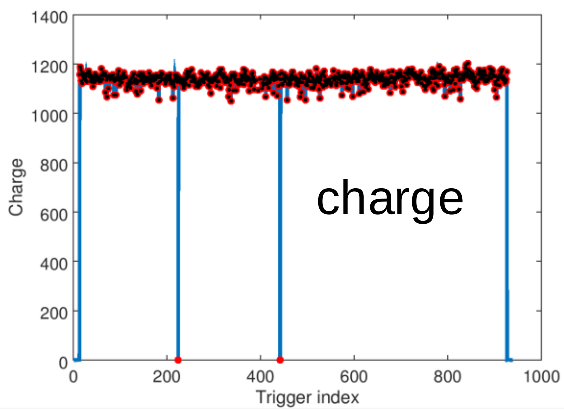
change in timestamp

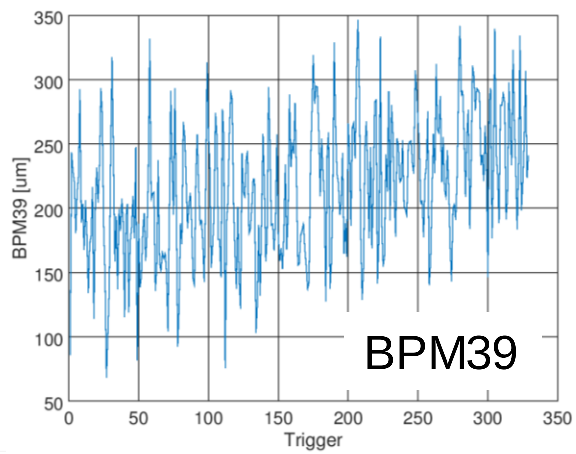


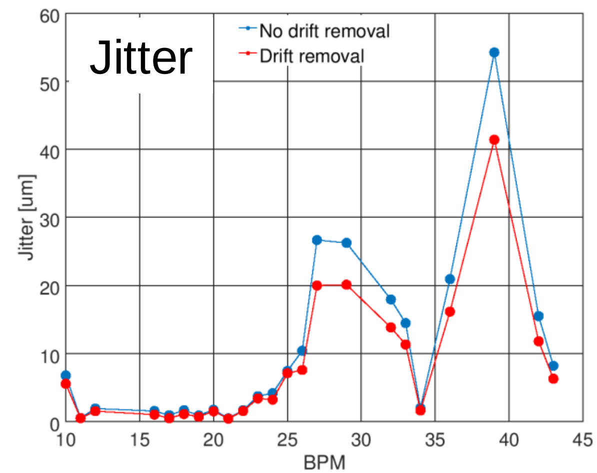
Change ~ 0.64 s → missed trigger
Insert dummy value in data set

