FPGA architecture to search for accelerated pulsars with SKA

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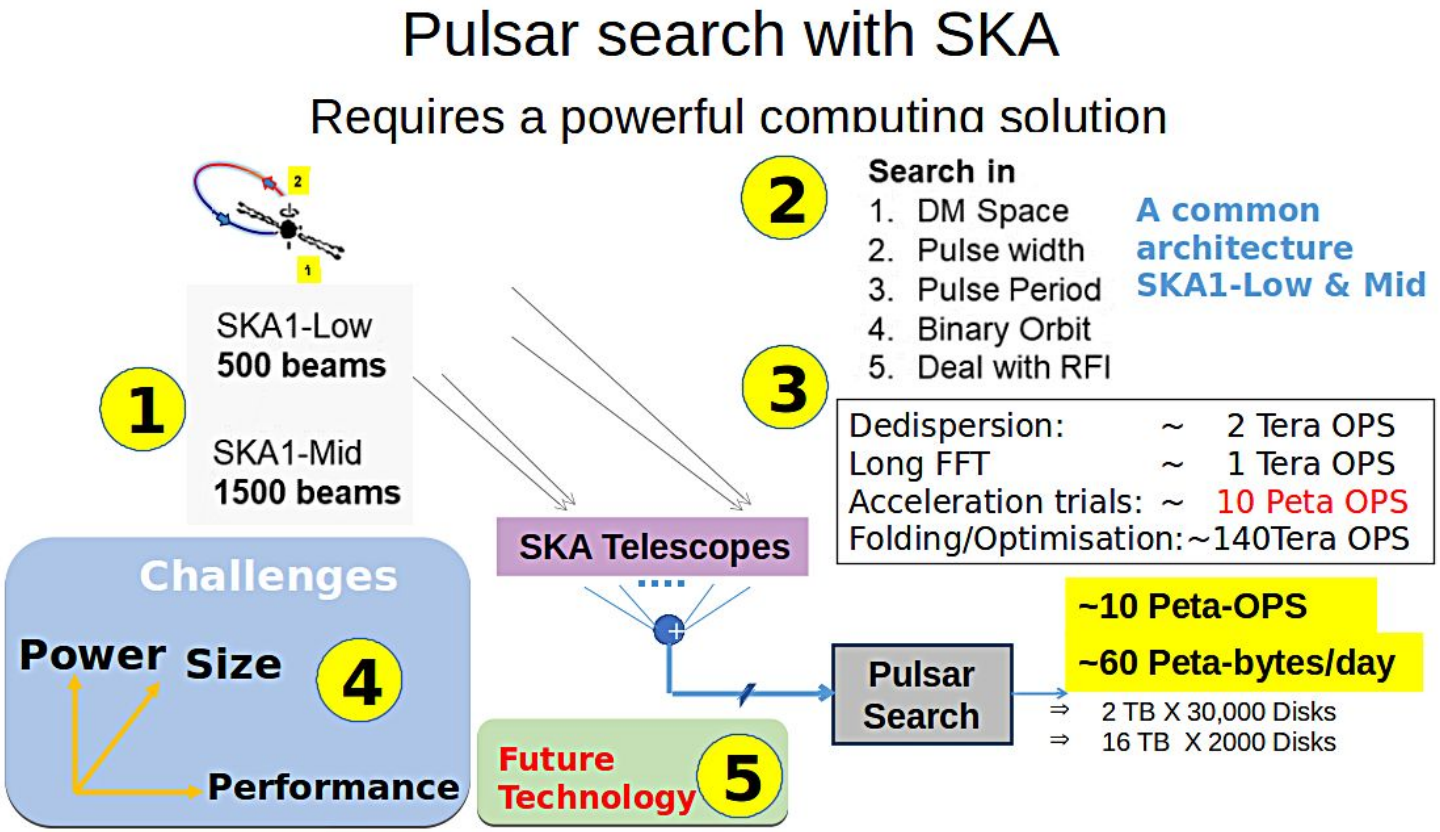
Outline

