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THE OWENS VALLEY SOLAR ARRAY
EXPANSION PROJECT
OVSA EXPANSION PROJECT

- Move existing array’s five 2-m antennas
- Upgrade existing two 27-m antennas
- Add 8 more antennas, for total of 13

Science includes microwave imaging spectroscopy of solar flares, active regions, and other solar features (using only 2-m dishes)
- Also install cooled receivers on 27-m dishes for calibration, and for observing Blazars (Readhead) and other transient sources (Kulkarni)
FEATURES OF NEW SYSTEM

- MRI-R$^2$ (ARRA) funding, $5.2$ M, starting late September 2010.
- Transmit 1-18 GHz RF over 20-GHz optical links
- All downconversions done in control building
- 16 element, dual-pol FX correlator
- 500 MHz instantaneous BW (each pol), 512 spectral channels, real time RFI detection
- 20 ms dump time, 34 tunings in 0.68 s to cover entire band
- Real time imaging pipeline, daily data products
Budget (defined about 1 year ago) calls for:

- 16 Roach + 16 iADC for F-engines (one for each dual-pol channel pair
- 8 Roach for X-engines
- Fujitsu (?) 10GB switch
- Total correlator budget $150 k

Would like to get update of estimates from experts on number of boards needed, best ADC to use, opinion on whether Roach 2 could be used for this project, etc.

We will be hiring one RF and one digital engineer. Please let me know of anyone who might be interested.
As we disassemble the existing array, we will leave three antennas operating for a time as a 3-element array (FASR Subsystem Testbed—FST—Liu et al. 2007, PASP 119, 303). FASR is the Frequency Agile Solar Radiotelescope, a large $N$ (~100) solar-dedicated array.

FST was designed with a software correlator, dumping real-time digitized data at ~1% duty cycle (data volume ~300 GB/day), and we used it to develop the Spectral Kurtosis (SK) RFI excision algorithm (Nita et al. 2007, PASP 119, 805).

We are working now on a ROACH-based four-input (single pol) correlator to replace this software approach, for 100% duty cycle and smaller data volume.
EXAMPLE DATA FROM EXISTING FST

(a) Zebra Burst
(b) Spike Burst
(c) Fiber Burst
Plan to use one ROACH for four-channel F-engine incorporating SK algorithm (without truncation)

RFI flags will be generated on Power PC, which will also calculate geometric delays and provide coarse (1 ns) delay information to F-engines.

4-bit quantized output is sent via XAUI to iBOB X-engine for correlation and phase adjustment for fractional delay.

An external control computer will record the data.
SK SPECTROMETER AND GENERALIZED SK

- Papers on Spectral Kurtosis theory
  - Nita et al. 2007, PASP 119, 805
  - Nita & Gary 2010, PASP 122, 595

- Papers on hardware implementation
  - Liu et al. 2007, PASP 119, 303 (FST)
  - Dou et al. 2009, PASP 121, 512 (KSRBL)
  - Gary et al. 2010, PASP 122, 743 (KSRBL+ROACH)

- Implementation on IBOB
  - http://casper.berkeley.edu/wiki/Kurtosis_Spectrometer
IBOB version of SK truncates power prior to squaring (due to limited on-board FPGA resources).

This can lead to shift of SK if scaling is not properly done.

We tested a ROACH version at full resolution, so that no scaling is necessary. Results were exact compared to theory!
SUMMARY OF SK PERFORMANCE

- For a laboratory demonstration, see [http://web.njit.edu/~gary/assets/Phone_RFI.htm](http://web.njit.edu/~gary/assets/Phone_RFI.htm)
- This is an example using the Korean Solar Radio Burst Locator
- Excellent performance for narrowband, and especially highly intermittent RFI.
- Does not work well for RFI from digital transmissions (e.g. data links, XM radio, digital TV).
Purpose of SK: To distinguish between Gaussian noise (astronomical signal) and non-Gaussian noise (RFI)

SK estimator, derived from power \(S_1\) and power-squared \(S_2\), is unity for Gaussian noise

Original definition is

\[
SK = \frac{M + 1}{M - 1} \left( \frac{MS_2}{S_1^2} - 1 \right)
\]

where \(M\) is the number of accumulated samples.

Caveat: power-squared must be derived from individual spectral samples from FFT, with no averaging => can only use with hardware specifically designed for SK.

We wish to relax this requirement, so that SK can be used for hardware with some averaging or accumulation of power estimates before power-squared is calculated.
Consider a spectrometer that accumulates $N$ spectral samples prior to dumping the data, i.e.

$$P_N = \sum_{j=1}^{N} x_j$$

The generalized SK can be developed by squaring the power of these accumulated samples and summing over $M$ measurements to form

$$S_1 = \sum_{i=1}^{M} (P_N)_i; \quad S_2 = \sum_{i=1}^{M} (P_N)_i^2$$

The generalized SK is then

$$SK = \frac{MNd + 1}{M - 1} \left( \frac{MS_2}{S_1^2} - 1 \right)$$

where $d = 1$ for spectral domain, and $d = \frac{1}{2}$ for time domain data.

This expression reduces to the previous expression for $N = 1$, as expected. RFI detection works best, of course, for $N = 1$. 
A number of researchers have incorrectly attempted to use the original form of SK for RFI excision in their spectrometer output, and were puzzled that although they got a constant value for SK, it was not unity.

The generalized SK expression shows why. For large $M$, the expression for generalized SK approaches the expectation value $Nd$ rather than unity.

In fact, in several cases we have seen where, for example, a spectrum analyzer or a square-law detector is used to measure the power, the precise value of $N$ is unknown. A perfectly valid approach is to determine $N$ for your system from the data, and use it in subsequent RFI excision.

Much of the effort of deducing the theory of generalized SK was not in finding the expression itself, but rather in determining the theoretical thresholds outside of which spectral bins should be flagged as RFI. The generalized SK paper (Nita & Gary 2010, MNRAS 406, L60) presents a simplified means of calculating those thresholds (which are constant for a given instrument, or given combination of $M$ and $N$). We can also provide IDL and Matlab routines for calculating them.
Excellent agreement with theory for non-RFI simulation.

With RFI,
CONCLUSIONS

- We are currently working on a four-element SK correlator (2-month project) for replacement of FST. This shows the power of CASPER for very rapid, targeted development.

- We are soon to embark on a 16-element, dual-pol array (OVSA Expansion), and are looking to hire both RF and digital engineers—starting as soon as October 2010. This is a three-year project, with development taking no more than 18 months before build-out. Is ROACH2 a viable option?

- I note that the FASR project received a high ranking (#2 behind HERA) in the just-announced Astro2010 decadal survey results. We anticipate the OVSA Expansion project to serve as a learning experience (size is about 10% of FASR), and although it is too early to say, I hope we can move on to FASR on this same three-year timescale.