Change ~ 0.32 s → update
Keep

No change → duplicate
Discard



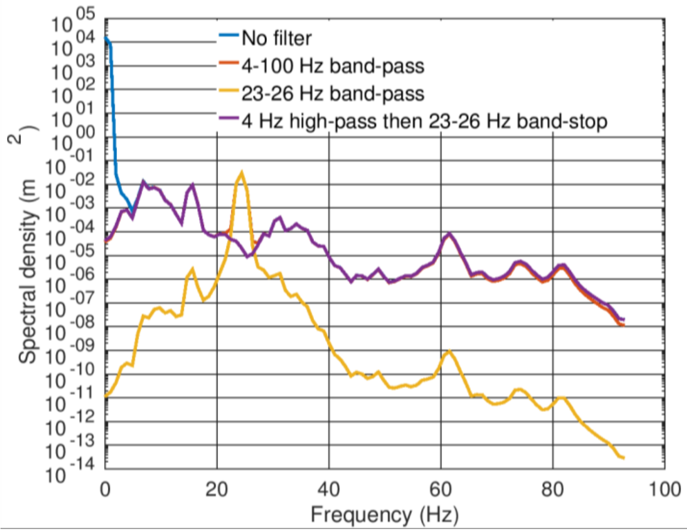


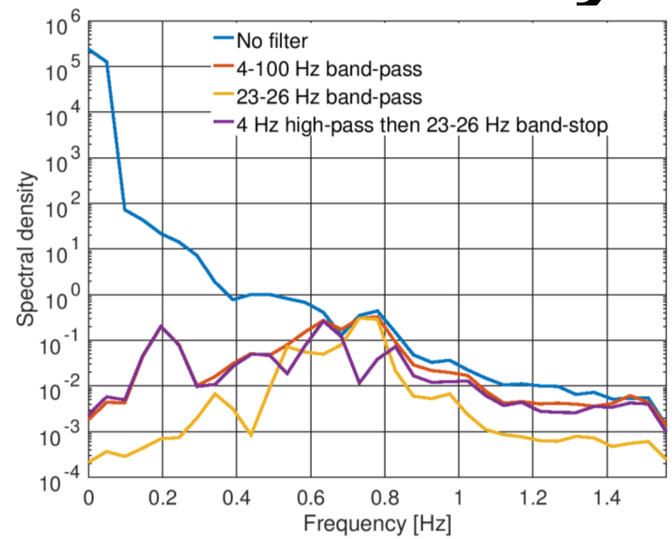


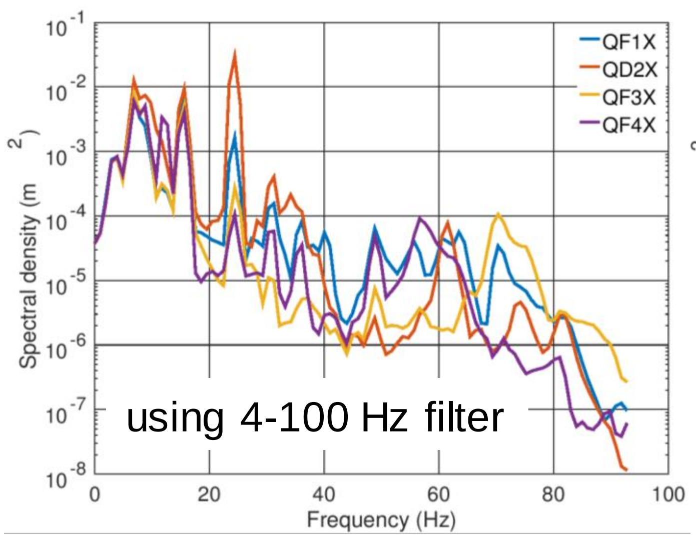
Latest results

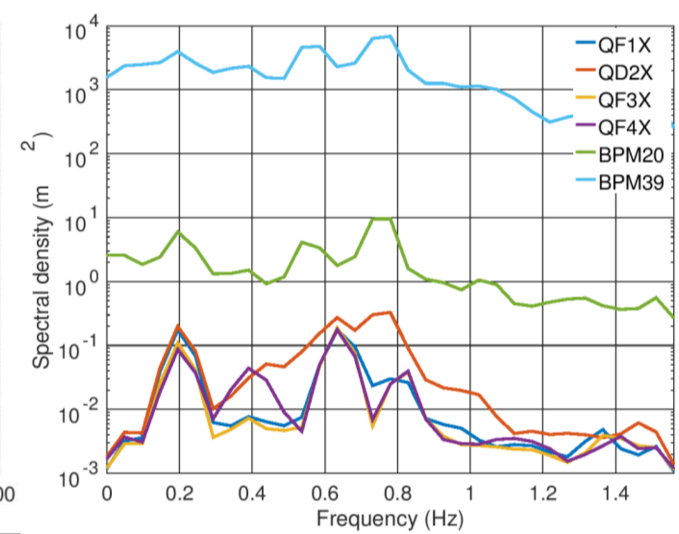
- From owl shift on 24 February 2017
- Seismometers placed on first four quads
- Several studies performed:
  - K1 gain scan, QD2X, 23-26 Hz filter
  - K1 gain scan, QF1X, 23-26 Hz filter
  - K2 gain scan, QD2X, 4-100 Hz filter
  - And many runs with feed-forward off

Spectral density





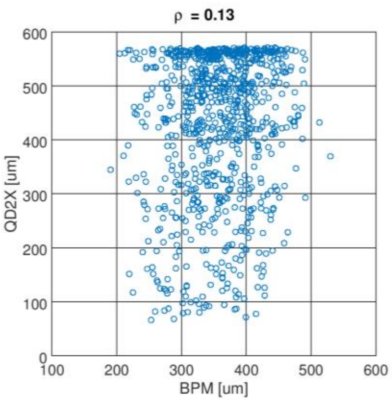




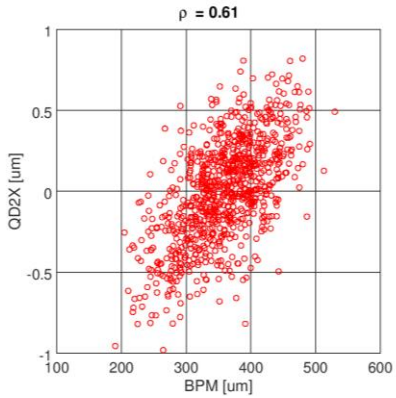
- Natural frequency of seismometer data is 1000 Hz, so synchronization signal used to down-sample to 3.12 Hz
- 23-26 Hz peak aliases to 0.76 Hz in down-sampled spectrum
- BPM spectra are similar and feature three prominent peaks: 0.20 Hz, 0.56 Hz, 0.76 Hz

