Digital Receiver with Interference Suppression for Microwave Radiometry

NASA Instrument Incubator Program
Annual Review

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Instrument Incubator Program

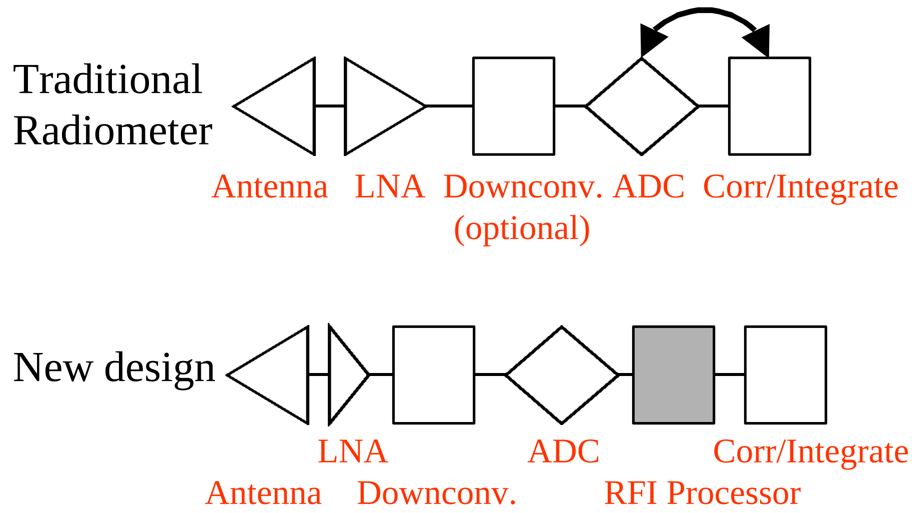
Digital Receiver with Interference Suppression for Microwave Radiometry

ESTO
Earth Science Technology Office

PIs: Joel T. Johnson and Steven W. Ellingson, The Ohio State University

Description and Objectives

Future sea salinity and soil moisture remote sensing missions depend critically on L-Band microwave radiometry. RF interference is a major problem and limits useable bandwidth to 20 MHz. An interference suppressing radiometer could operate with a larger bandwidth to achieve improved sensitivity and more accurate moisture/salinity retrievals.



Approach

A prototype radiometer will be designed, built, and used to demonstrate operation in the presence of interference. The design includes a processing component to suppress interference.

Co-I's/Partners

Dr. Grant Hampson, OSU

TRL levels: from 3 to 5/6

Schedule and Deliverables

Year 1: Complete design and begin construction

Year 2: Finish construction and begin tests

Year 3: Demonstrations and space system design

Application/Mission

Results will apply to all future microwave radiometer missions. Future L-band soil moisture and salinity missions are primary focus.

Project Schedule

Digital Receiver with Interference Suppression for Microwave Radiometry

Page 1 of 1

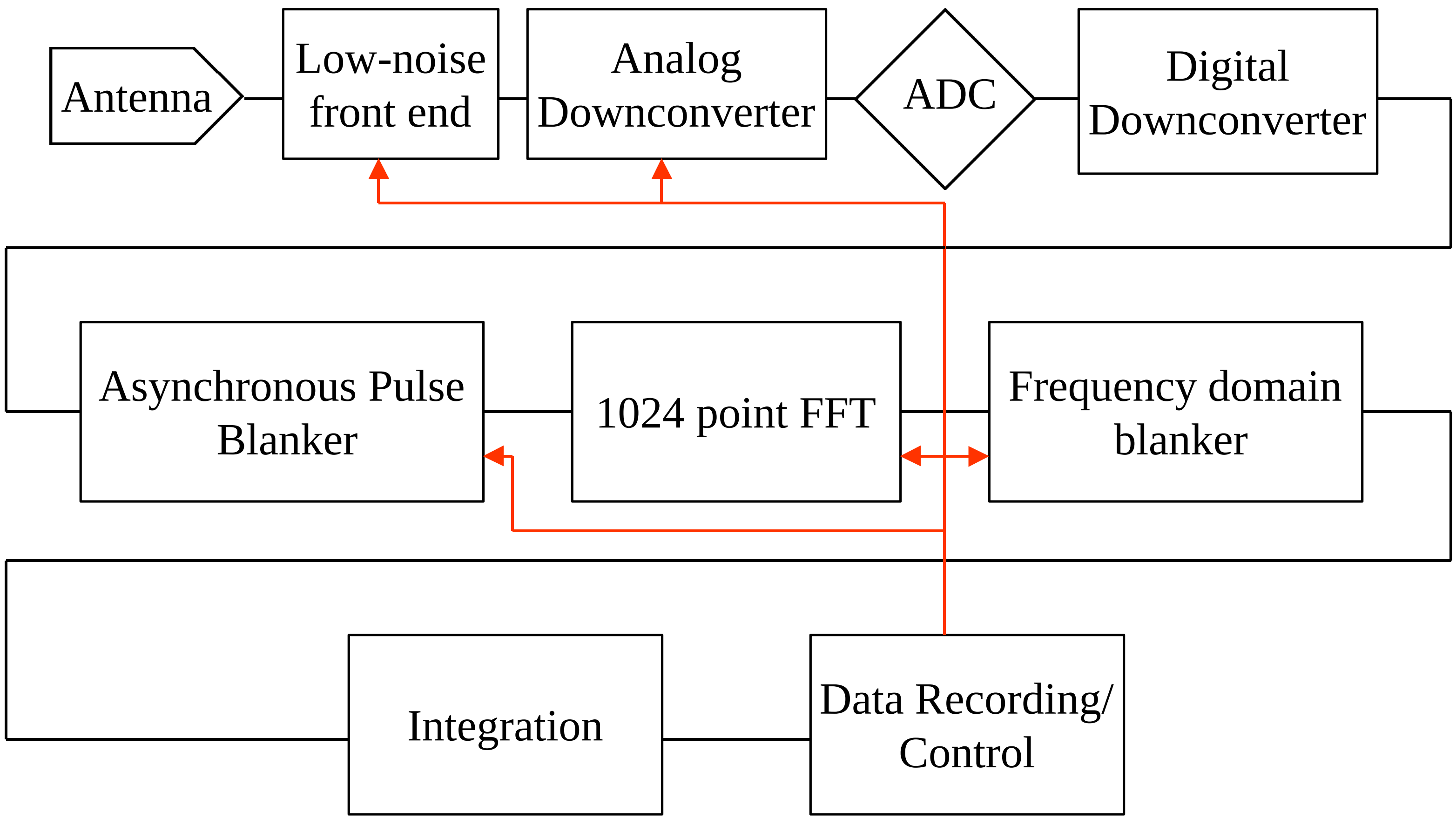
Start Date	End Date	TASK
3/11/02	8/31/02	Complete Instrument Design and Order Parts
9/1/02	11/30/02	Progress in Breadboard Instrument Fabrication and Algorithm Development
12/1/02	5/31/03	Progress in Breadboard Instrument Fabrication and Algorithm Development
6/1/03	11/30/03	Complete Breadboard Instrument Fabrication; Progress in Laboratory Tests
12/1/03	5/31/04	Progress of Studies of Space Deployment and Advanced Algorithms; Progress of Larger Scale Observations
6/1/04	11/30/04	Progress of Studies of Space Deployment and Advanced Algorithms; Progress of Larger Scale Observations

