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Development of an Agile Digital Detector for RFI Detection and Mitigation on Spaceborne Radiometers

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Introduction

- RFI can cause significant errors in science data
  - L- and C-Band soil moisture measurements over land
  - L-, C- and X-band ocean measurements
- High levels of RFI are relatively easy to detect
  - Mitigate using analog parallel subband filter approach
- Low levels of RFI present more difficulty
  - Low integrated energy looks like science signal
  - High-power, short-duration → low integrated energy
  - Many sources (*e.g*. air-traffic control radars) match this profile
- Digital signal processing approach
  - Based on statistical properties of natural emission vs. man-made interference

Project Objectives

- **Technical Objectives**
  - Design, develop and field test candidate RFI mitigation detectors
  - Develop RFI mitigation algorithms and characterize their performance
    - Empirical field testing
    - Analytical performance models
  - Develop a space qualified candidate point design
- **Technology Infusion**
  - Integrate RFI mitigation detectors with established ground based and airborne microwave radiometers
  - Demonstrate capabilities to the science community

Progress of Technology Infusion

- **Spaceflight Opportunities**
  - SMAP mission (recommended by NRC Earth Science Decadal Survey) has included the ADD subsystem in their baseline design
  - IPO NPOESS MIS radiometer design studies include versions of ADD in their trade space
- **National Radio Astronomy Observatory**
  - Frequency Agile Solar Radiotelesope (FASR) national facility includes ADD RFI detection and mitigation subsystem in its baseline design

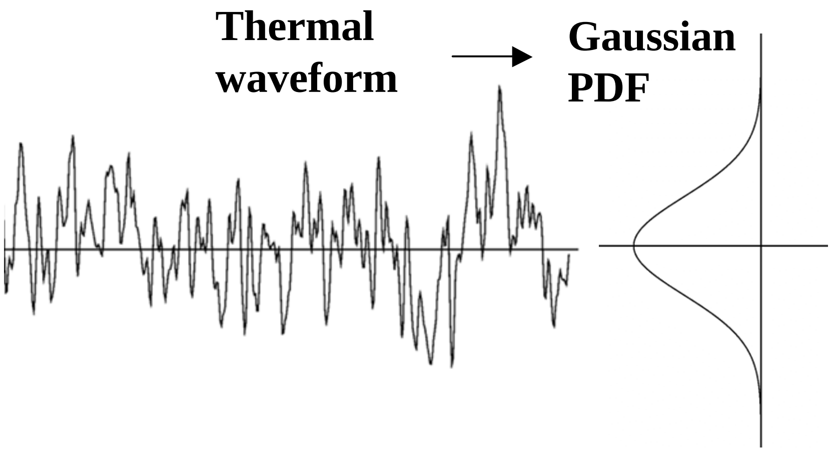
Project Schedule

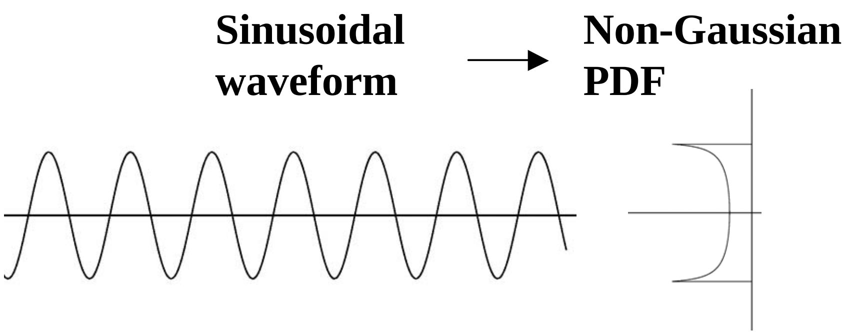
- Year 1 (7/05-6/06)
  - Prototype RFI Detector development
  - Ground based & airborne campaigns
- Year 2 (7/06-6/07)
  - Campaign data analysis
  - Define space flight detector requirements
- Year 3 (7/07-6/08)
  - Advanced detection and mitigation algorithm development
  - Spaceflight detector brassboard development
- Follow On
  - Working with SMAP and MIS Programs