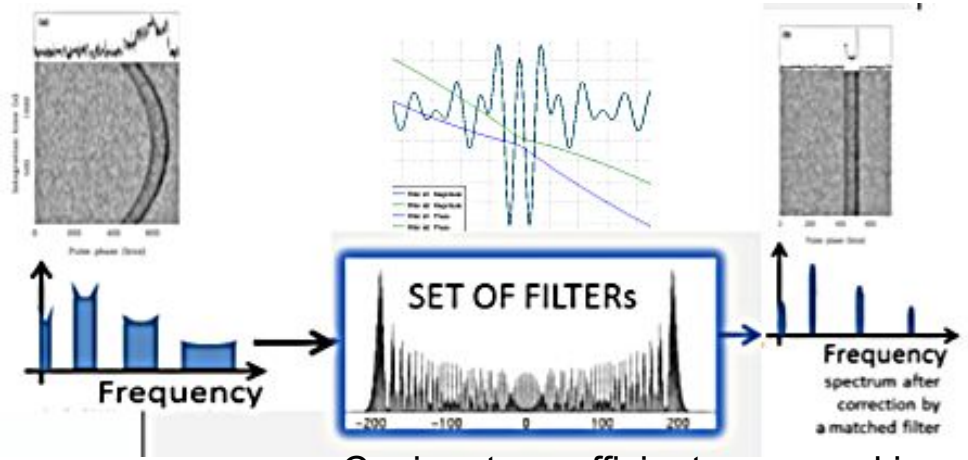
- Introduction
- Design Philosophy
- Design Details
  - Matched Filtering
  - Filter output plane
  - Harmonic Positions
  - Acceleration Processing
  - Harmonic Summing
  - Firmware Design
- Prototype Implementation
- Future Work and Conclusion

1.Introduction



2. Design Philosophy

Search for pulsars in binary systems, where the pulse frequency changes significantly during an observation can be undertaken either in a time or frequency domain.



Conjugate coefficients are used in the matched filtering.

We use frequency domain approach known as **Fourier domain acceleration search (FDAS)**

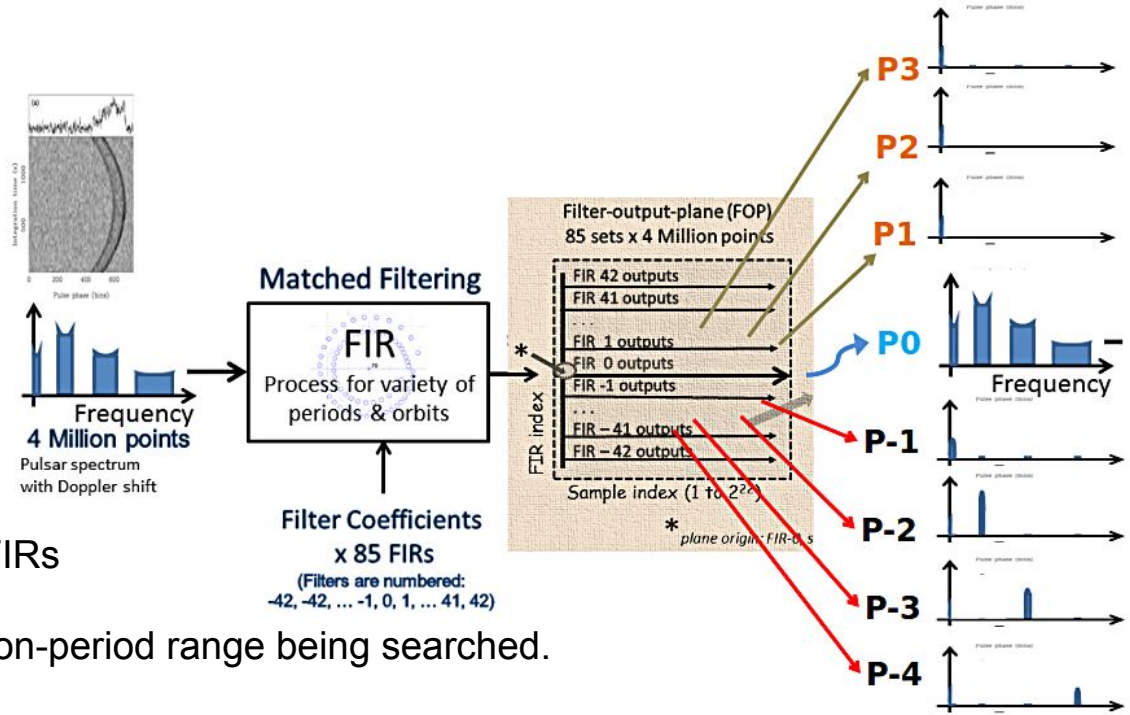
A complex form matched filters used to deaccelerate the input signals
A new FPGA architecture developed for FDAS