- Project “year 1” is 9 months, 3/11/02-11/30/02; interim review held at 4.5 months

Progress in Year One

- Milestone 1: "Complete Instrument Design and Order Parts"
  - System block diagram and designs of components complete
    - Analog Front End
    - Analog Downconverter
    - Digital Back-End
    - Interference Suppression Processor
- Milestone 2: "Progress in Breadboard Instrument Design and Algorithm Development"
  - Several components currently in initial implementation
    - Analog downconverter, A/D, Digital IF, Asynchronous Pulse Blanker (APB), FFT, Spectral Domain Processor (SDP)
  - APB design specifies basic adaptive excision algorithm
- Addition: Developed LISA system for airborne RFI survey with GSFC
- Current TRL Status: In transition from TRL 3 to TRL 4

System Block Diagram



Budget/Personnel

- Budget for year 1: 239.5K + 21K equipment
- Remaining as of 9/30: ~31.5K + 0K equipment (15.7K/month in 2 mo)
- No cost under- or over-runs are expected
- Tentative budgets for years 2/3: 294.4K/288.9K

- Personnel:
  - J. T. Johnson, S. W. Ellingson: co-PIs
  - G. A. Hampson: Research Scientist
  - D. R. Wiggins: Graduate student (graduated June 02)
  - Currently screening graduate student candidates

- Document Server (password protected): http://esl.eng.ohio-state.edu/~swe/iip/docserv.html

- Annual report to be delivered by Dec 10 2003

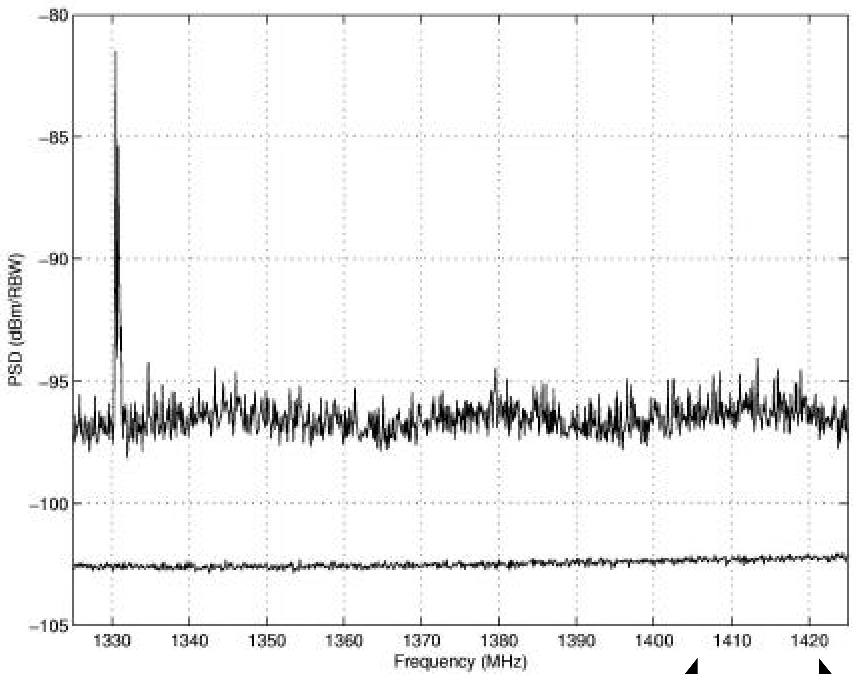
Plans for 12/1/02-11/30/03

- 12/1/02-5/31/03: “Progress in Breadboard Instrument Design and Algorithm Development”
  - Complete implementation of front end, full FFT processor, and post-FFT processing stages
  - Refine combined time domain and post-FFT processing algorithms
  - Test/refine algorithms with data from LISA measurements
- Interim review (teleconference?): late May to early June 2003
- 6/1/03-11/30/03: “Complete Breadboard Instrument Fabrication; Progress in Laboratory Tests”
  - Test complete system; study accuracy and stability (TRL 4)
  - Begin outdoor tests at ESL: calibrated observations of a large water pool (TRL 5-6)
  - Refine algorithms as necessary in tests; document performance
- Annual review (ESL or GSFC?): early October 2003

Initial Results: RFI survey from ESL roof

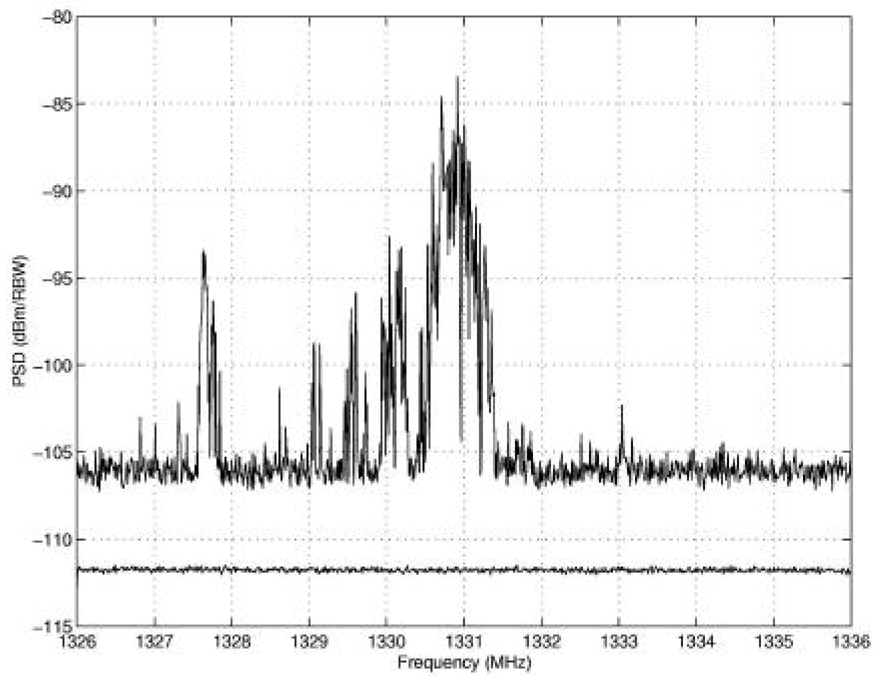
- Spectrum analyzer measurement with
  - low gain antenna on ESL roof
  - interim low-noise front end

