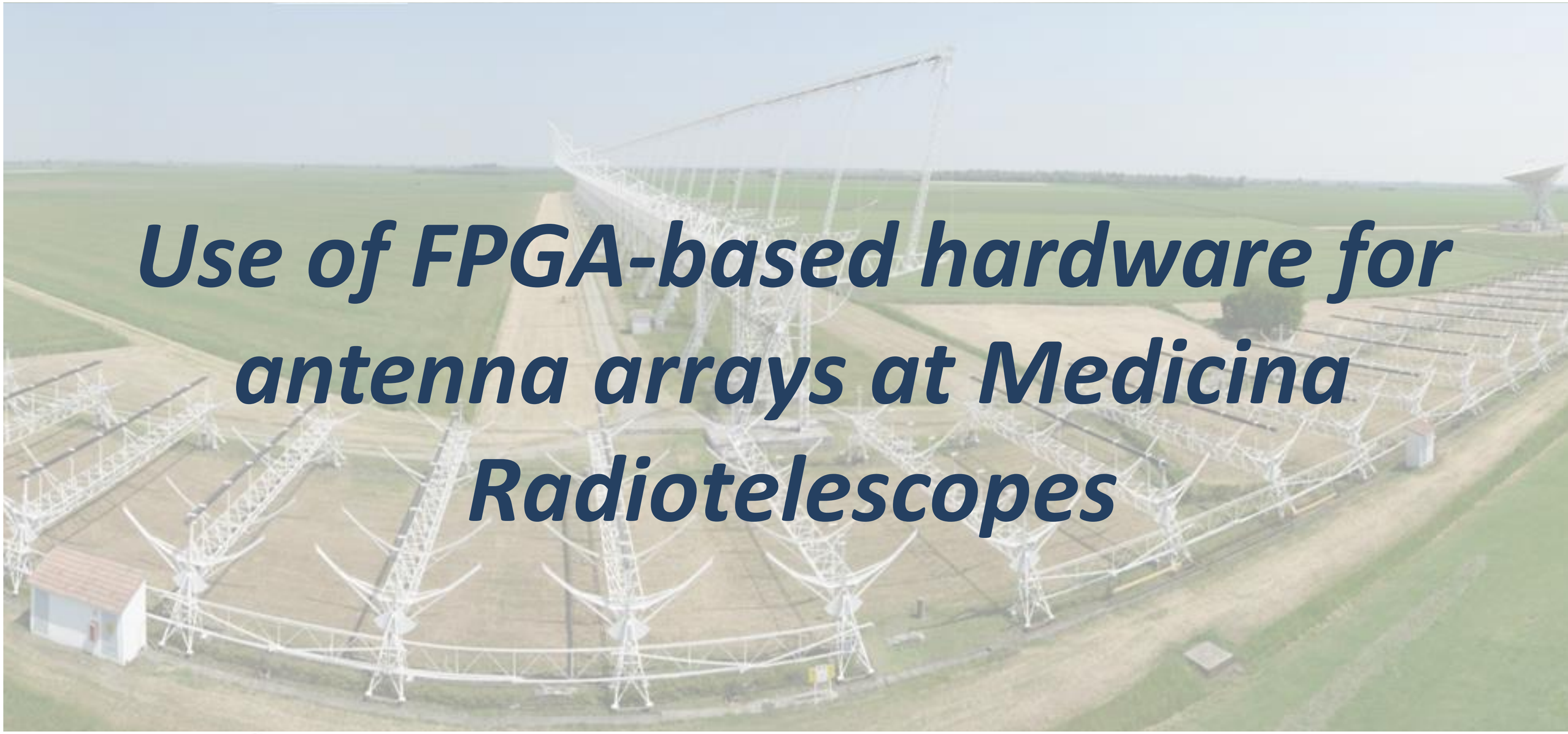

Use of FPGA-based hardware for antenna arrays at Medicina Radiotelescopes

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Applicazioni FPGA in ambito Astrofisico
Torino, May 18, 2016

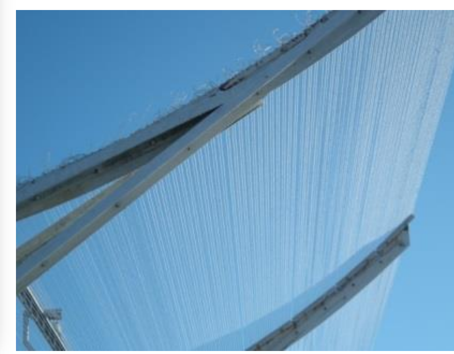
Outline

- The “Northern Cross” Medicina Radio Telescope
- FPGA-based Hardware at Medicina
- Signal Processing Algorithms for Antenna Arrays
- Applications:
  - Direct Imager and FX Correlator for BEST-2 Array
  - Medicina Array Demonstrator
  - Space Debris Observation with Northern Cross Radio Telescope