Theory of Operation

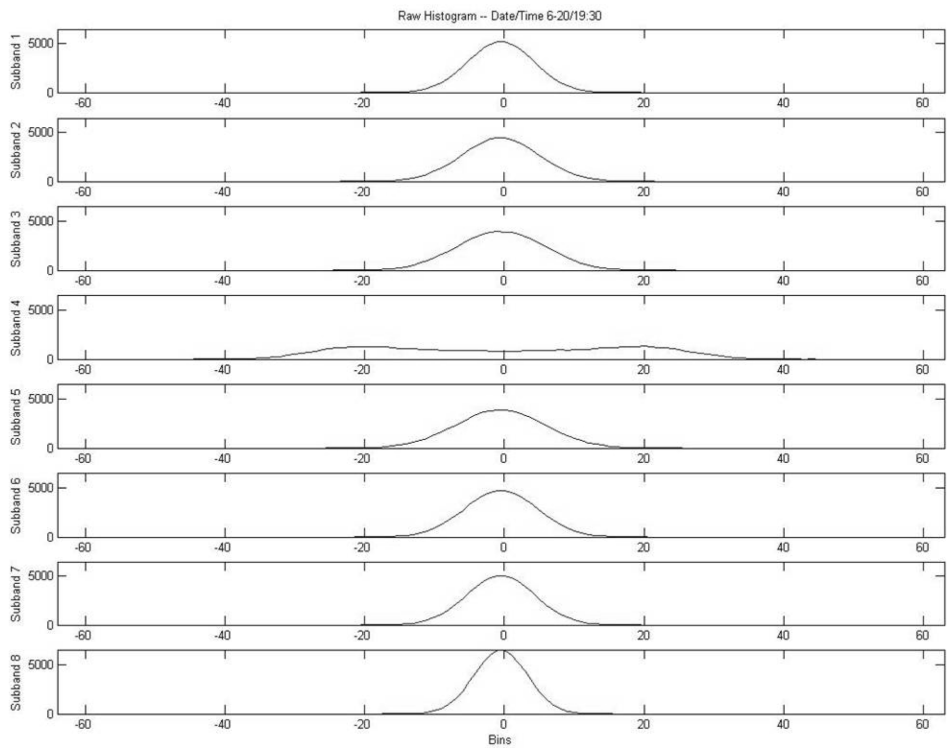
- Desired radiometric (science) signals generated by thermal noise
  - Amplitude of electric field has a gaussian (bell-curve) probability density function (PDF)
- RFI is man-made
  - PDFs will often be non-Gaussian
- Exploiting this distinction is the basis of the Agile Digital Detector (ADD)