1325-1425 MHz, RBW 100 kHz



Quiet band

1326-1336 MHz, RBW 10 kHz

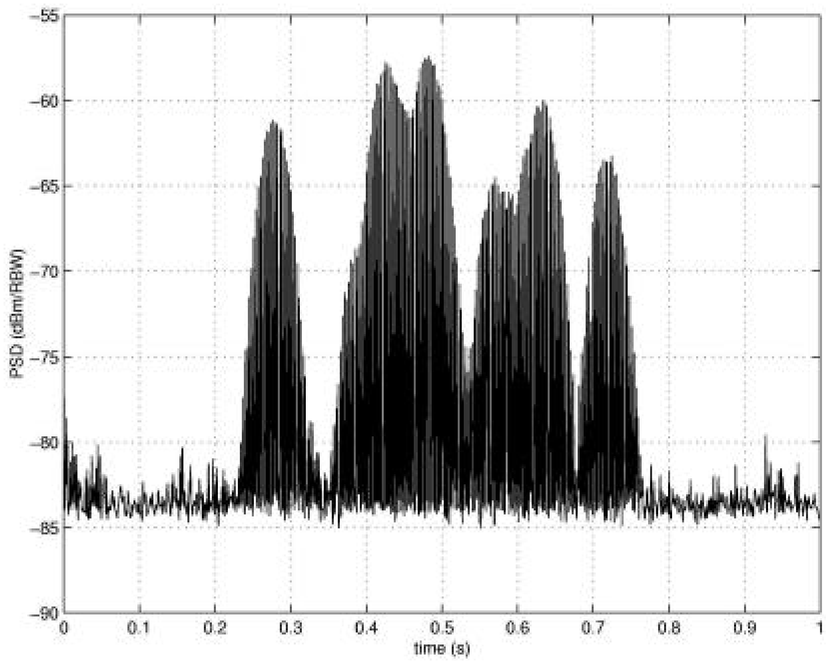


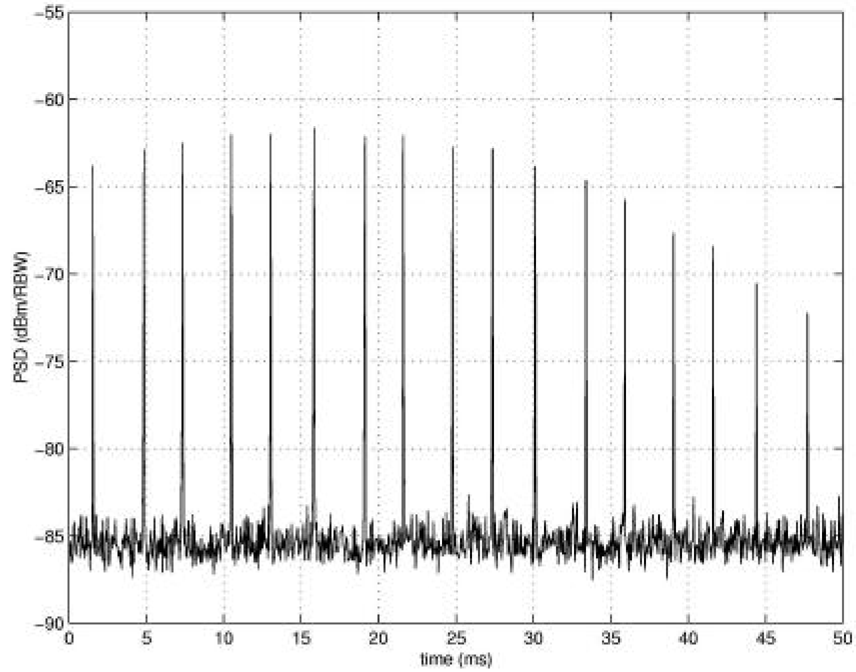
Some frequency spread apparent

- Strong interferer at 1331 MHz

Initial Results: RFI Measurement in Time Domain

- Time domain ("zero span") spectrum analyzer measurements from ESL roof with low-gain antenna: 1331 MHz +/- 1.5 MHz





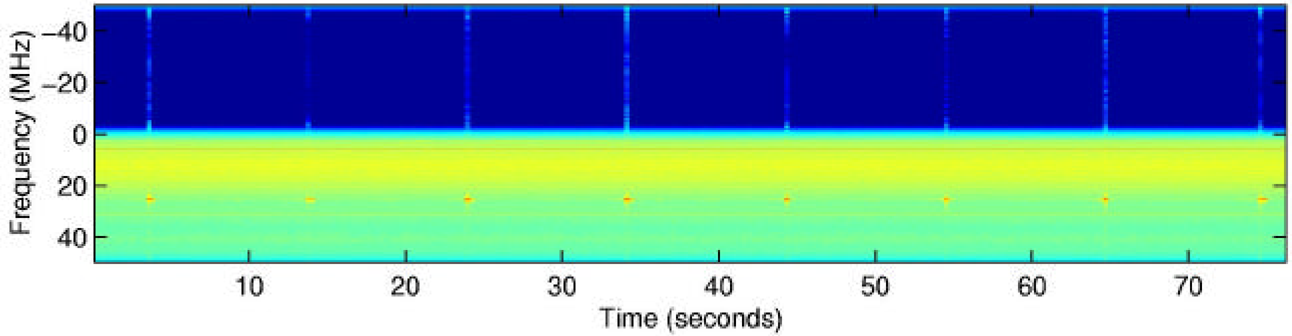
- ATC radar in London, OH (43 km away): PRF 350 Hz, 2 usec pulses plus multipath, approximate 10 sec rotational period

Initial Results: Time Blanking of ATC Radar

- Initial tests with available front end and low gain antenna on ESL roof
  - 1306 +/- 50 MHz including digital IF, APB, FFT, and integration
  - Spectra integrated over 42 ms