The “Northern Cross” Medicina Radio Telescope

E/W arm
Single antenna
564 m x 35 m

N/S arm
Array of 64 antennas
640 m x 23.5 m



2000 Km of steel wires to fulfill the reflective surface.

Total area = 28000 m^2
N. of dipoles on the focal lines = 5632
Frequency = 14 MHz @ 408 MHz

1st Generation CASPER Processing Boards…

CASPER

IBOB

- 1x Xilinx XC2VP50 Virtex II Pro FPGA
- 2x ZDOK+ connectors (for A/D)
- 2x CX4 10Gbps serial connectors
- 1x RJ45 Ethernet interface
- 1x RS232 interface
- 2x 512k x 36-bit SRAMs

VIRTEX-II PRO

BEE2

- 5x Xilinx XC2VP70 Virtex II Pro FPGA
- 4x CX4 10Gbps serial connectors per FPGA
- 1x 10/100 RJ45 Ethernet interface
- 1x RS232 interface
- 4 GB of DDR2-SDRAM per FPGA

VIRTEX-II PRO

…2nd Generation CASPER Processing Boards…

CASPER

ROACH-1

- 1x Xilinx Virtex-5 XC5VSX95T FPGA
- 2x Z-DOK+ 40 differential pair connectors
- 4x CX4 10Gbps high-speed serial connectors
- 1x Embedded PowerPC (Linux OS) for remote monitoring, programming and control
- 1x RS232 DB9 serial port
- 1x 10/100/1000Mbit RJ45 Ethernet
- 2x 36Mbit QDRII+ SRAMs
- 1x 4GB DDR2 DRAM

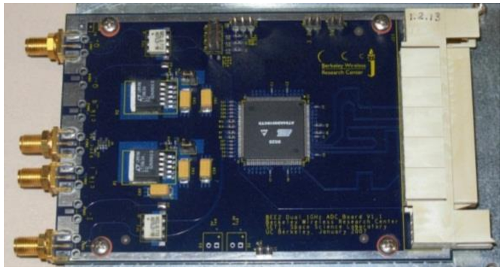
ROACH-2

- 1x Xilinx Virtex-6 XC6VSX475T FPGA
- 2x Z-DOK+ 40 differential pair connectors
- 2x Multi-gigabit transceiver break out card slots, supporting up to 8x10Ge links which may be CX4 or SFP+
- 1x Embedded PowerPC (Linux OS) for remote monitoring, programming and control
- 1x RS232 DB9 serial port
- 1x 10/100/1000Mbit RJ45 Ethernet
- 4x 72Mbit QDRII+ SRAMs connected to the FPGA
- 1x 16GB DDR3 RDIMM slot connected to the FPGA