Quad-BPM correlation

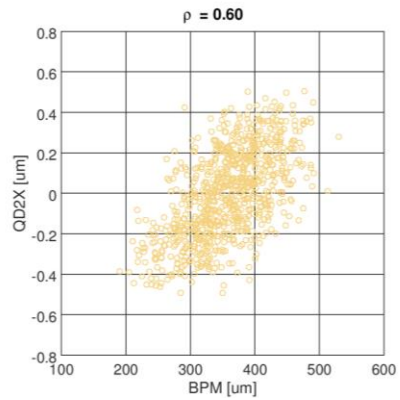
No filter



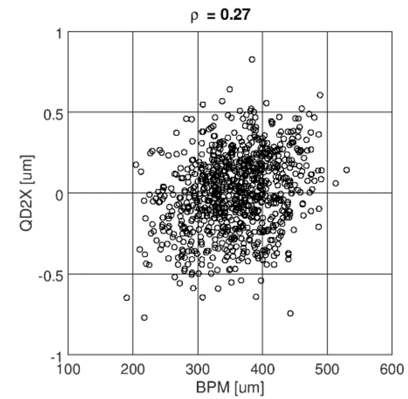
4-100 Hz band-pass



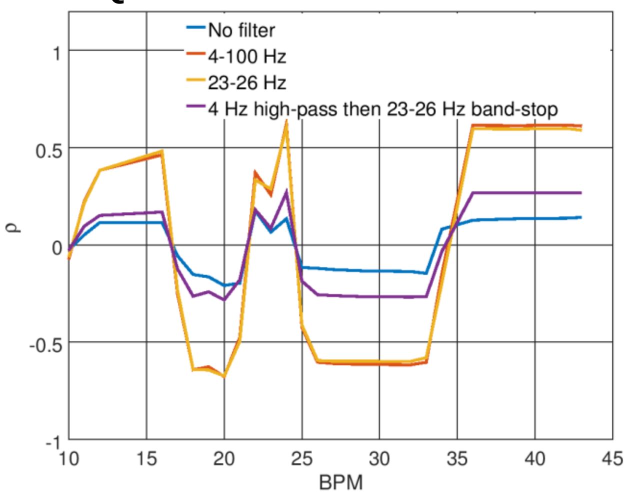
23-26 Hz band-pass



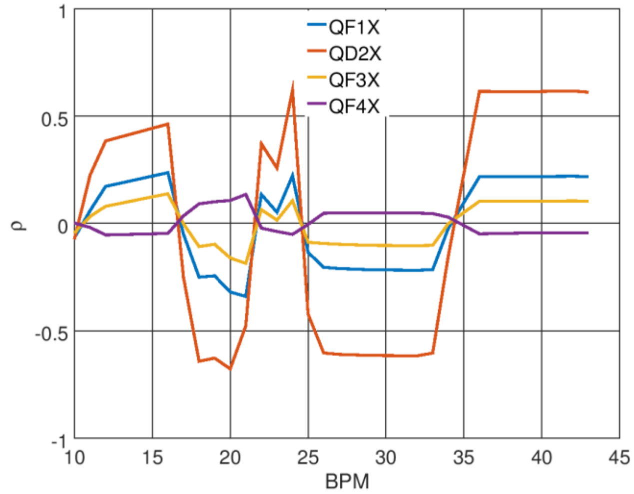
4 Hz high-pass 23-26 Hz band-stop



QD2X-BPM correlation

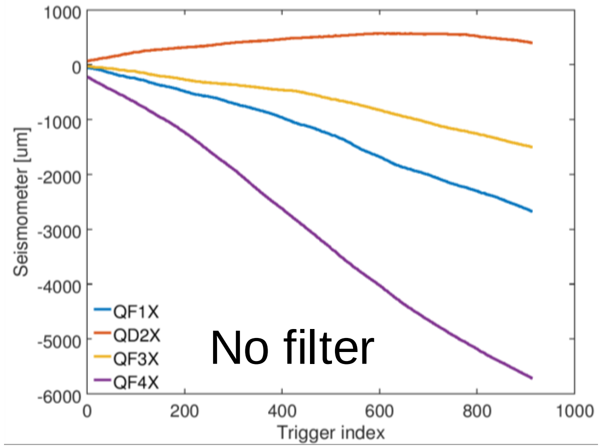


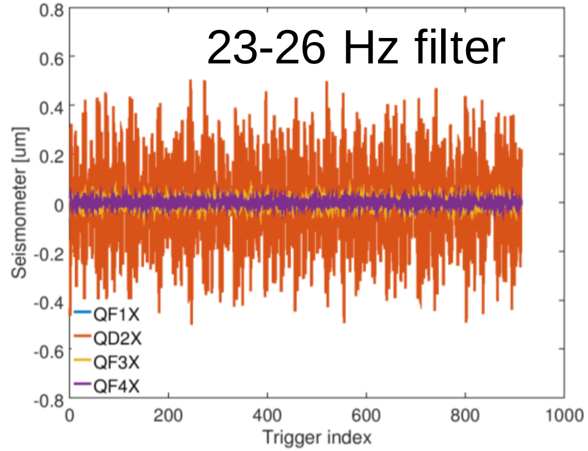
4-100 Hz band-pass filter



