Progress on Graychip filters

BPM project

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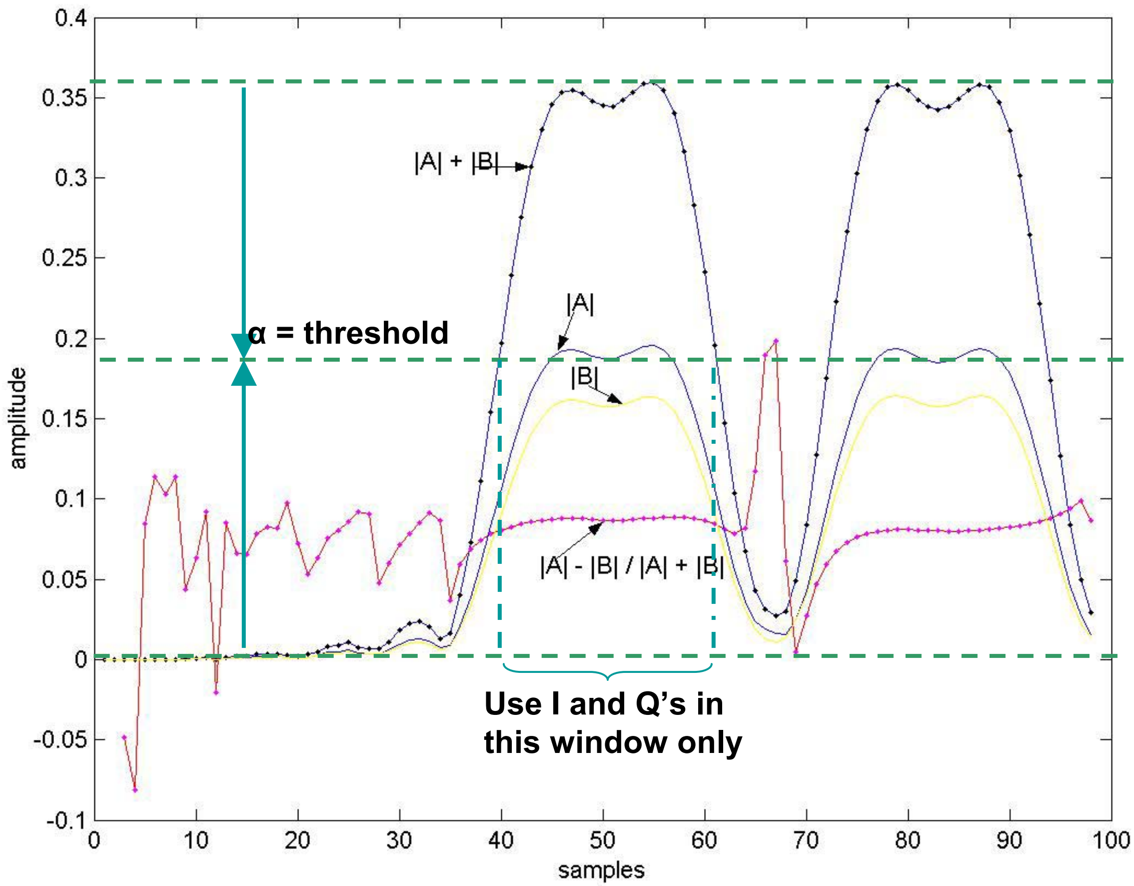
Status of filters

- Two filters have been generated:
  - The “batch envelope” filter for the closed-orbit mode.
    - Graychip Filter settings:
      - Requires one Graychip channel
      - CIC decimates by 4.
      - CFIR decimates by 2, compensates CIC freq. response.
      - CFIF decimates by 2. Cutoff frequency ~300KHz.
    - Filter post processing (on Altera FPGA)
      - Selects samples with high Signal to Noise ratio ($|A|+|B|>\alpha$).
      - Sums I’s and Q’s (separately) to get 1 I/Q pair per batch.
      - Sums batch values to eliminate low frequency signal oscillations (e.g. betatron oscillations).
    - NEW: Filter testing does not require to modify FPGA firmware.

“Batch envelope” filter



|A|-|B|/|A|+|B| is fairly constant for |A|+|B|>Threshold.

The example shows about 25 useful points per batch.

The samples are averaged to provide a single I and Q pair per batch.

Batch numbers are averaged again to improve estimate and lower the data bandwidth.