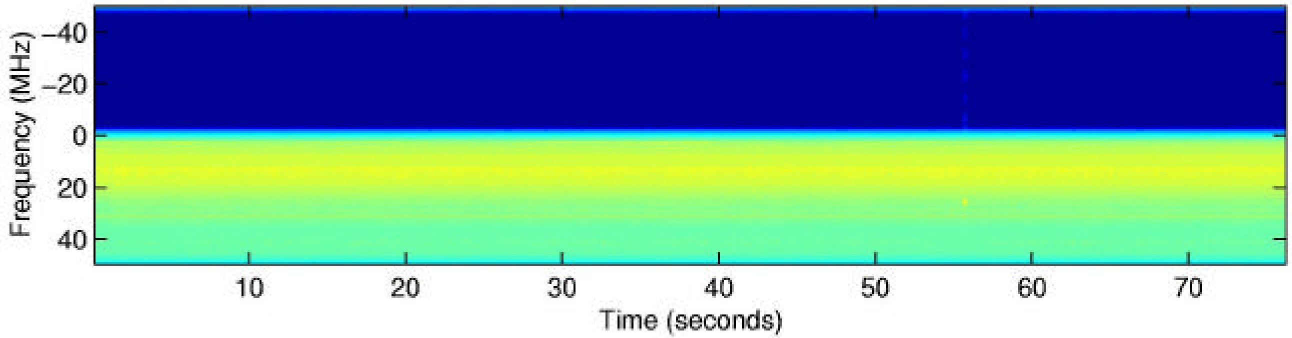
Without APB on

Rotation rate of ATC radar at 1331 MHz clearly visible



With APB on

APB effectively removes radar RFI

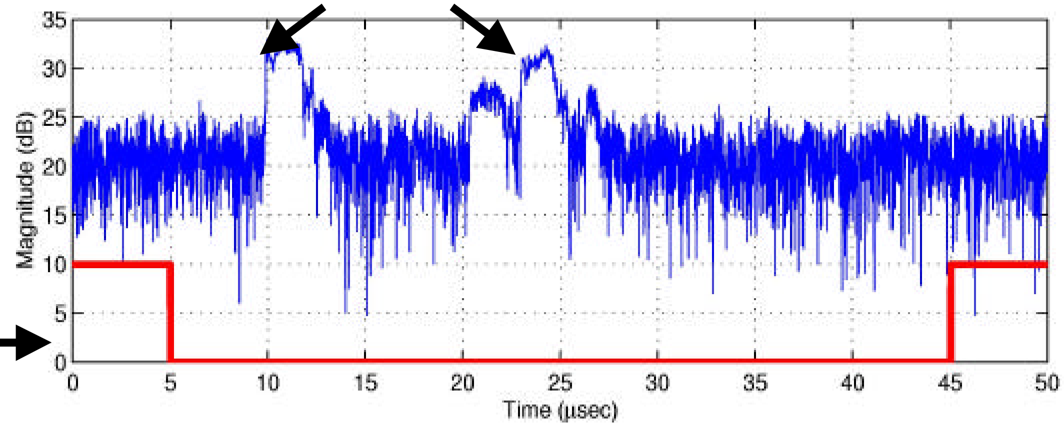


Initial Results: Time Blanking of ATC Radar

- Time domain results:

Direct path Multi-path?

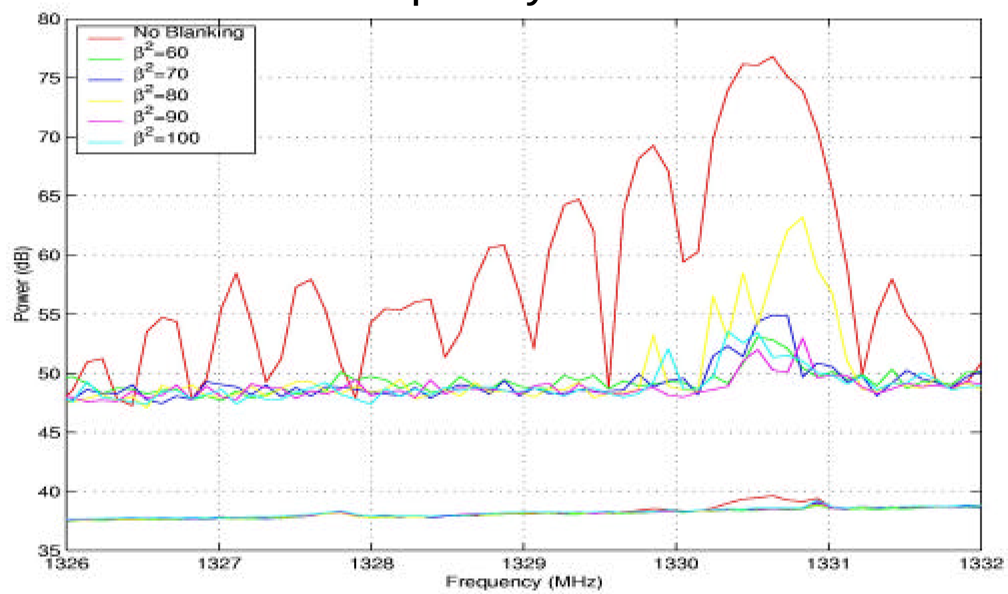
APB “Blanking” decision



- Effect of varying APB threshold in frequency domain:

“Max held” spectra

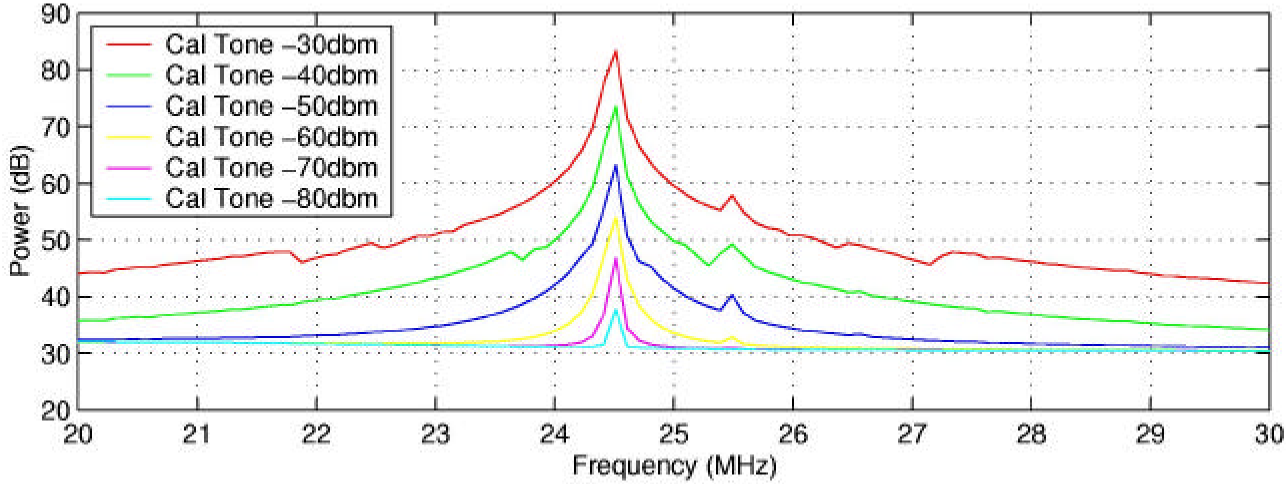
Averaged spectra



Initial Results: System Dynamic Range and Stability

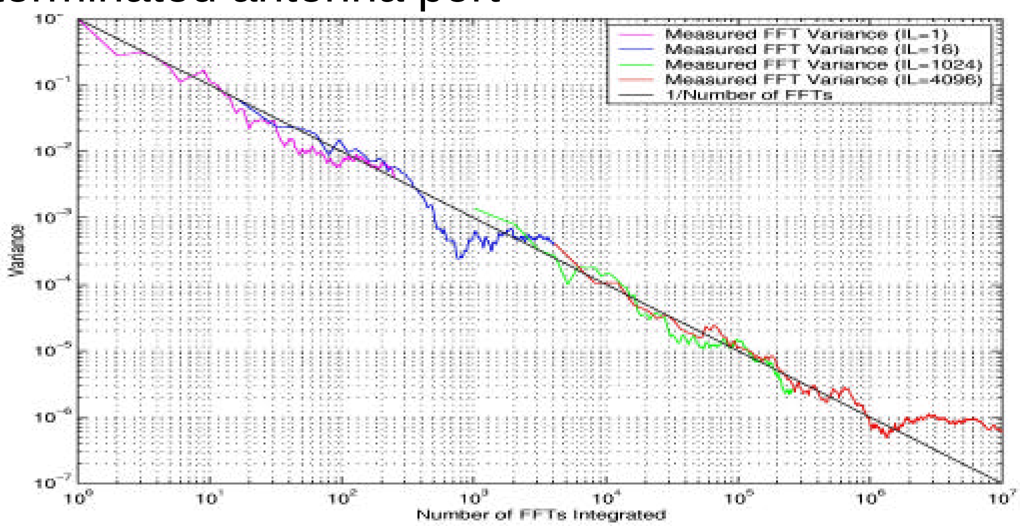
- Single tone injected into system front end: 50 dB dynamic range visible

