Improving Sensitivity on Kea CubeSat GPS Receivers

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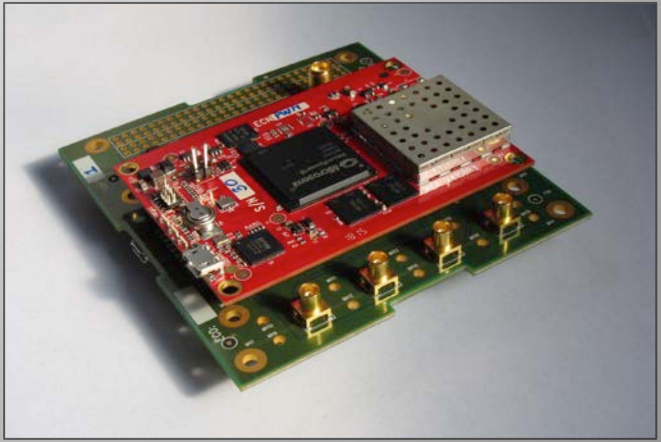
Kea CubeSat GPS Receivers

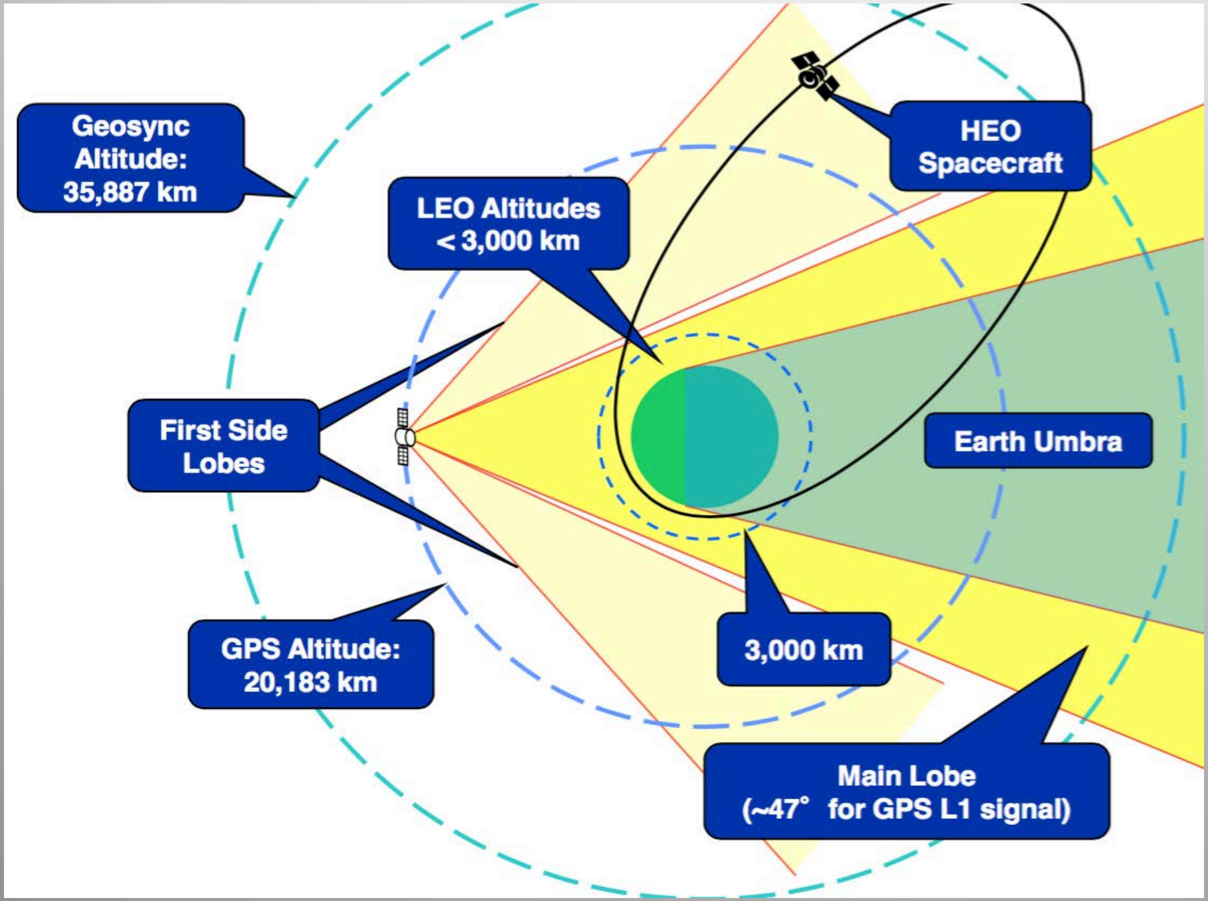
- Follow-on from Namuru V3.2R3A developed for DST-Group Biarri program
- L1 C/A code GPS receiver with features designed to support in-orbit and high dynamics operation
- SmartFusion 2 SoC & BL2627 RFFE
- To be flown on 3 CubeSat missions
  - Buccaneer Risk Mitigation
  - UNSW QB50 EC0 and
  - USyd QB50 iInspire 2