3. Design details - Matched filtering

FDAS module receives RFI mitigated complex spectra generated from a dedispersed time-series.

Each spectrum is processed in a set of 84 matched filters

FIR filters used for Matched filtering
FFT method used to implement the FIRs

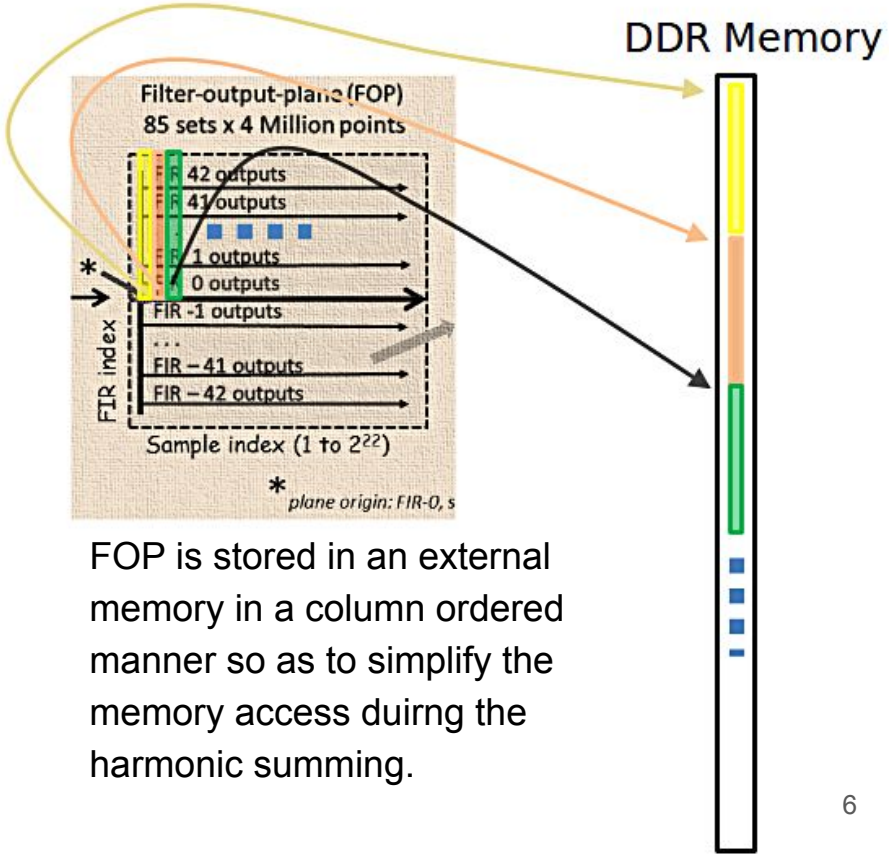


Each FIR probes a unique acceleration-period range being searched.

FIR outputs are detected and saved in a filter-output-plane (FOP) array
FOP array is processed using a harmonic summing module

3.1 Design details - Filter output plane (FOP)

FOP is an intermediate product in the FDAS
Stored as an array in the FPGA external memory
FIR-numbers Vs Frequency-bins as row Vs Column of the FOP Array



FOP is stored in an external memory in a column ordered manner so as to simplify the memory access duirng the harmonic summing.