Thermal Noise Amplitude Probability Distribution





Outdoor Sky Cal with sinusoidal RFI
8 Subband Probability Density Functions



- T_B = 40 K plus ~260 K sine wave injected into subband 5

RFI Detection Using Higher Order Moments

- The kurtosis of a random variable, *x*, is defined as

$$k = \frac{< (x - < x >)^4 >}{< (x - < x >)^2 >^2}$$

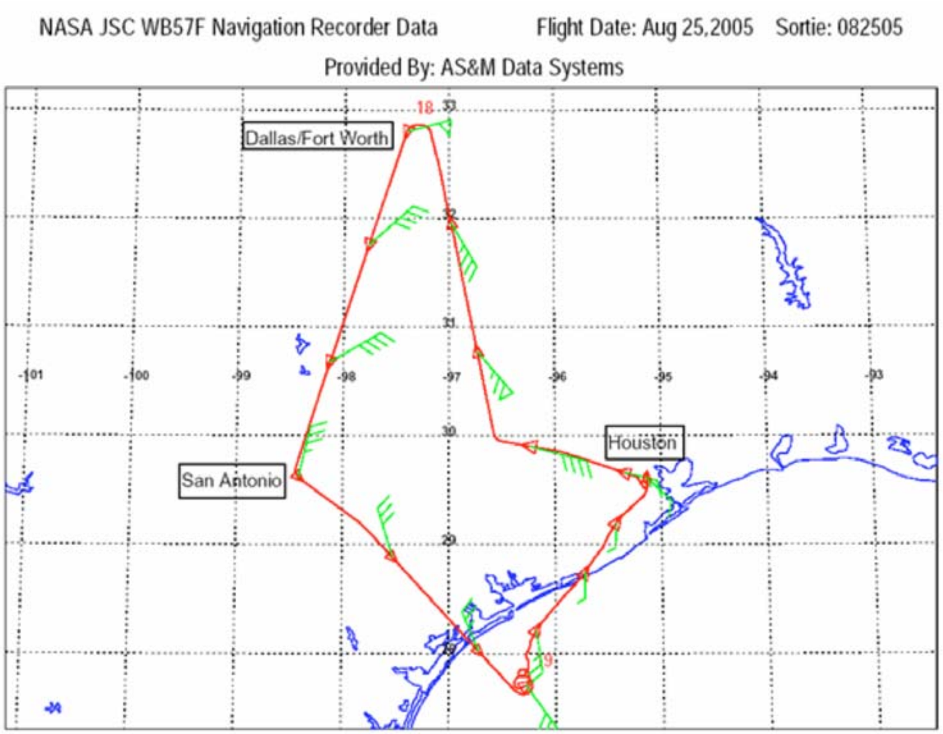
- k=3 for a gaussian distributed r.v., independent of σ_x^2
  (*i.e.* k=3 for natural thermal noise, independent of brightness temperature)
- The standard deviation of an estimate of k after a finite integration time is

$$\Delta k = \sqrt{\frac{24}{B\tau}}$$

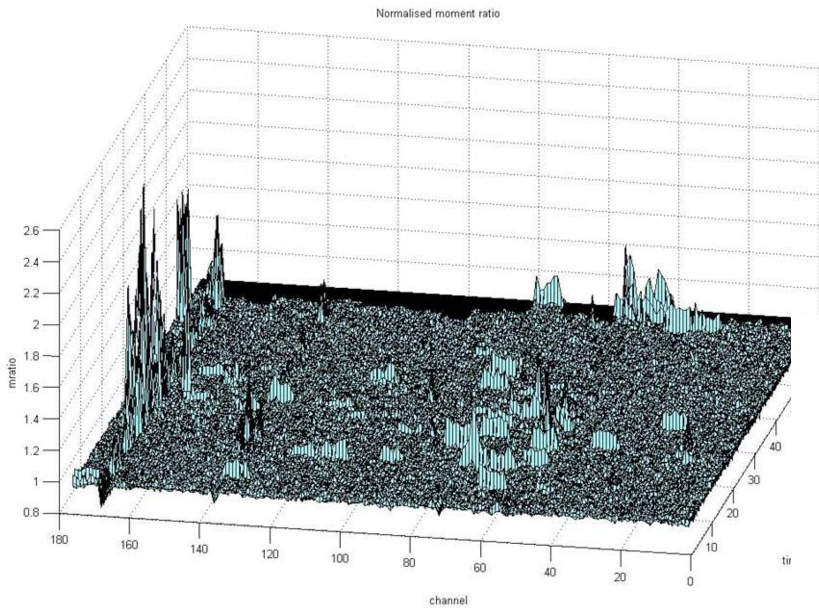
- For prototype radiometer operation (B=3 MHz & τ=0.3 s), Δk = 0.005
- RFI Detection Flag if |k – 3| > 3Δk