High Sensitivity in Space

- Some space applications have weak signals
- GPS Radio Occultation
  - Signals passing through the atmosphere's limb are weak and subject to ionospheric fading
  - Continuous phase lock needed for carrier phase observations
- GPS in medium, high or geostationary orbit
  - Space Service Volume aims for consistent performance in MEO, HEO & GEO
  - Navigation requires use edges of GPS beam pattern and side-lobes

Space Service Volume



http://www.**gps**.gov/governance/advisory/meetings/2015-06/bauer.pdf

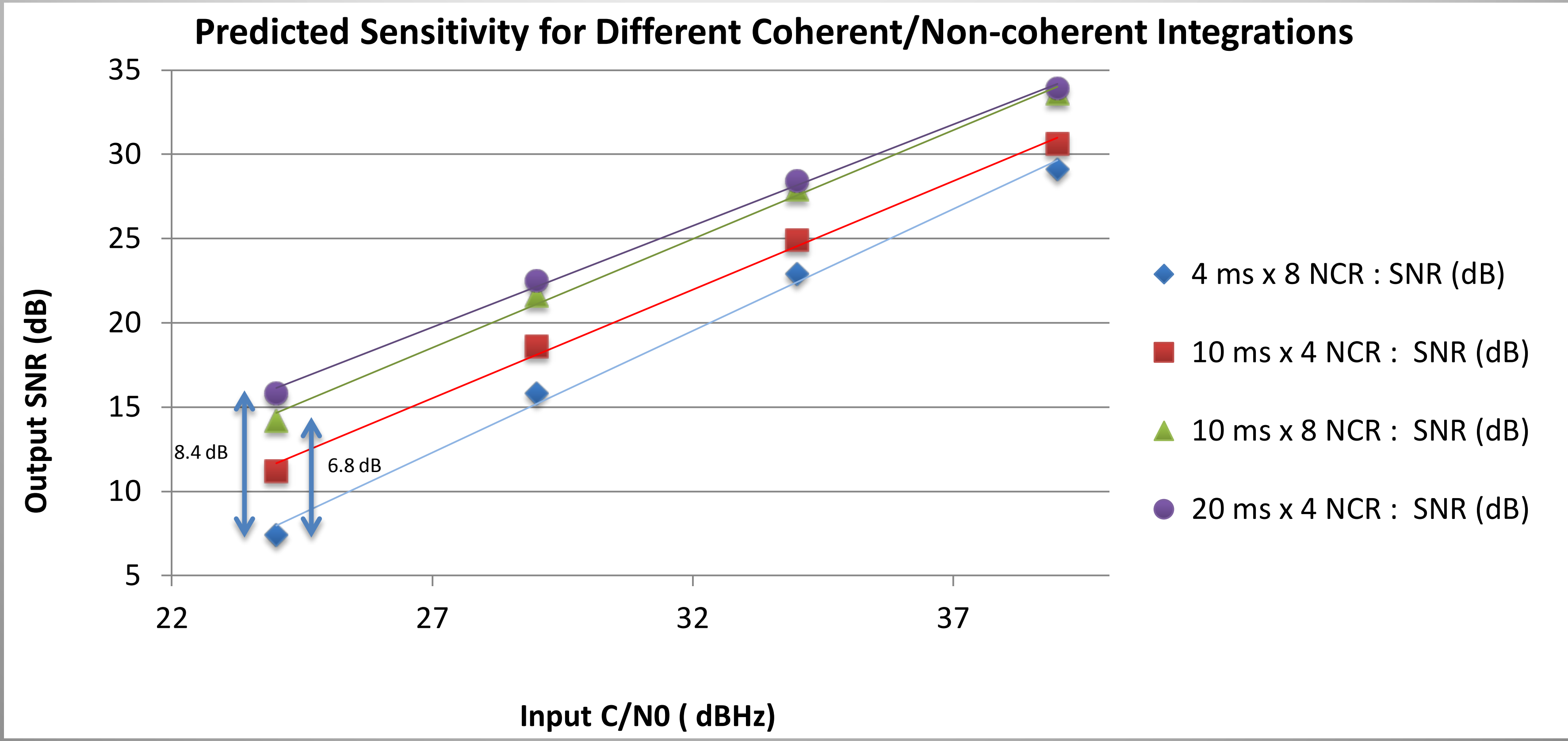
High Sensitivity GPS

- High sensitivity techniques developed for cell-phone AGPS
  - Combination of longer coherent integration (CI) periods (i.e. separate accumulation of in-phase and quadrature phase channels)
  - Up to 20 ms without data wiping
  - Longer CI reduces squaring losses, but increases number of searches
  - Non-coherent integration (NCI) for additional sensitivity (i.e. accumulation of magnitude or magnitude squares of I & Q)
- Acquisition assistance for reduced search times
  - Less feasible for MEO, HEO & GEO, but TLEs could be used