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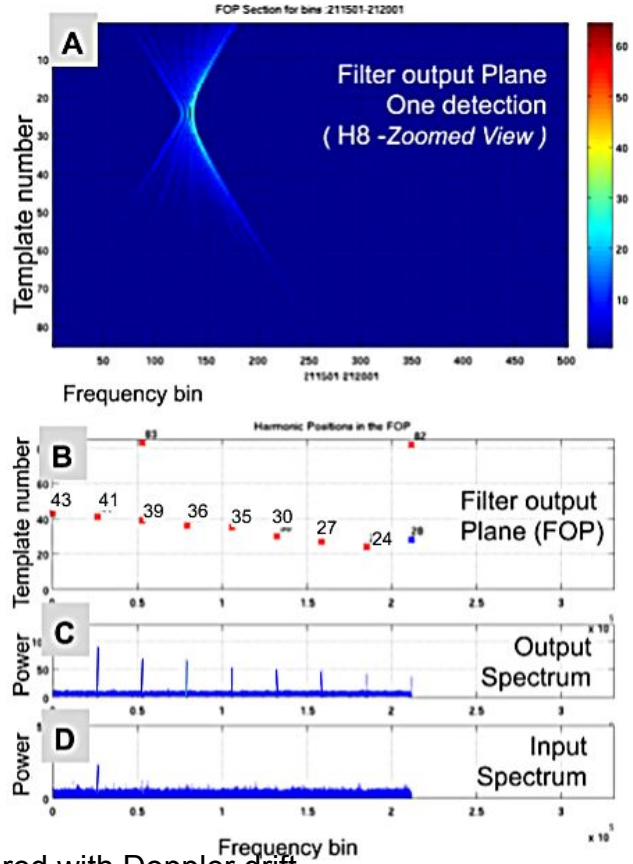
Outputs above a threshold is a detection

Unaccelerated Periodic signals & Harmonics

- detections appear along FOP middle row

Accelerated Periodic signals & Harmonics

- deconvolved by matched filters
- detections appear across the FOP
- positive acceleration along upper half of FOP
- negative acceleration along lower half of FOP



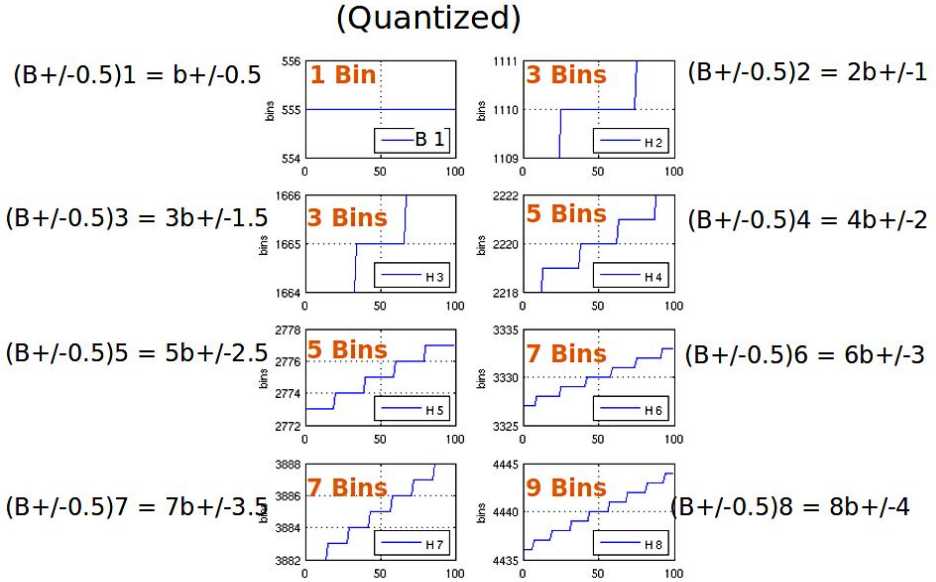
A: view of the filter output plane around a harmonic position.
B: FOP showing multiple (eight harmonics and a few spurious) detection.
C: Recovered spectrum after the matched filtering.
D: Input spectrum shows only the fundamental and the higher harmonics are smeared with Doppler drift.

3.2 Design details - Harmonic Positions

A fundamental frequency being probed could be a non bin-centered frequency in the FOP and hence their higher harmonics are to be traced around a set of neighbouring bin positions.