C-Band Field Deployment – with NOAA/ETL PSR

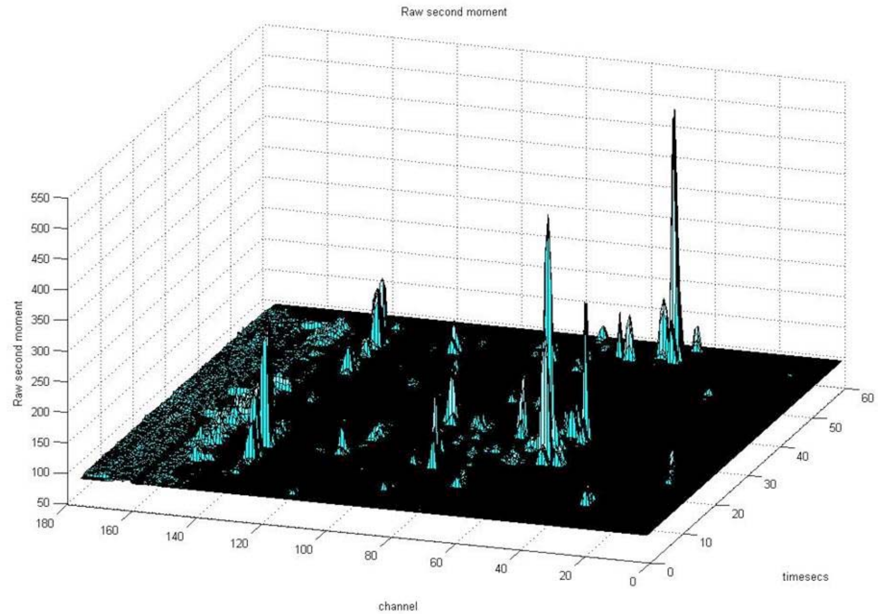
- Operated on WB-57 over Texas, 25 August 2005



Example of PSR Flight Data
Kurtosis and 2^{nd} Moment Spectra

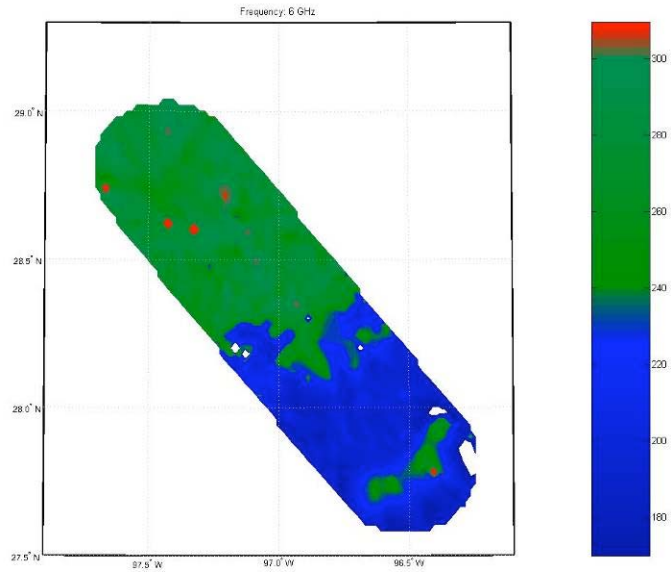


- **Kurtosis (left) and 2^{nd} moment (below) 5.5-7.5 GHz spectra v. time over Dallas Metro area**

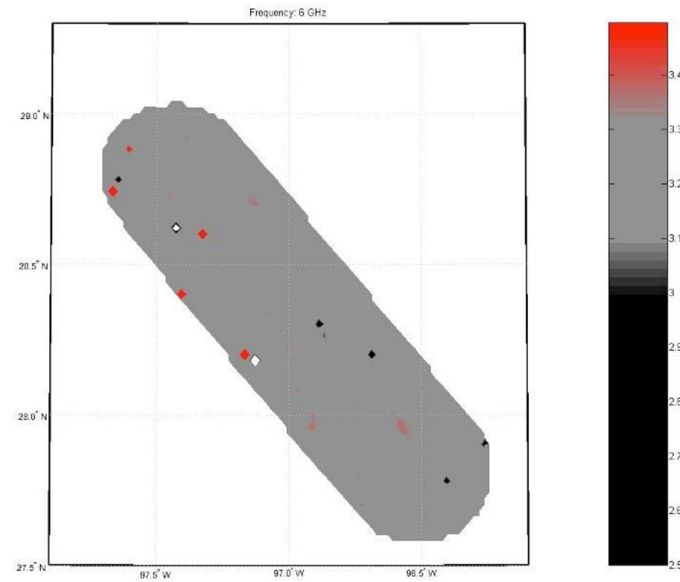


- ch = 50-80 (~6 GHz), intermittent times
  - Strong non-gaussian kurtosis
  - Strong, correlated effect on T_B
- ch = 170-180 (~7.5 GHz), t = 0-60s
  - Strong non-gaussian kurtosis
  - Not so noticeable effect on T_B