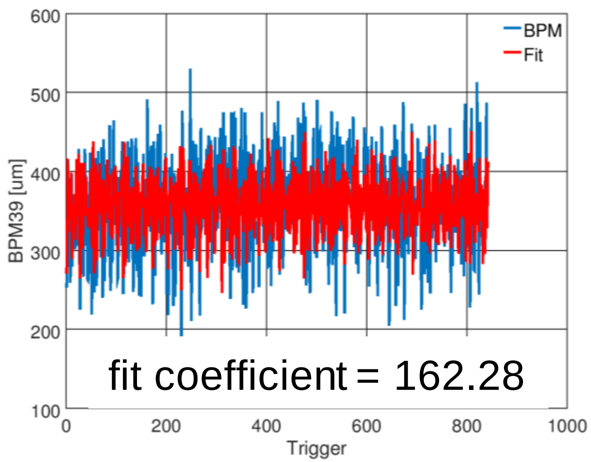
- Most correlation due to 23-26 Hz peak
- Highest correlations observed for QD2X

Fit to BPM data

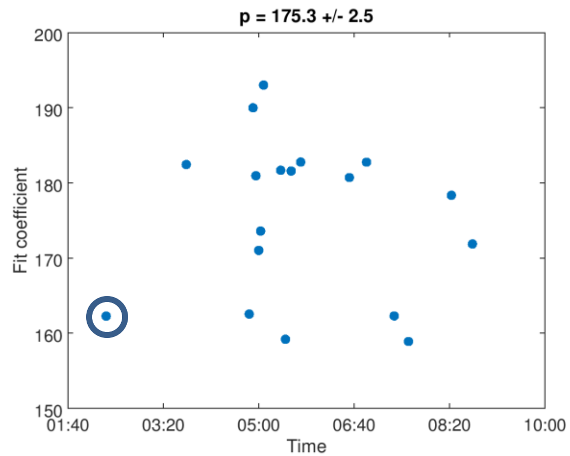




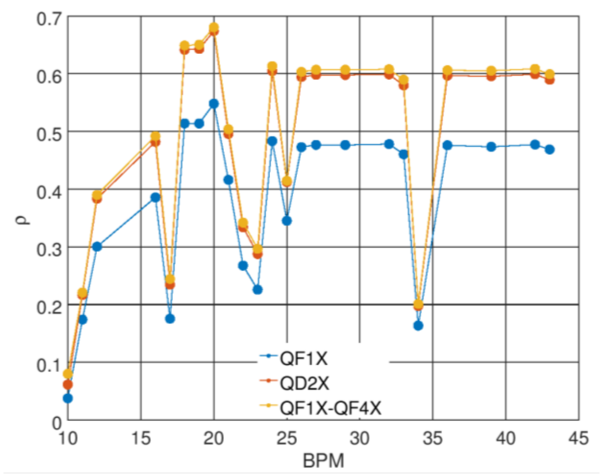
- Perform linear fit of (filtered) quad position to BPM position i.e. $y_P = p_1 y_Q + p_2$
- Fit coefficient stable to within 10% for ~8 hours
- Fitting using additional quads not necessary