Nominal max is
54 dB from ADC
+30 dB from FFT
- 6 dB margin



- Stability test with terminated antenna port

Follows ideal behavior
up to millions of FFTs:
further tests planned
with complete system
front end



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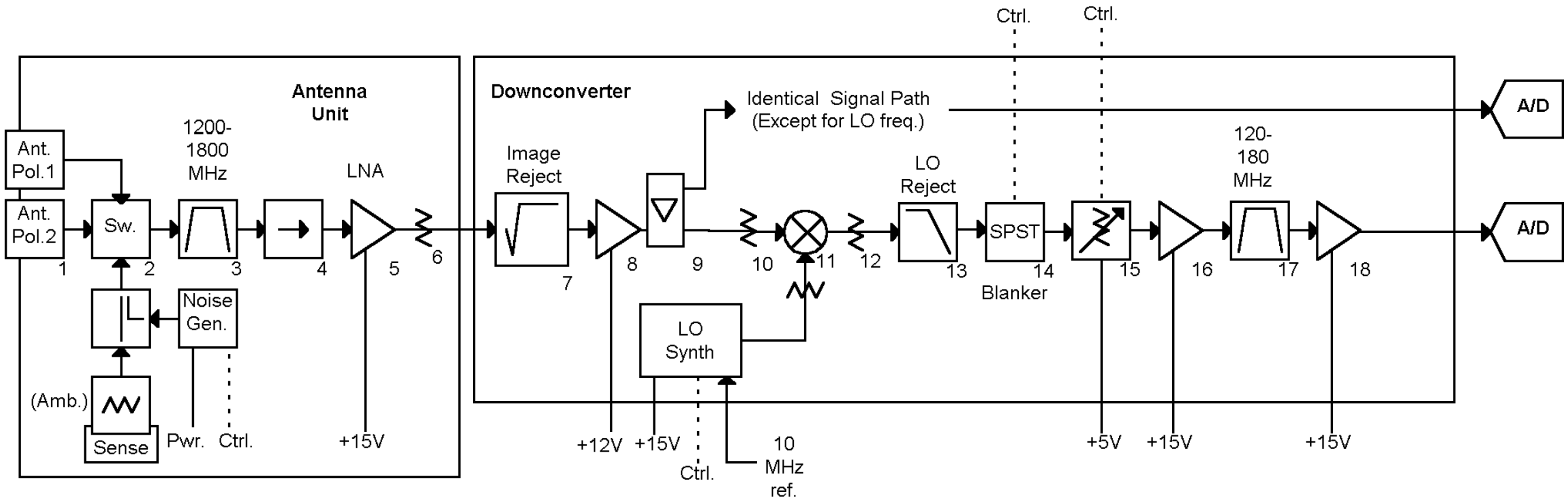
Radiometer Front End/Downconverter

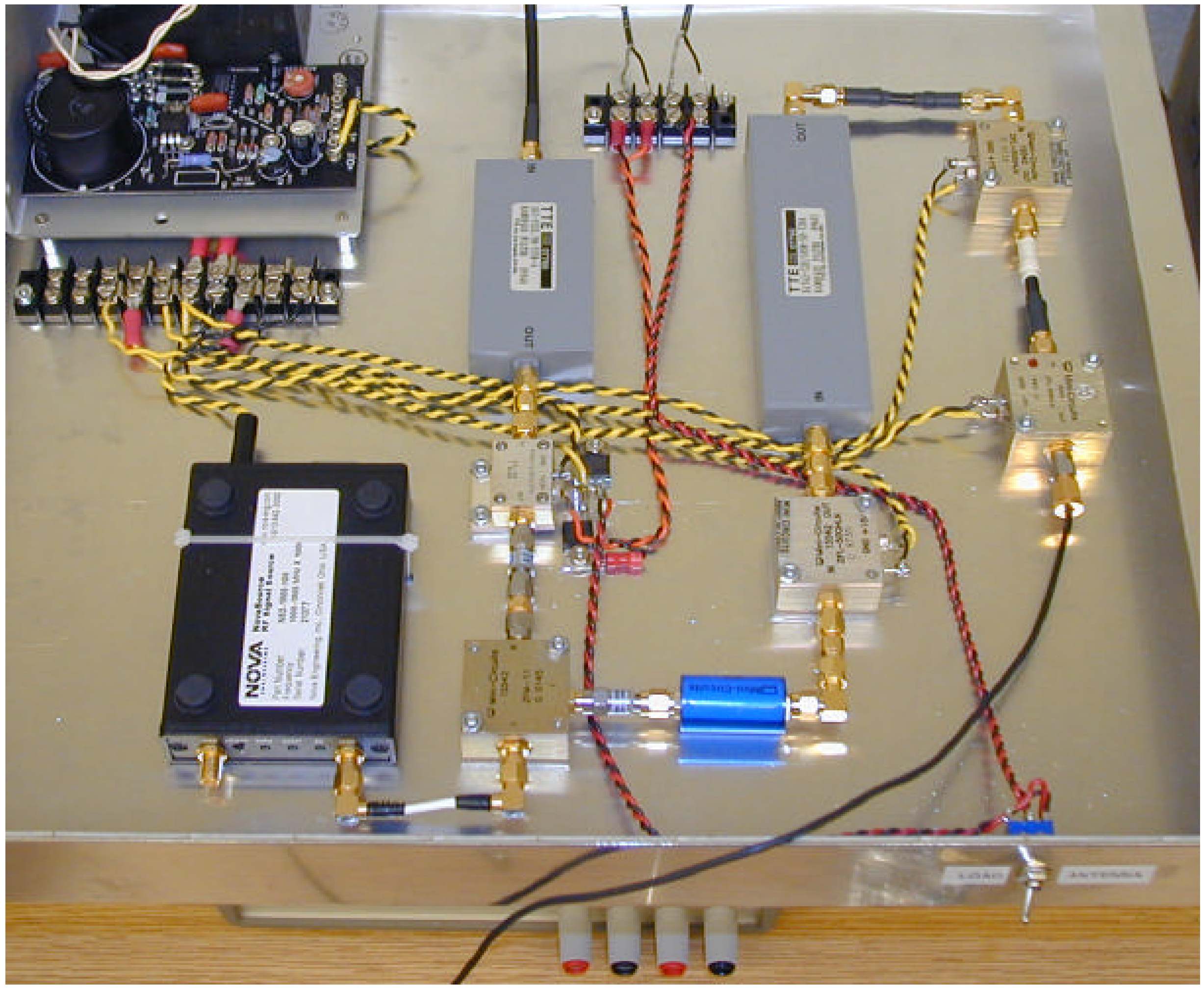
- Relatively standard super-het design: expected Tsys approx. 400K