Radiometer Brightness Temperature and Kurtosis Images



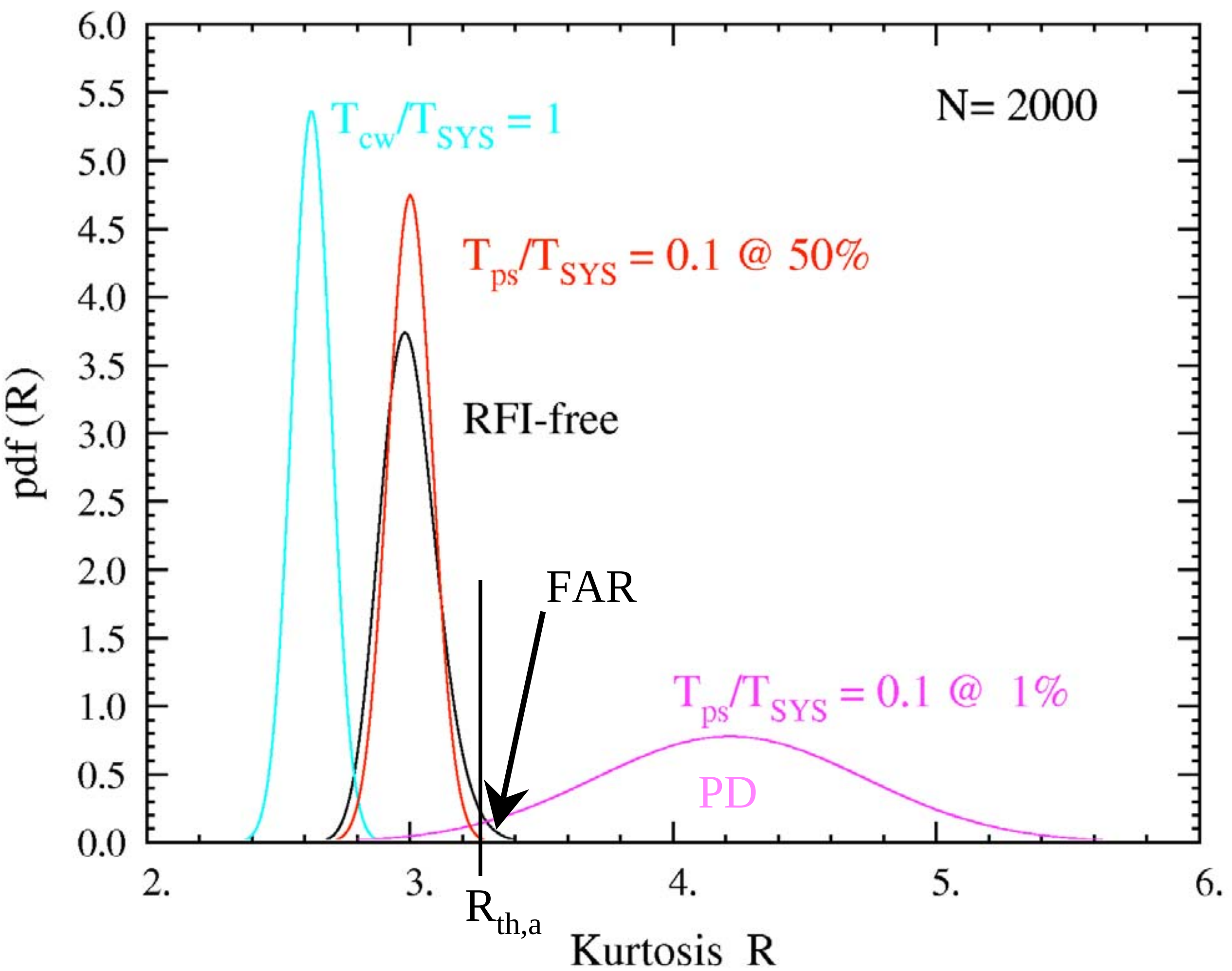
Brightness Temperature Image



Kurtosis Image

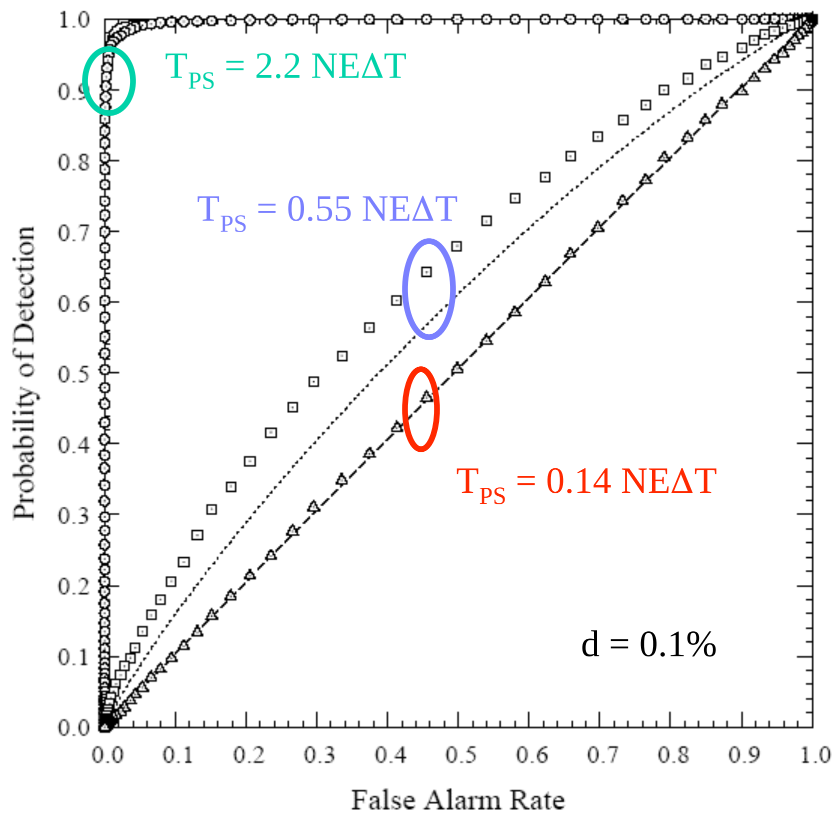
- Overflight of Galveston, TX coastline
  - TB image (left) sensitive to both natural and artificial emission (artificial emission, coastline and islands all affect TB)
  - Kurtosis image (right) only sensitive to artificial emission

Kurtosis Algorithm Detection Concepts



False Alarm Rate and Probability of Detection of Pulsed Sinusoidal RFI

- For RFI power level at brightness temperature equivalent to 2NEΔT, detection threshold can be set to give:
  - 90% probability of detection
  - 3% false alarm rate
- 0.1% duty cycle case corresponds to ARSR-1 operating mode
- Higher duty cycle reduces detection