Signal to noise in the "batch envelope" filter

- The matched filter is a linear filter widely used to recover deterministic signals embedded in white Gaussian noise (WGN) because it optimizes the S/N ratio.
  - $y(n) = x(n) * s(n)$, where $s(n)$ is the deterministic signal and $x(n)$ is the noisy signal. i.e. $x(n) = s(n) + w(n)$. ($w(n)$ is WGN).
  - $S/N = \varepsilon/\sigma^2$, where ε is the energy of the signal and σ^2 is the noise variance.
  - S/N increases with the number of "signal samples".
  - The matched filter meets the Cramer-Rao lower bound.
- We can do better than the matched filter by choosing only "signal samples". In a batch we have enough "signal samples" that can be detected applying a simple threshold cut.

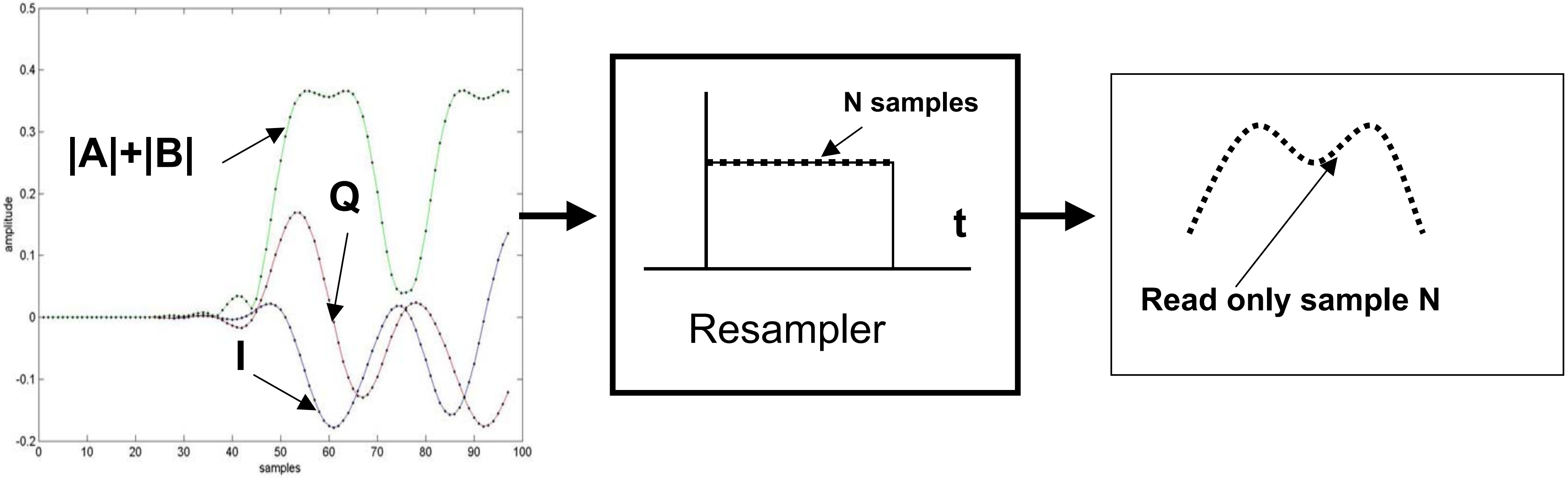
“Batch envelope” filter testing

- Why filter testing does not require to modify FPGA firmware?
  - Filter post processing (on Altera FPGA)
    1. Selects samples with high Signal to Noise ratio ($|A|+|B|>\alpha$).
    2. Sums I’s and Q’s (separately) to get 1 I/Q pair per batch.
    3. Sums batch values to eliminate low frequency signal oscillations (e.g. betatron oscillations).

- Part 1. can be emulated using the resampler filter.
  - Set the resampler filter as a time average filter with a window equal to the number of samples expected to sum up in each batch. Say this number is N.
  - The resampler convolutes the input signal. The Nth sample out of the resampler waveform is the value we are looking for. We can discard all the other points.
  - Offline we must divide by N to finish part 1.
  - Parts 2 and 3 must be done offline.

- High output bandwidth but easy to setup and check the validity of the “envelope filter”.