- 100 MHz split into two back-end channels due to ADC limits
- Stability: analog gain reduced by high dynamic range ADC, low order analog filters, internal cal loads
- Temperature sensing of terminator, thermal control requirements to be determined
- Final implementation awaiting integration with system antenna

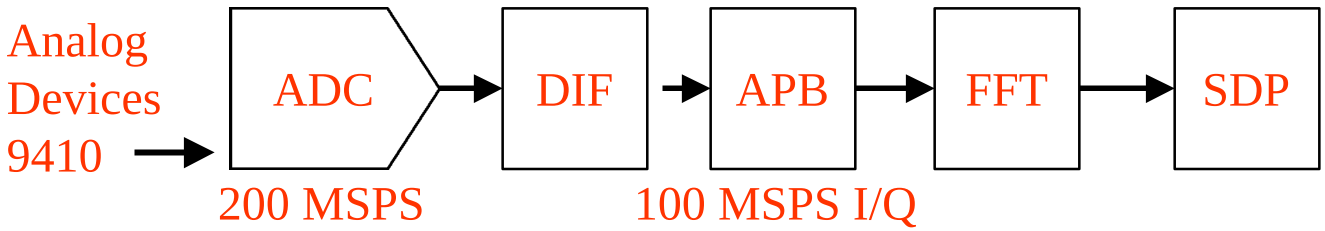
Analog Downconverter: Current Implementation

- Near identical to final design without power divider, var. attenuator, and analog blanking switch



Digital Back-End

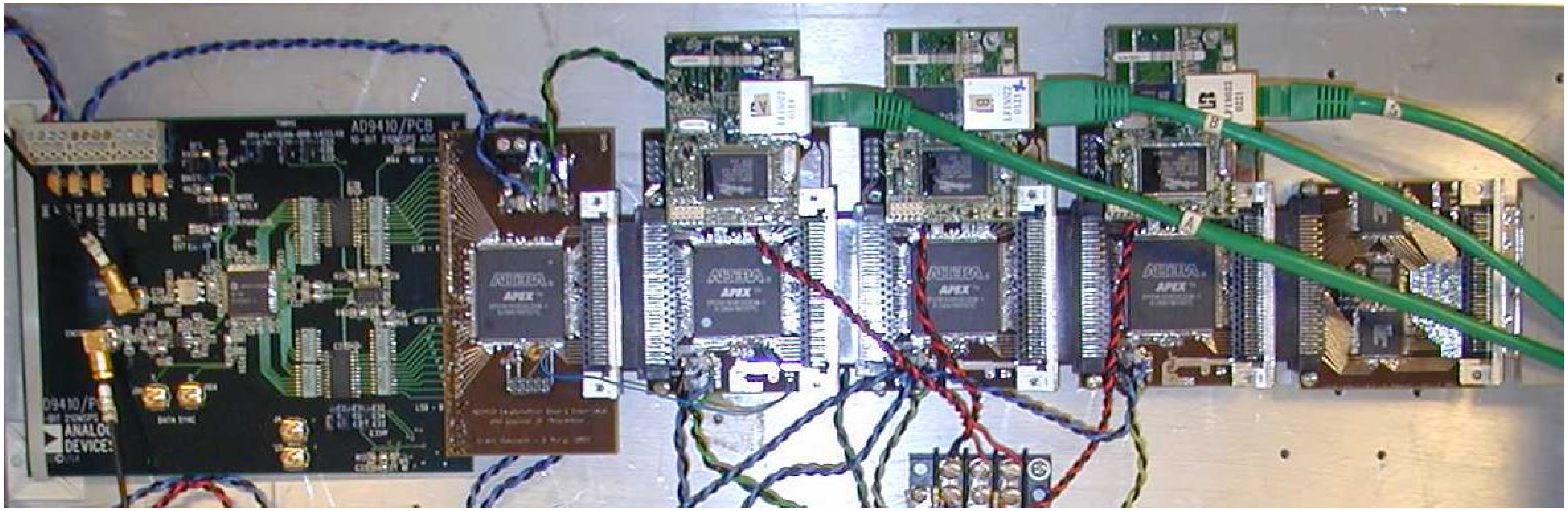
- System design includes digital IF downconverter (DIF), asynchronous pulse blanker (APB), FFT stage, and SDP operations



- Each block currently implemented on separate boards to simplify testing and reconfiguration
- Microcontroller interface via ethernet for setting on-chip parameters
- Using Altera FPGA's: order of 4000 LE, $150 (full data rate FFT block will require 2 larger FPGA's with order of 12000 LE, $512 each)
- Designs for all components complete; DIF, APB, FFT, SDP, and capture card initial implementations functioning

Current Digital Back-End Implementation

- Modular form used for processor boards: note microcontrollers



ADC DIF APB FFT SDP Capture

- Altera's Quartus software used for FPGA synthesis, fitting, and simulation (AHDL)
- Altera FIR and FFT Megacores
- Four layer circuit board layout
- LabWindows CVI software with PCI-DIO-32HS digital I/O card

Interference Suppression Algorithms

- APB updates mean/variance of incoming time domain signal; a sample > β standard deviations above the mean triggers blanker
- Blanking operates on down-stream data exiting a FIFO; blank signals before and after blanking trigger
- Parameters: blanking window size, precursor length, threshhold
- With multiple "blanking timing registers" (BTRs), additional "pulses" occurring during blanking window can trigger more blanking events

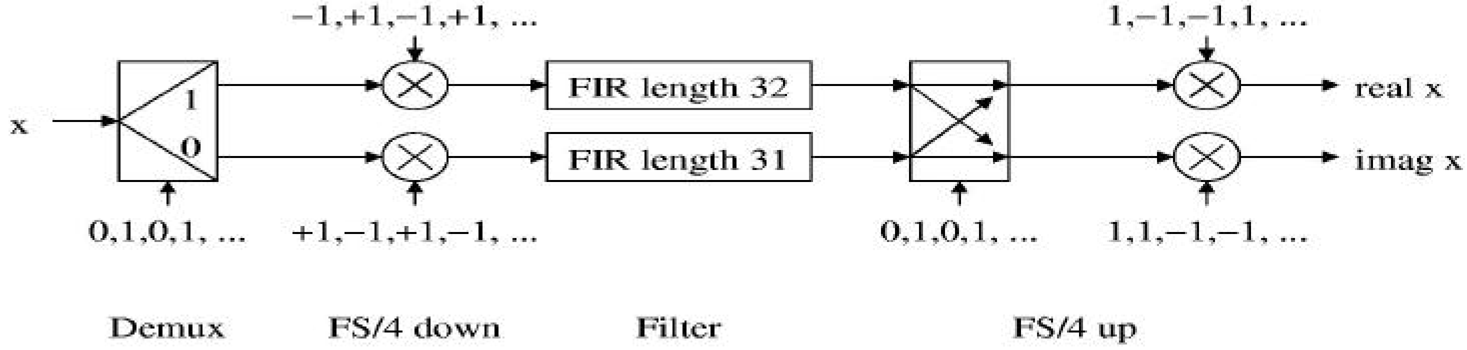
- Post-FFT: two methods
  - similar to APB, monitor per-bin mean/variance in time and blank outliers
  - unlike APB, can also blank outliers in freq. response at single time
  - window lengths and thresholds to be quantified in future work