- Search acceleration hardware
  - Useful for acquisition, but not for tracking

KeaV41SBR4 Modifications

- Pre modification sensitivity not great!
  - 4 ms coherent integration (CI), so bandwidth is 250 Hz
  - 8 non-coherent rounds of integration (NCRI)
  - PLL ran at 2 x 4 ms, but detection as above
- Improvements required
  - Ability to support up to 20 ms CI, with 4+ NCRI
  - DSP produces ½ dumps for FLL to allow FLL to run at the same rate as the PLL
  - PLL runs at up to 20 ms, so bandwidth is 50 Hz
  - Detection using 20 ms x 4+ NCRI
  - Automatic switch to higher CI when bit-synchronisation achieved

Sensitivity Predictions



van Diggelen Sensitivity Spreadsheets

Adaptive Thresholds

- High sensitivity requires SNR to be maximized
- Longer coherent integration reduces squaring losses
- Additional non-coherent integration further improves SNR

BUT

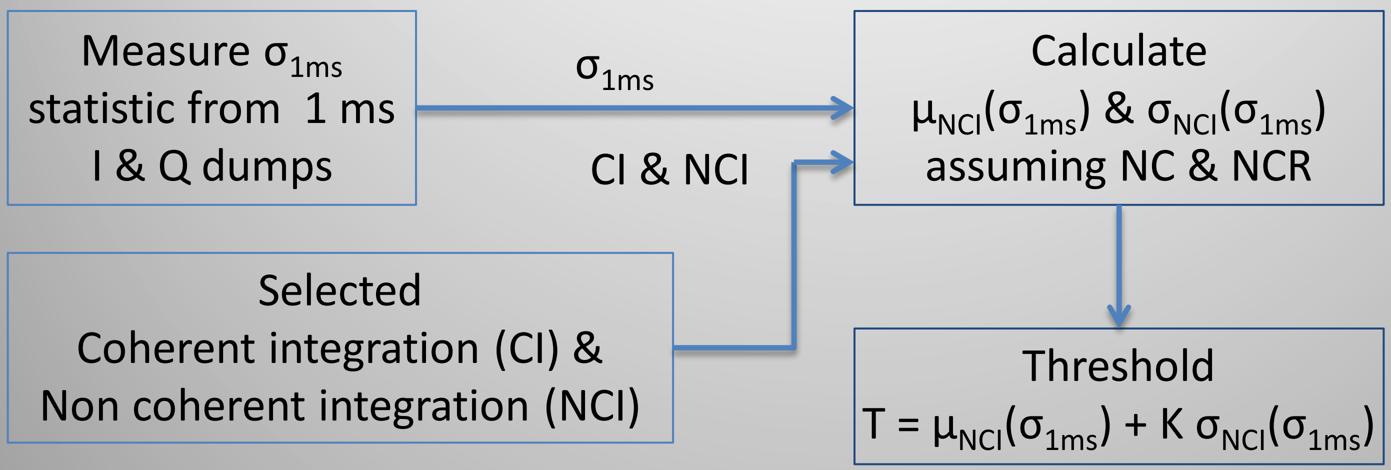
- Detection requires comparison of CI & NCI against a detection threshold
- Question: How to set the detection threshold?
- Answer: Adaptively estimate the threshold using a correlator noise finger/tap