Fit coefficient



BPM-fit correlation

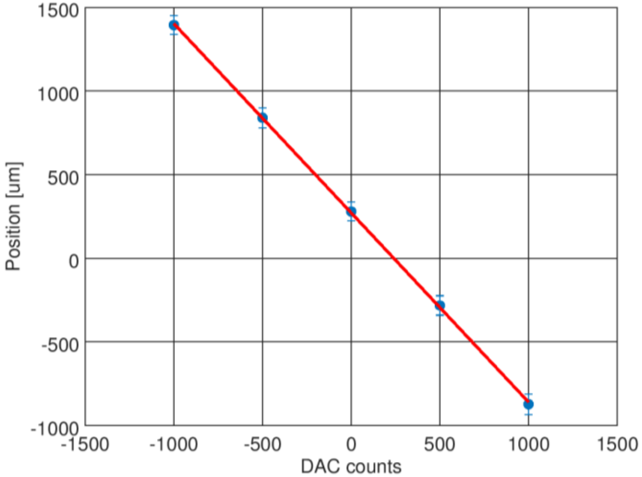


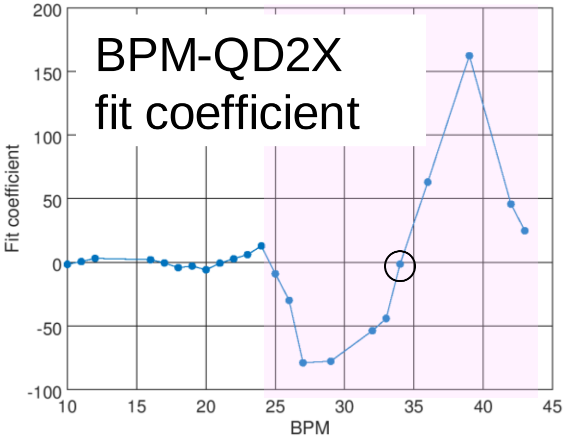
Feed-forward gain

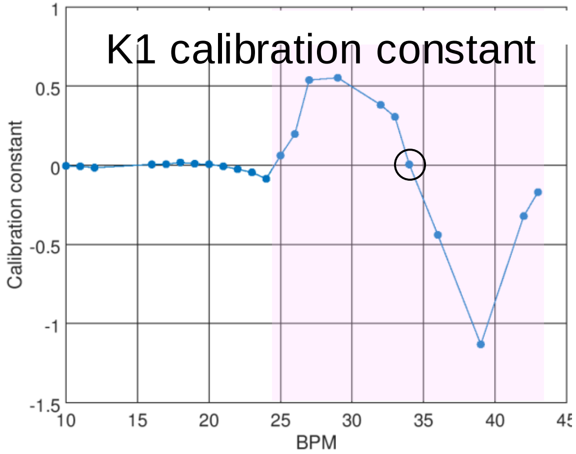
Ratio of two measured parameters
- Fit coefficient of BPM data to QD2X data
- Kicker calibration constant [μm/count]