- Parametric: remove interferer based on parametric fit to a specific functional form; to be explored further in future work

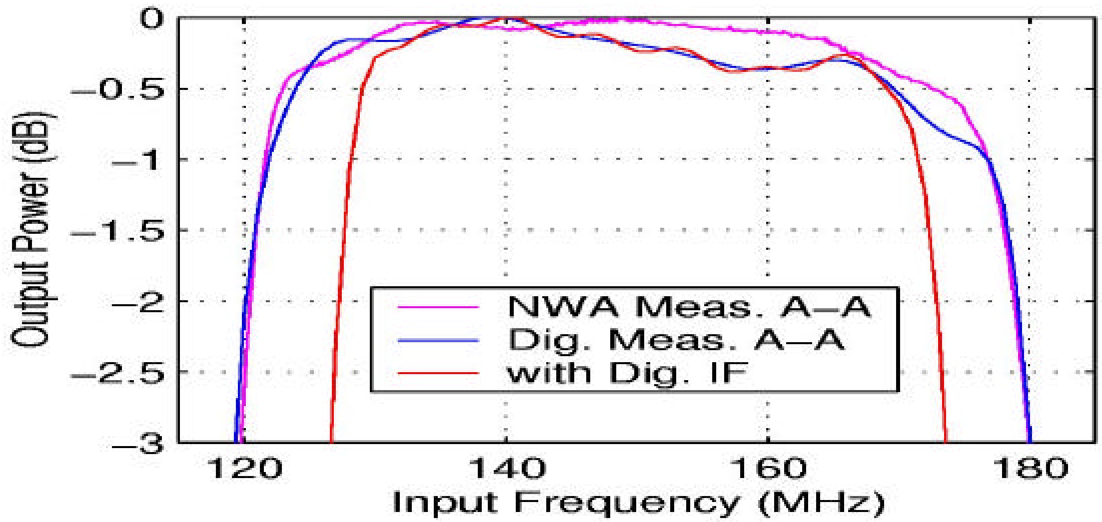
- Calibration effects corrected in real-time by appropriate scale factors

Digital Downconverter

- Fs/4 down-conversion, digital filtering to 50 MHz, Fs/4 down/up conversion for simplicity in implementation

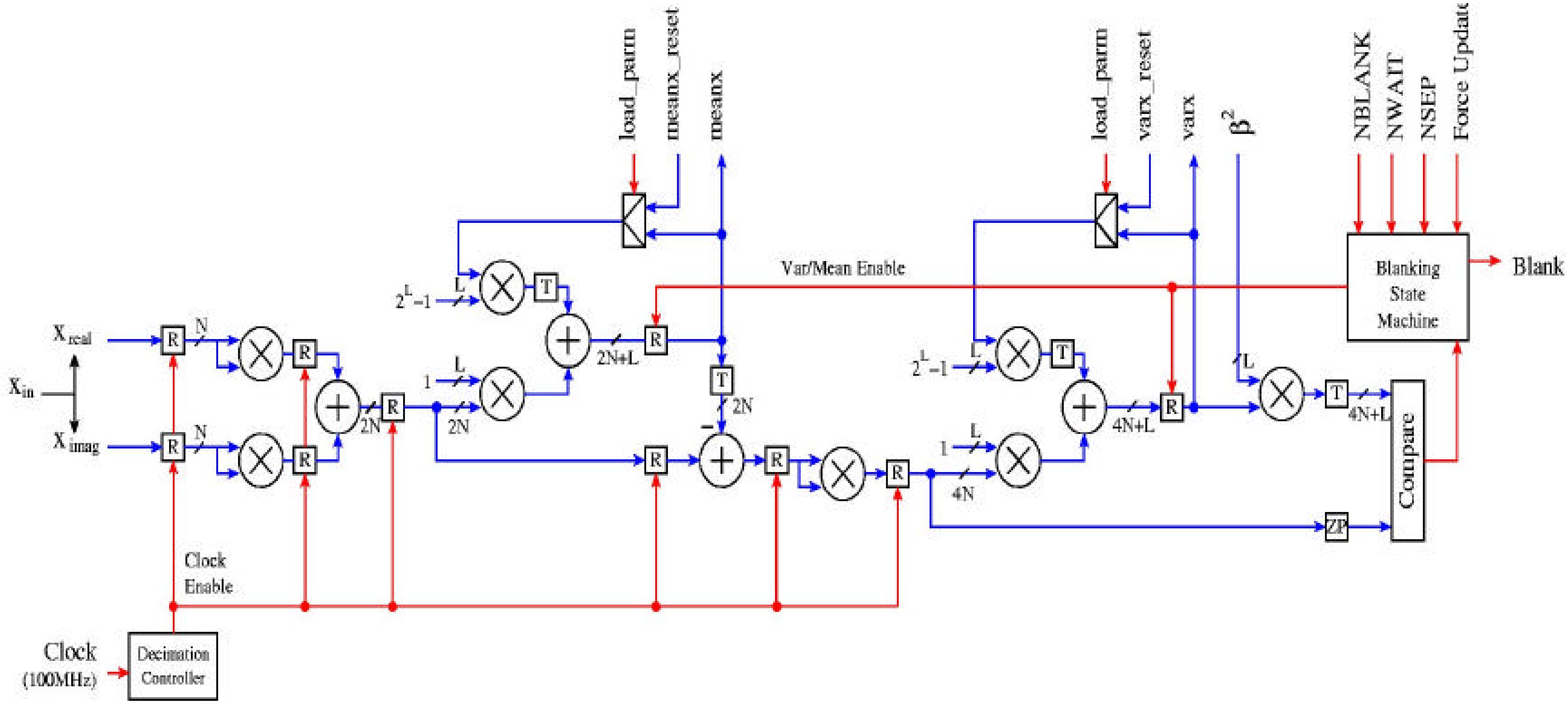


- Measurement of digital filter response:



Asynchronous Pulse Blanker

- Fully parallel digital processing system for implementing APB:



- Detection operates at 1/4 system clock rate due to precision requirements: still sufficient to capture pulses given pre-cursor blanking
- Initial implementation with one BTR