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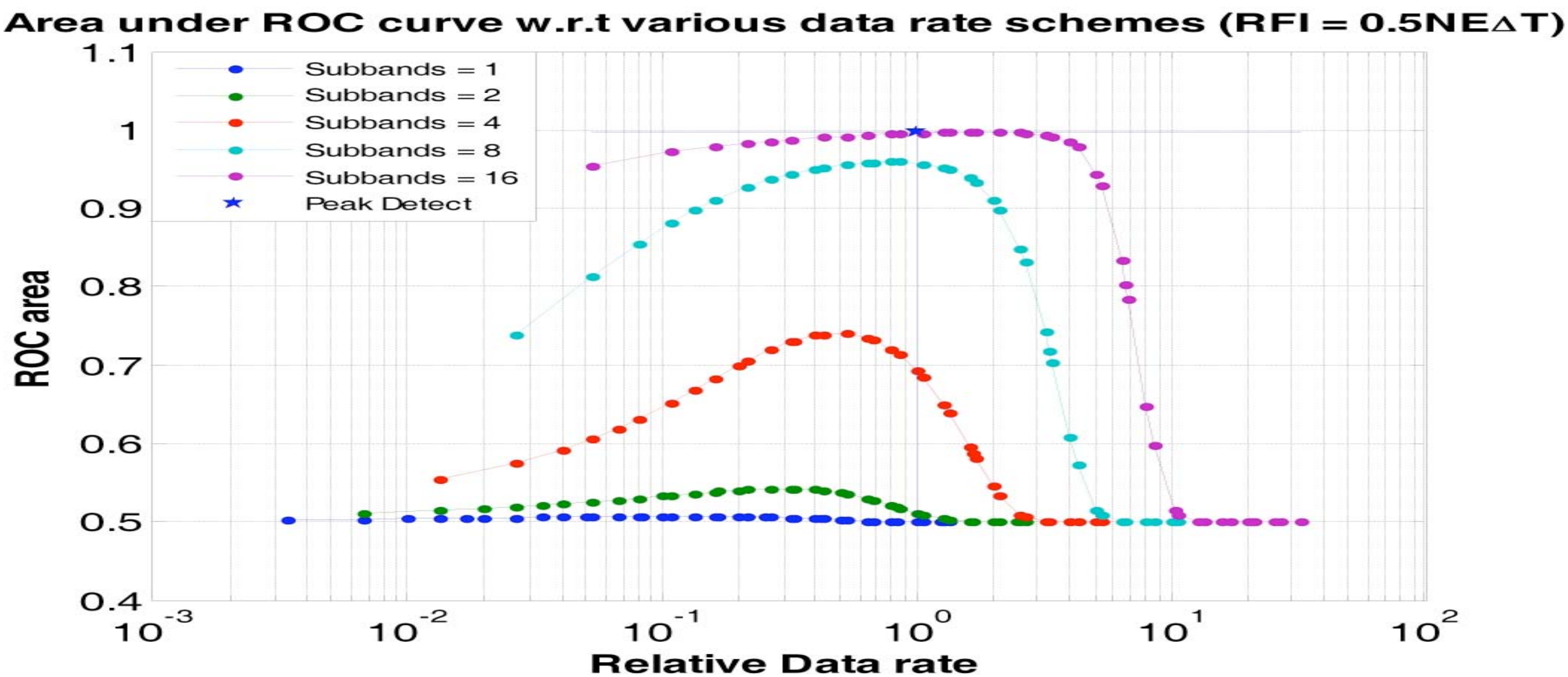


- **Plot comparing the ROC area for the kurtosis algorithm under various data rates schemes and subbands with the matched peak detection algorithm (blue *) (RFI power = 0.5NEDT)**