$$T = \mu + k\,\sigma$$

μ & σ are the (estimated or measured) mean & standard deviation of the NCIs

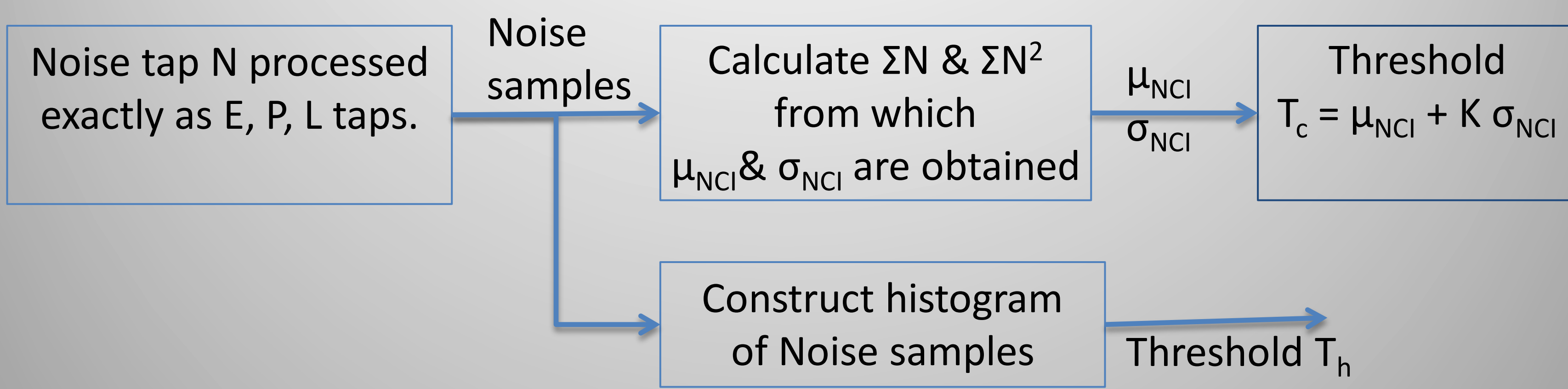
k is a constant that sets the false alarm rate (FAR)

Noise Tap Usage – 1 ms I/Q statistics



- σ_{1ms} values update at 1 kHz, so faster response time
- Not effective in the presence of Multiple Access Interference (MAI) / Cross Correlation Noise

Noise Tap Usage – NC & NCI statistics/histogram

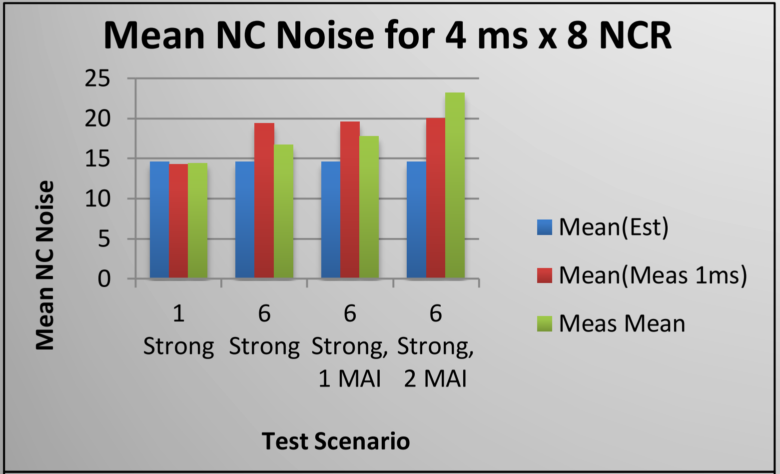


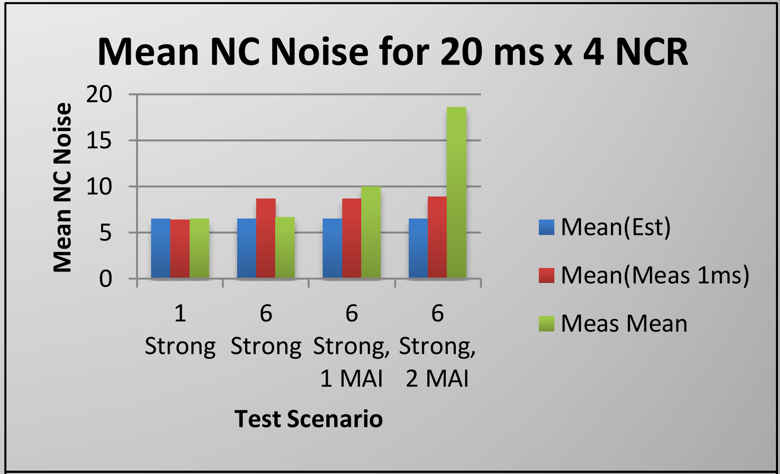
- Slow update rate of 1000/(CI*NCR) Hz / input sample
- Need (say) 100 samples for meaningful statistics
- Threshold calculated from μ_{NCI} & σ_{NCI} assumes Normal distribution
  - BUT this is not necessarily true (approaches Normal ~ Central Limit Theorem)
- Histogram method allows Th to be directly extracted with a given False Alarm Rate and can be maintained efficiently
  - See the paper for details