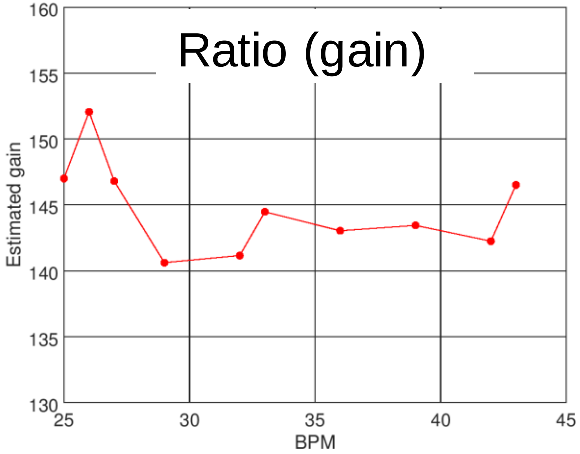
Calculated K1 gain for this run: ~145

Kicker calibration: K1→BPM39



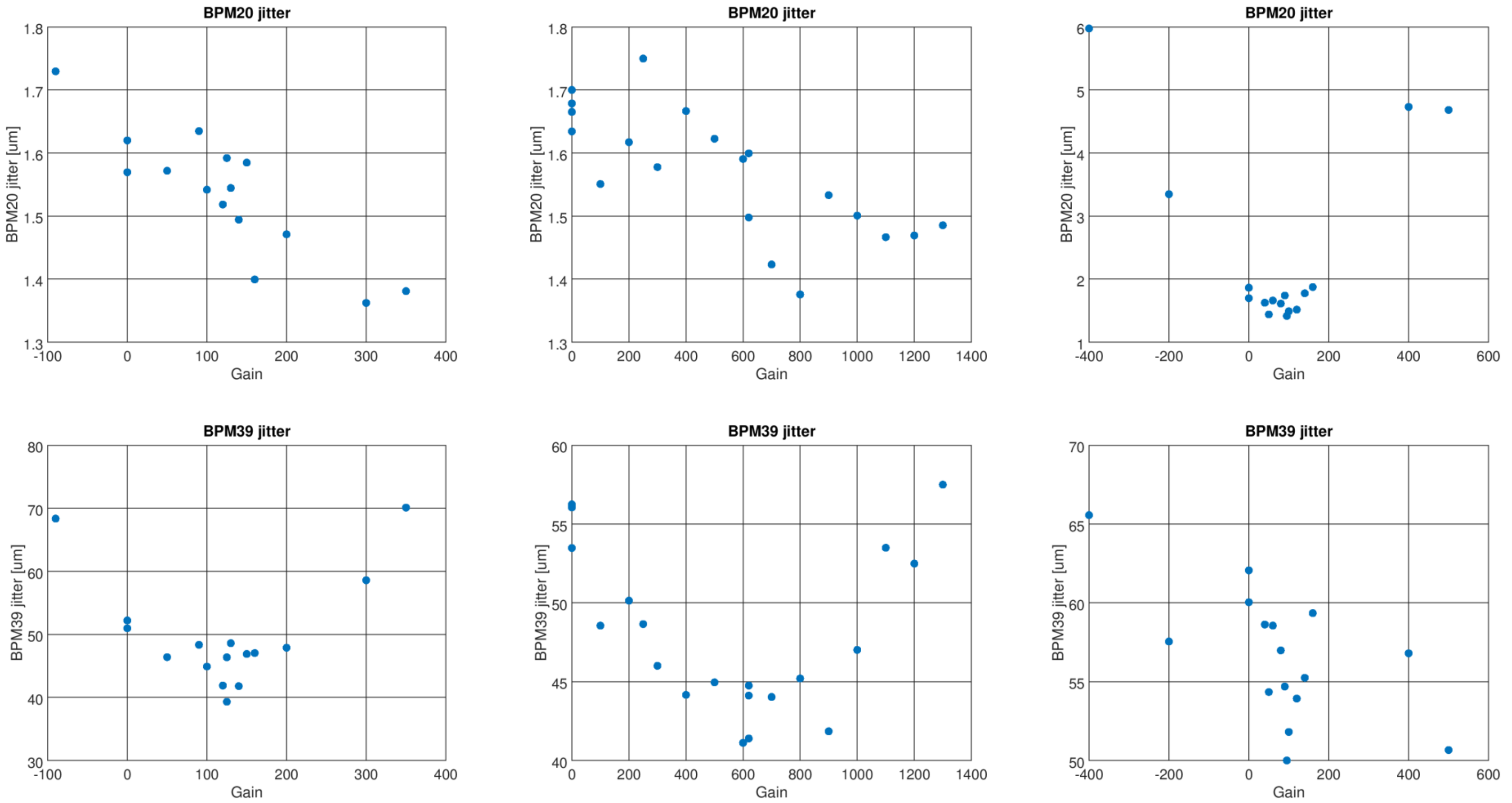






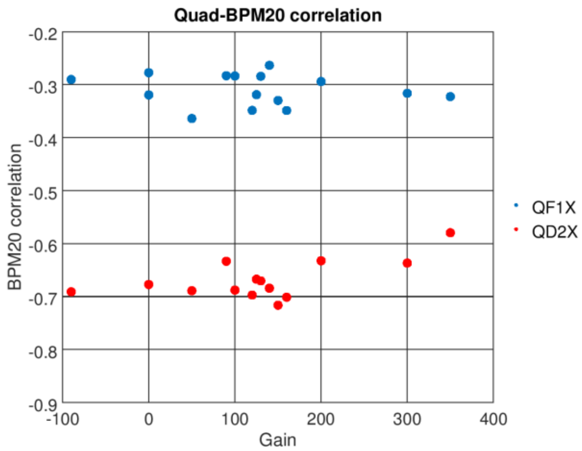
Results: BPM jitter

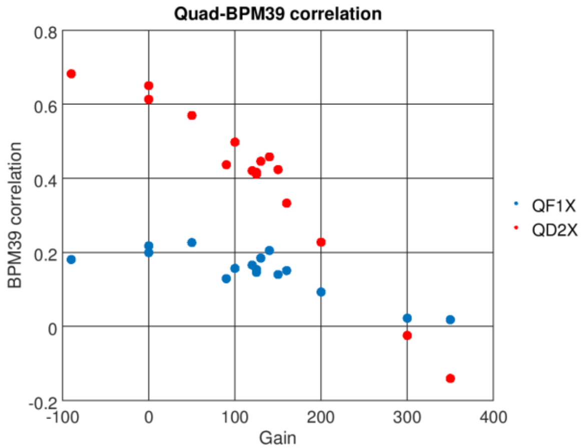
K1, QD2X, 23-26 Hz | K1, QF1X, 23-26 Hz | K2, QD2X, 4-100 Hz