Development of ADD Flight Brassboard

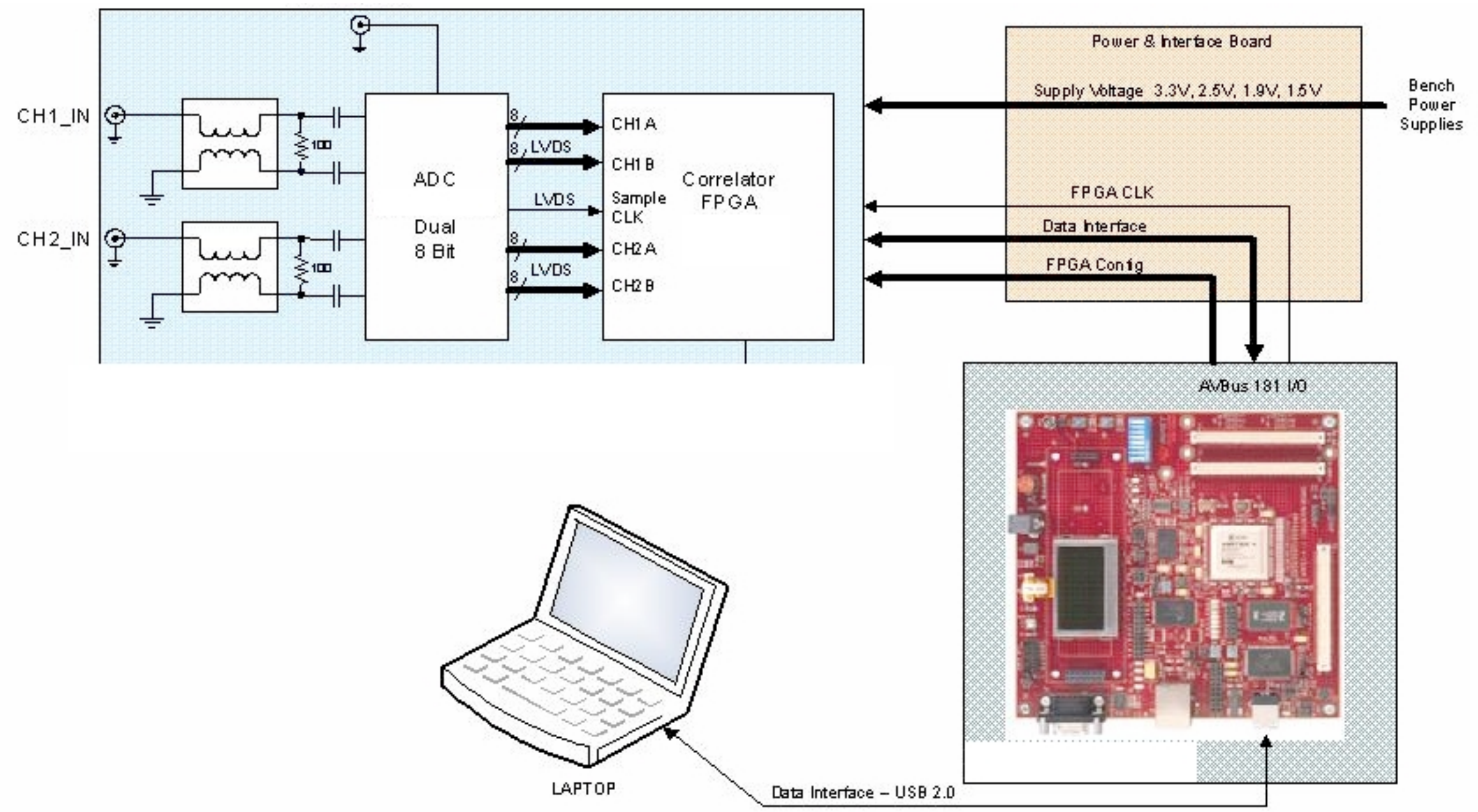
ADD Brassboard Requirements

- Two Channel, V and H polarization
- Input (from RF front end)
  - 1401.75 to 1425.75 MHz band limited (24MHz BW)
  - (-10 dBm) signal amplitude
- Use ADC to
  - downconvert the RF input
  - Sample at Nyquist rate for subsequent digital filters
- Signal Processing
  - 1^{st}, 2^{nd}, 3^{rd}, and 4^{th} moments for V and H (full BW) and each of 16 subbands
  - 16 equally spaced subband filters (24MHz/16 = 1.5MHz each)
  - Complex correlation of full BW and each of 16 subbands:
    - Real <Iv*Ih> + <Qv*Qh>
    - Imag <Iv*Qh> - <Qv*Ih>

ADD Brassboard Objectives

- Purpose
  - Test and characterize ADC and FPGA digital signal processing.
    - System SNR, with analog radiometer data as benchmark
    - Power requirements
    - Mass and physical configuration estimates.
  - Establish requirements
    - ADC clock rate
    - ADC clock jitter specification
    - Power regulation and noise limits, for ADC in particular.
- Design
  - Brassboard parts to be functionally equivalent to space qualified parts.
  - Circuit board layout is critical at high frequency. Successful layout to be duplicated in flight design.

Brassboard Block Diagram



Conclusions

- **Direct measurement of higher order moments (1^{st}, 2^{nd}, 3^{rd} and 4^{th}) can be used to reliably detect non-gaussian RFI**
- **The signal kurtosis is a very robust statistic on which to base a detection algorithm**
- **Digital subbanding allows RFI to be removed**
- **Experimental verification demonstrates performance in a relevant science application environment**
- **In design trade space for two pending spaceborne radiometer programs**
- **Flight brassboard testing planned for Summer 2008**