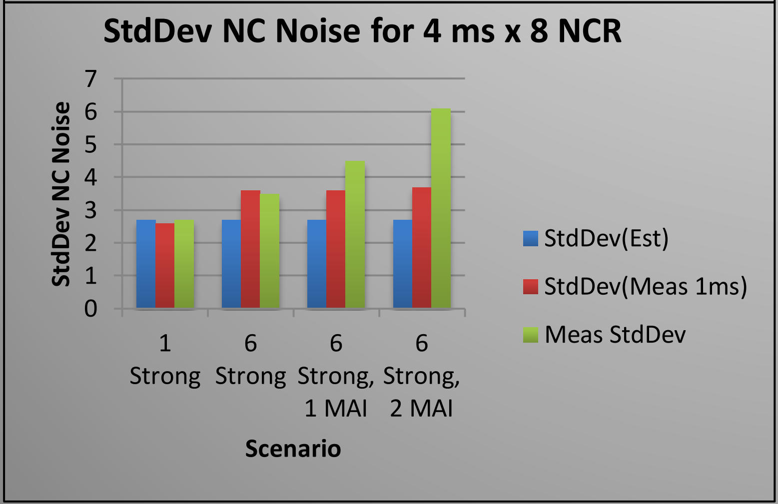
Matlab Experiment

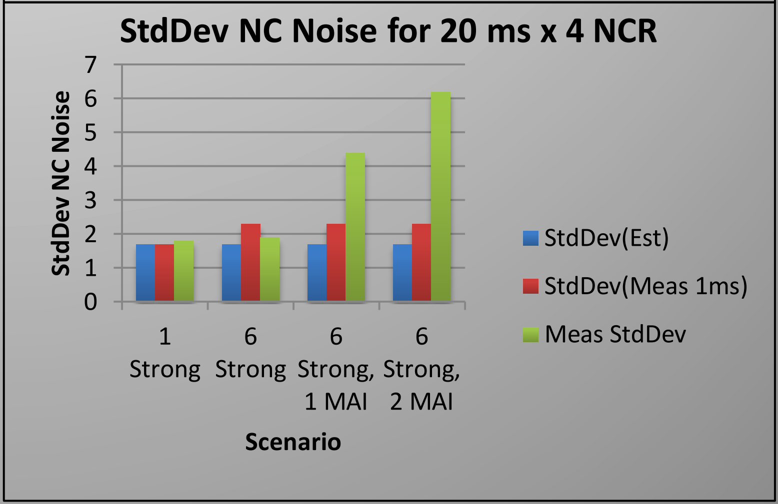
- Create signals at IF in Matlab that are down-converted and de-spread with noise & E,P,L taps
- Four satellite scenarios considered
  - 1 strong, rest weak
  - 6 strong
  - 6 strong, SV1 affected by 1 SV MAI
  - 6 strong, SV1 affected by 2 SVs of MAI
- Two different tracking scenarios
  - 4 ms & 8 NCR, same as legacy Namuru & Kea
  - 20 ms & 4 NCR, highest sensitivity setting
- Estimate μ_{NCI}, σ_{NCI} analytically, derived from 1 ms dump statistic σ_{1ms} and from NCI noise samples directly