Harmonics (2 to 8) of a non bin-centered fundamental will appear along (3 to 9) neighbouring bins.

To sum up to eight harmonics
Total of 40 bin positions to be considered



1 + 3 + 3 + 5 + 5 + 7 + 7 + 7 + **9** = 40

3.2 Design details - Acceleration Processing

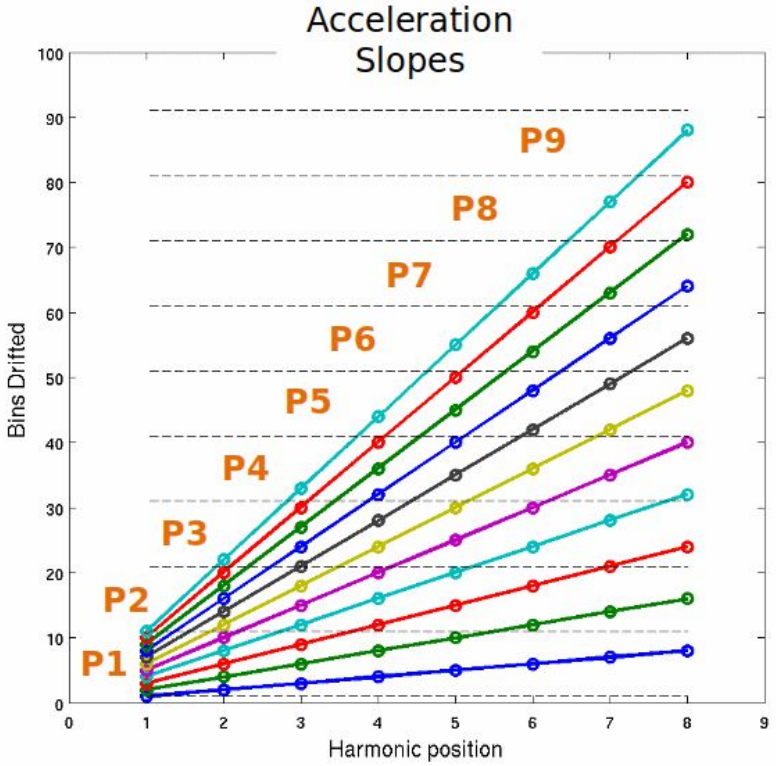
A complexity locating fundamental & harmonics in FOP

Accelerated signals and their harmonics can get deconvolved by different matched filters

Position of the harmonics will drift along the FOP rows.

Each filter deconvolves a narrow range of acceleration and frequency combination.

Acceleration processing is carried out across 11 steps.



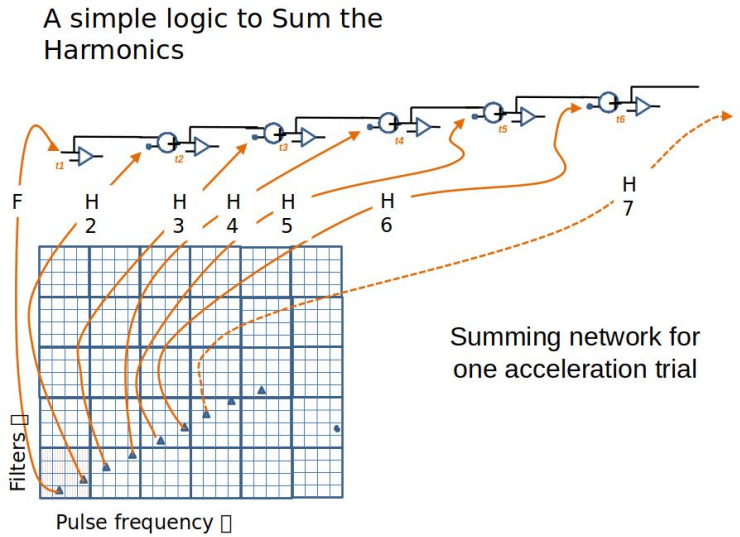
3.2 Design details - Harmonic Summing

Summing fundamental & harmonics in the FOP is a complex task

Harmonic summing process should be able to

- Sum the harmonics along neighbouring frequency-bins,
- Sum fundamental and harmonics along the filter-rows
- Sum different harmonics from different filterrows

Harmonic summing module is realised by arranging the adders as illustrated in the Figure.