FFT

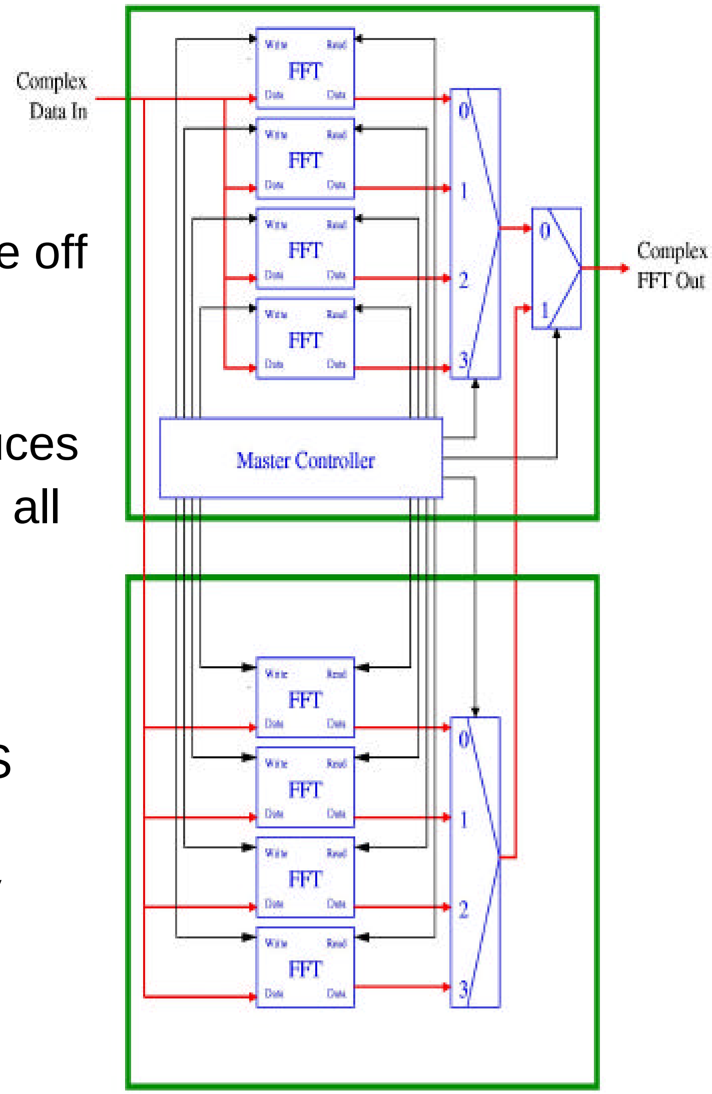
FFT's programmed using Altera FFT libraries, includes windowing

1024 points chosen as trade off of complexity and bin size

Computation of FFT introduces delay; insufficient speed for all data at 100 MHz

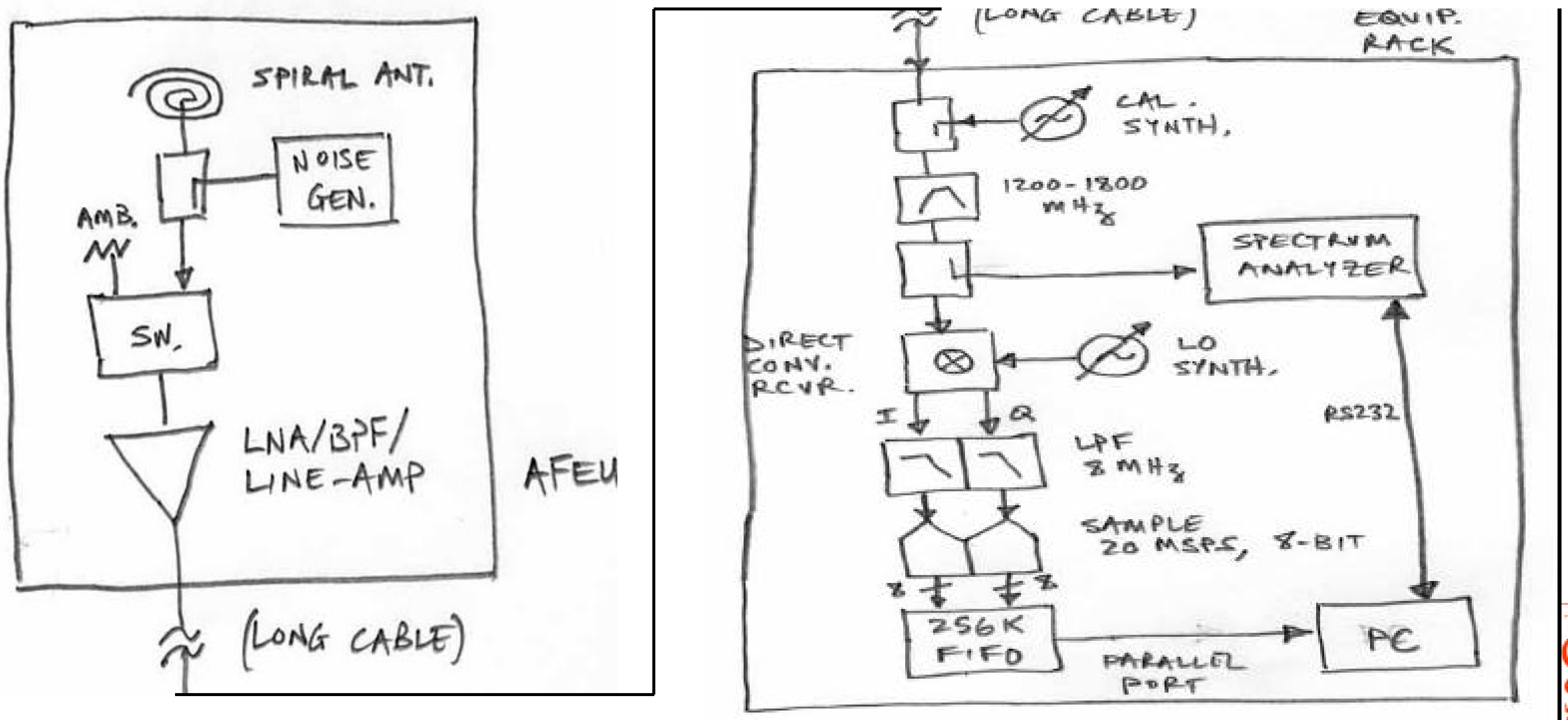
Propose 8 FFT blocks on 2 FPGA's to retain 100 MSPS

Currently implemented only a single FFT block (14% throughput)



LISA

- Measurements of RFI at multiple locations and from airborne platforms needed to develop robust interference suppression algorithms
- L-band interference surveyor/analyzer (LISA) developed for inclusion in NASA P-3 flights; first tests to occur with AESMIR
- Spectrum analyzer for wideband survey + custom 16 MHz digitizer
- Data useful for IIP project and for NASA researchers



Experiment Planning

- A series of experiments with the prototype will be conducted at ESL in years two and three for verification
- Observations of a large water tank planned; external cal sources are ambient absorbers and a sky reflector
- For operation in far field, spot size on ground proportional to antenna size; choose antenna diameter 1.2 m as a compromise between angular resolution and spot size
- Antenna provides ~15 deg beamwidth; operation from ESL roof yields antenna height ~10 m
- Resulting 3 dB spot size is ~ 6 m x 3 m for 55 deg operation; water tank should be approx. 20’ x 10’
- Cal targets will be of identical size to reduce effect of background contributions; time series of observations will be correlated with target temperatures
- Selection of parts (antenna, feed, antenna mount, temperature recording equipment, cal loads) currently in progress