Matlab Experiment - Statistics

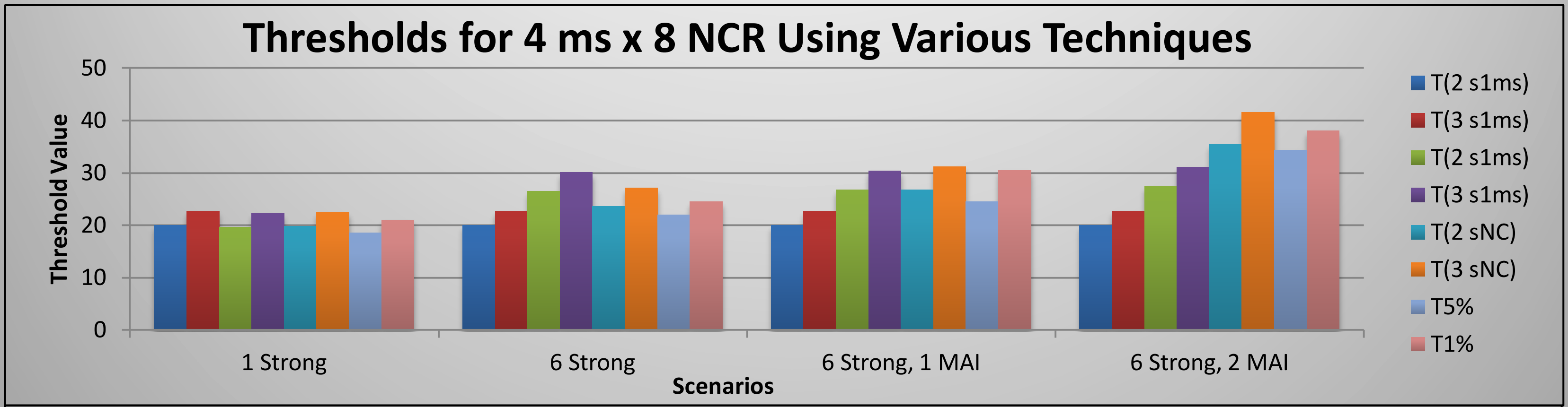


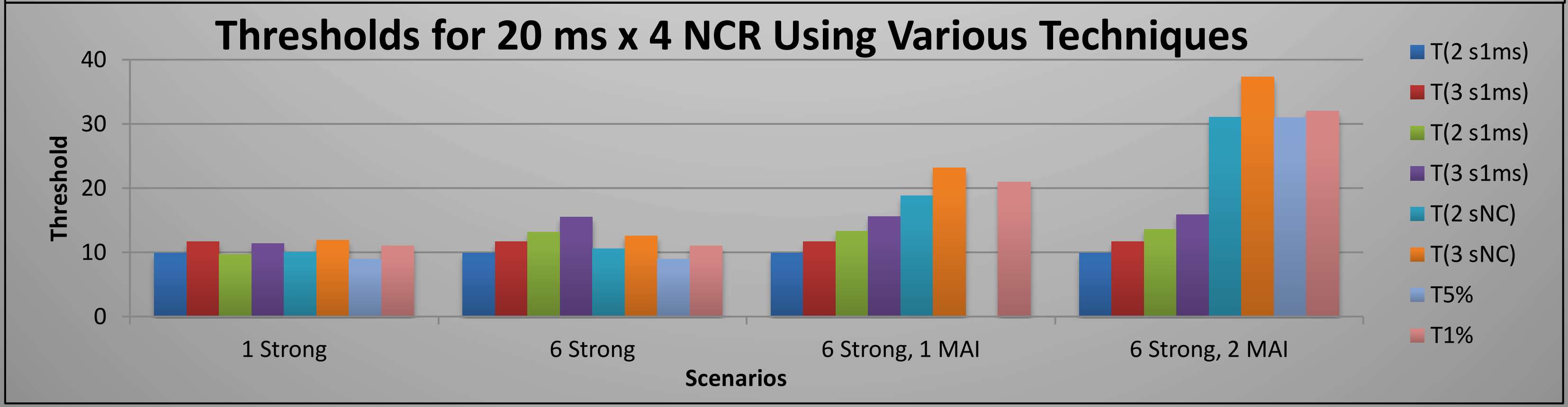






Matlab Experiment - Thresholds





Simulator Tests

- Legacy firmware tested against modified firmware with Spirent GSS8000 power gradually reduced using a splitter
  - Improvement of 6 dB achieved (as predicted)
    BUT
  - Legacy firmware stopped navigating at -2 dB, but only lost lock at -1 dB, whereas new firmware navigated down to -4 dB
  - Removing signal level quality thresholds allowed legacy receiver to track & navigate down to -1 dB, so only a 3 dB improvement
- Tuning the new receiver to use 10 ms x 8 NCR and repeating the test without the splitter gave the new firmware a 5 dB improvement over the legacy firmware
- Once 20 ms x 4 NCR tracking is improved, an additional 1.6 dB can be expected.

Conclusion

- Improved signal processing and other changes have improved Kea sensitivity by about 8 dB
- Thresholds are now determined adaptively using corrrelator noise taps
- Longer coherent integration reduces squaring losses
- Further 1.5 dB improvement possible

Questions