“Batch envelope” filter testing



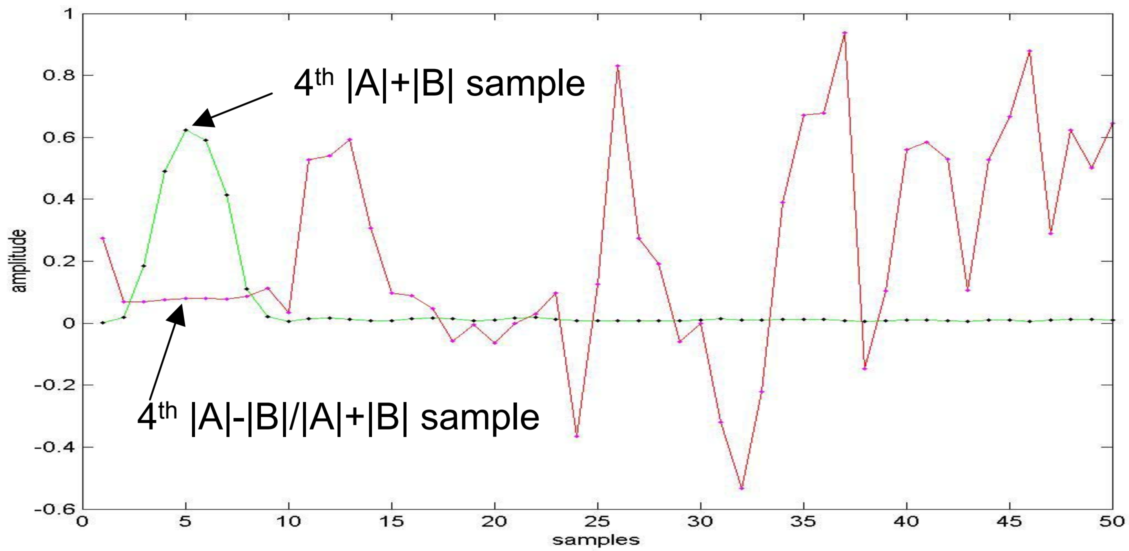
- I have generated a new Graychip configuration file.
- Filter is ready to be uploaded.
- I need to coordinate the test with Jim and Dehong.
- I will need help using the setup.

Wide band filter

- The wide band filter is to look at fast signals in the turn-by-turn, first-turn and short-gate modes.
- Filter characteristics:
  - The CIC filter set to minimum decimation (4).
  - The CFIR is not used but the signal is decimated by 2.
  - The PFIR is set as a 4-tap time average window filter.
  - The PFIR is set not to decimate.
  - The filter uses the 4 Graychip channels.
- This filter has been simulated with good results.
- This filter can also be tested without having to modify the FPGA firmware.
  - The a new Graychip configuration file is being generated.

Wide band filter

- The wide band filter is fast enough to see 4 samples per bunch (~396ns).
- The PFIR filter (4 tap time average) integrates the I's and Q's. The PFIR output reaches the expected "beam position" value asymptotically. The 4th PFIR output sample gives the I and the Q closest to the real beam position.



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Brainstorming on the wide band filter

- The “envelope” filter is proposed for closed-orbit mode and the wide band filter for all the other modes.
- Could we use the wide band filter for all the modes? Obviously, it would be simpler to have only one filter. Would the wide band filter produce a better or worse closed-orbit position measurement? Not sure yet.
- I think we could try the wide band filter with the closed-orbit mode signal using two different test statistics:
  - 1st test statistic: select the 4th sample after each bunch and average them.
  - 2nd test statistic: select the 4th sample of the first bunch and discard any other data.
- Compare the performance of these two statistics to the “envelope” filter.

Brainstorming on the wide band filter

- The answer to the performance question is not obvious.
- The strength of the "envelope" filter is that it uses many samples per batch, all with good signal to noise ratio.
- The "envelope" filter averages samples of the same batch but the samples come from different bunches.
- If averaging samples of the same batch introduces a new noise because some randomness in sampling different bunches (e.g. phase noise between bunches) we may counter effect the benefit of having more samples.
- The wide band filter could "follow" a single bunch in the batch (i.e. as if there was only one bunch in the machine) and forget all the other ones.

Other filter work

- Mark B. received the Ecotek schematics last week. Very necessary to understand how to modify the FPGA firmware.
- FPGA implementation:
  - ~~I hope we can start working on the implementation of the FPGA firmware soon. I'll ask for help to do that.~~
  - The FPGA firmware for the "envelope" filter is well advanced.
- Some "theoretical" work to understand the signal to noise performance in all filter configurations.