3.3 Design details - Firmware

- Industry partner M/s Covnetics Ltd, UK
- VHDL based design
- Modern FPGA Accelerator PCIe platform
- First implementation completed
- Design scaling through generics
- Diagnostic modes
- Early Power Estimates

3.4 Prototype implementation

Reduced version of FDAS

Implemented on a Bittware A10PL4 FPGA

Design consists of

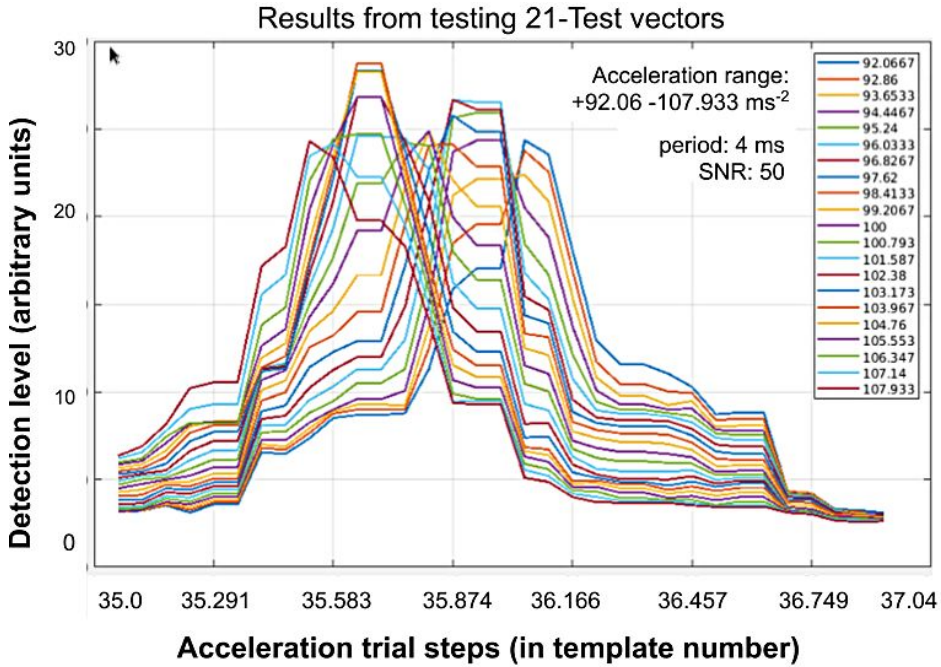
- Template matching with 85 FIRs
- Harmonic summing framework
- DDR4 memory banks for data storage

Meets the processing time estimates of 500 ms

Power consumption of about 35 W
Match with Early Power Estimates (EPE)

3.5 Matched filtering results

- Test with fake pulsar data
- Range of test vectors used
- FOP generated by prototype
- Analysed for harmonic recovery using Matlab tools
- Significant match with reference



Overlay of 21 result profiles from the prototype presented here. Acceleration cases between 92 and 108 m/s/s, period 4 ms and SNR 50 considered. The detections show peak values in the profiles and they shift (as expected) from the left to the right with accelerations changing from 107.9 to 92 m/s/s.

3.6. Future work and conclusion

Future work

Several enhancements to FDAS considered

1. New feature harmonic summing to handle non-bin centred fundamentals
2. A Matlab model of new summing structure developed
3. Harmonic Suming enhancement to add up to 16 harmonics for the zero acceleration
4. Improvements to the user interfaces
5. Enhancement to FPGA configuration mechanisms for remote sites
6. Tests with real telescope data

Conclusion

1. An FPGA Architecture developed to search for accelerated pulsars with SKA.
2. The design is based on a modern power efficient FPGA.
3. Prototype of the design with crucial functionalities implemented and tested
4. The template matching is fully functional
5. Upgrade options are being explored

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