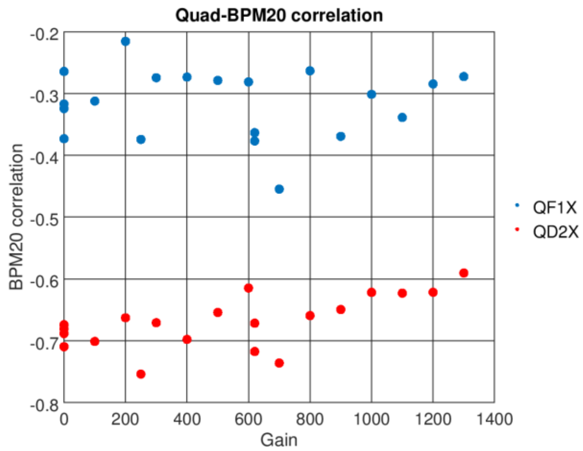
Results: Quad-BPM correlation

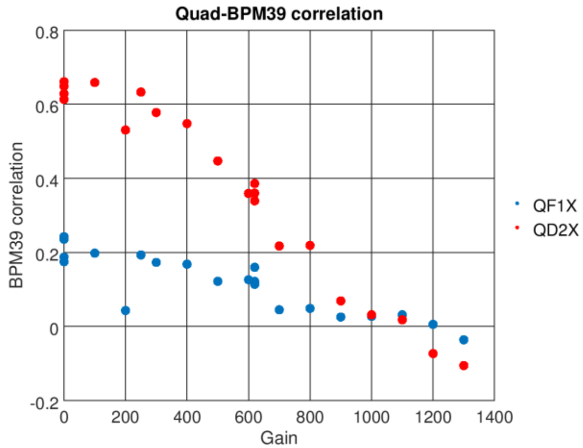
K1, QD2X, 23-26 Hz



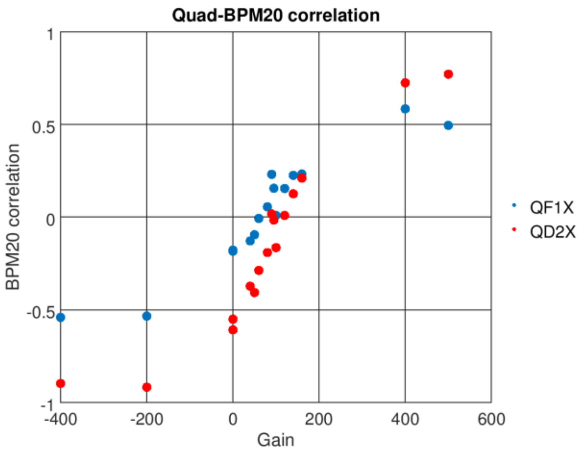


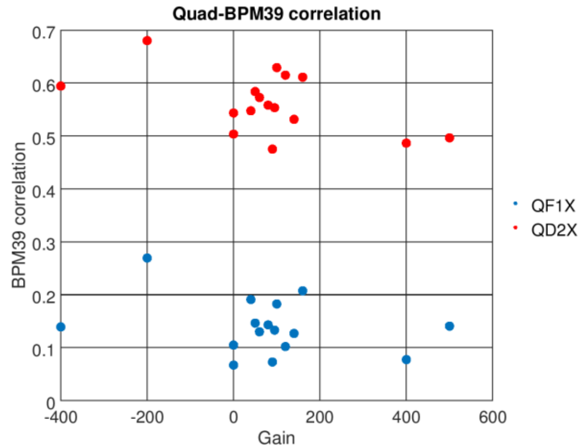
K1, QF1X, 23-26 Hz





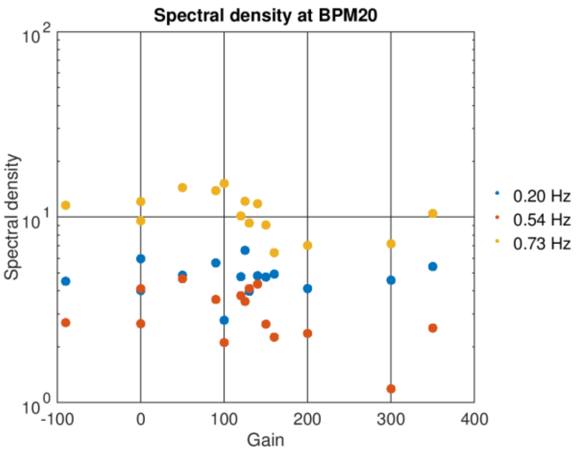
K2, QD2X, 4-100 Hz

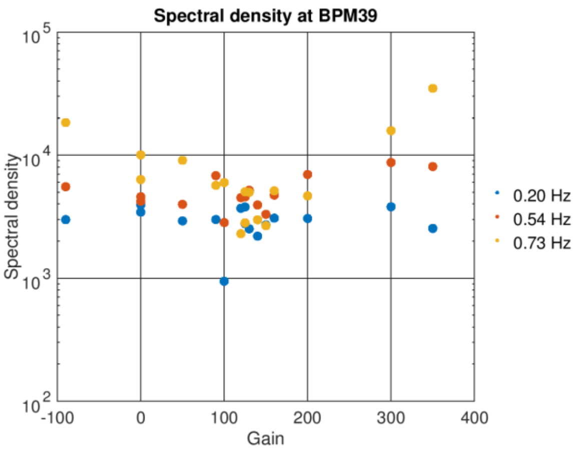




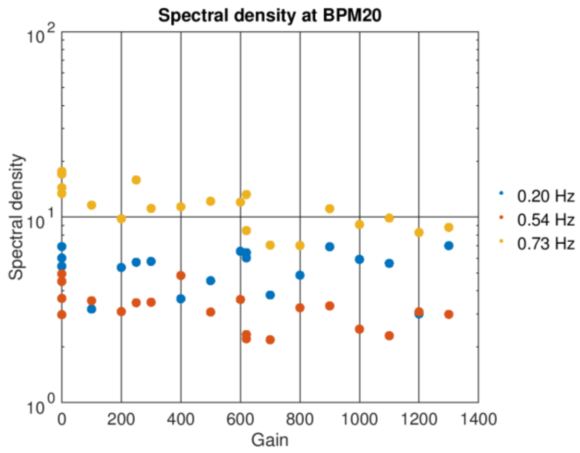
Results: Spectral density

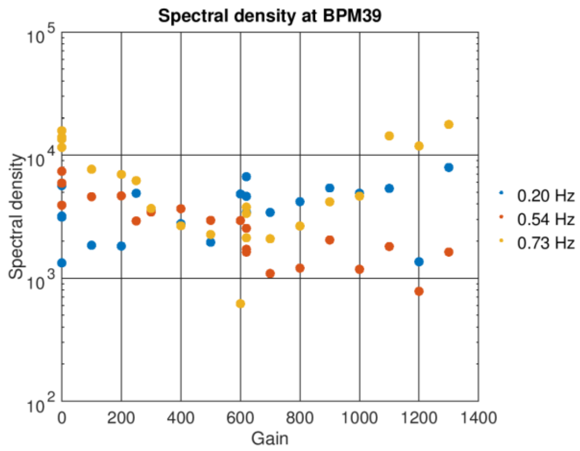
K1, QD2X, 23-26 Hz



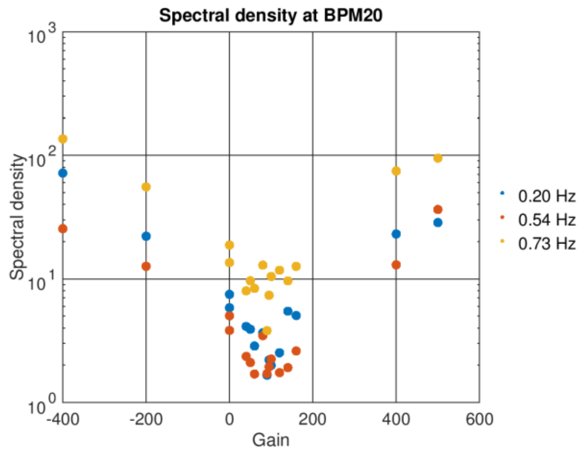


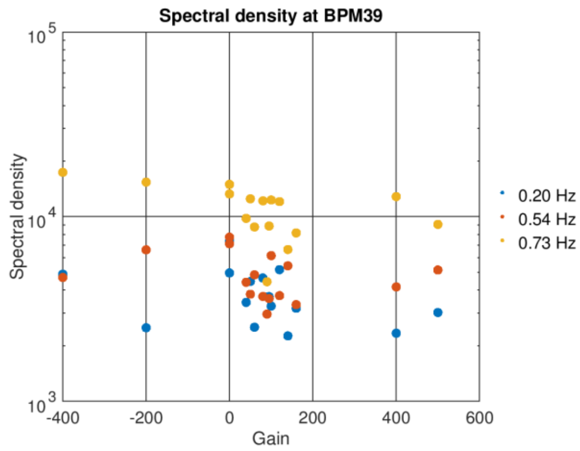
K1, QF1X, 23-26 Hz





K2, QD2X, 4-100 Hz





Conclusions

- Beam dependence on quad motion stable within 10% on 8 hour timescale
- QD2X correlation superior but decent performance achieved using QF1X
- Kickers highly decoupled (by design)
  - K1 corrects at BPM39, K2 corrects at BPM20
- Wide-band filter → wide-band correction

Summary

- Technique of ground motion feed-forward uses seismometers mounted on quads to correct vibration-induced beam motion
- Prototype system realized using an off-the-shelf FPGA unit in conjunction with the existing FONT hardware
- Consistently able to achieve ~20% jitter reduction → **technique validated!**

- Next step: demonstrate a “global” correction