SKA South Africa
SQUARE KILOMETRE ARRAY

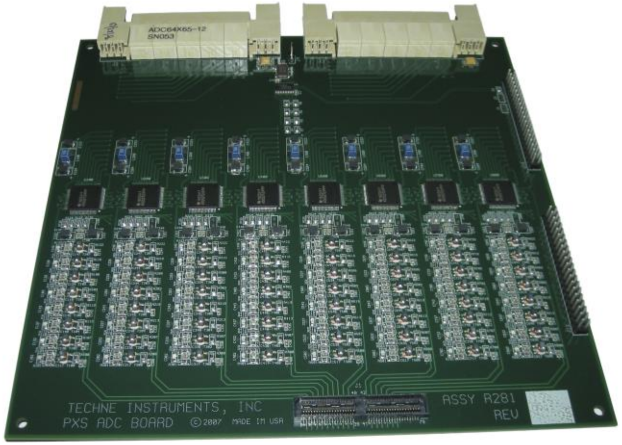
… and ADCs

ADC2x1000-8



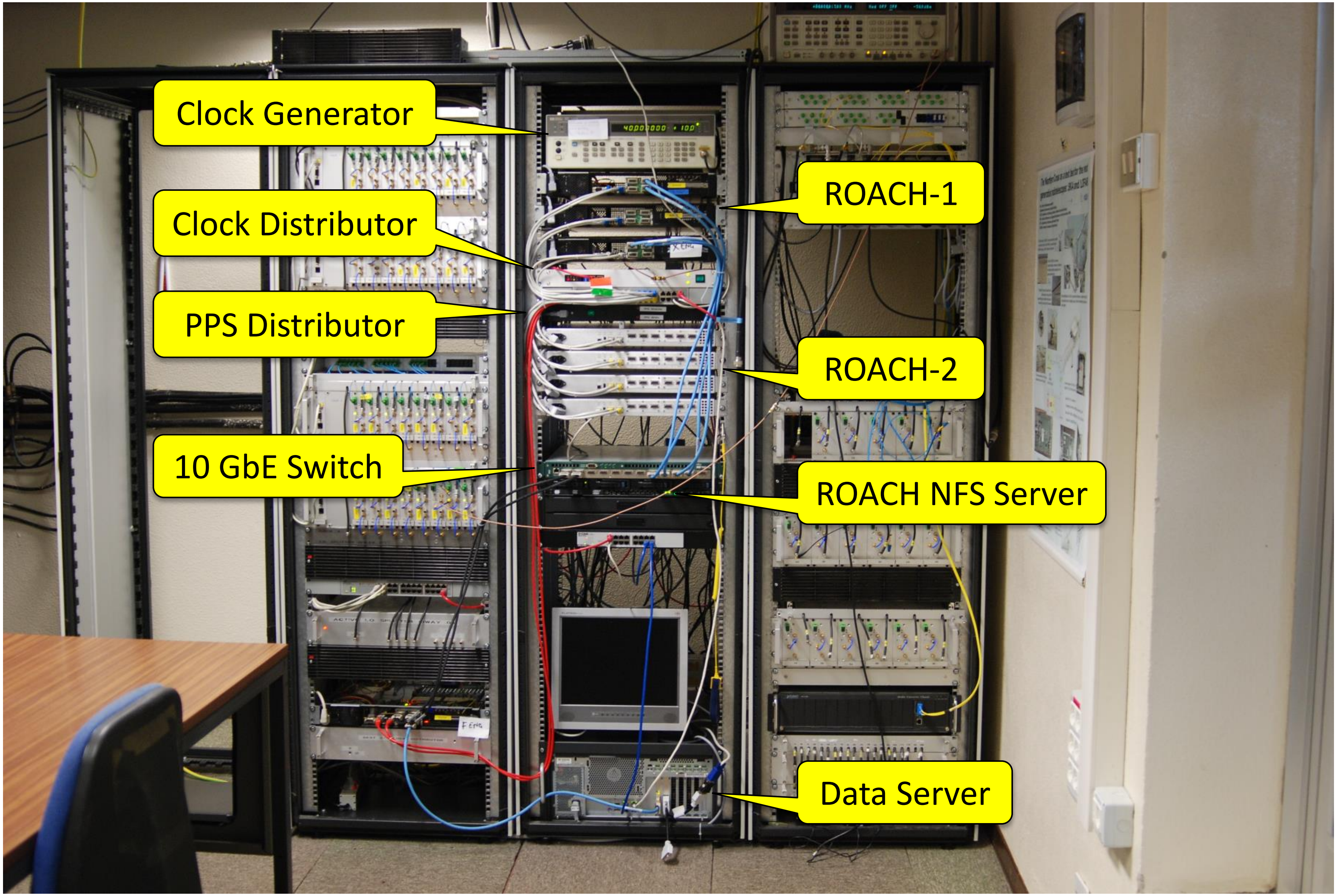
- Atmel AT84AD001B dual 1GSPS 8-bit ADC chip
- 1x Tyco Z-DOK+ 40 differential pair connector

64ADCx64-12



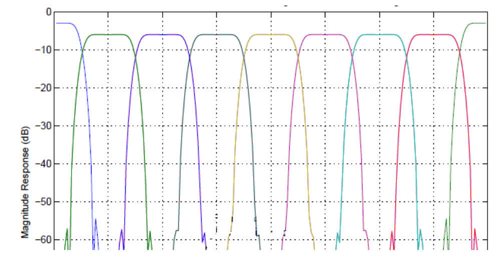
- 8x Texas Instruments ADS5272 8-channel, 12-bit ADC chip
- 64 inputs, 65 MSPS
- 64 Low-Voltage Differential Signal (LVDS) pairs via 2 Z-DOK connectors

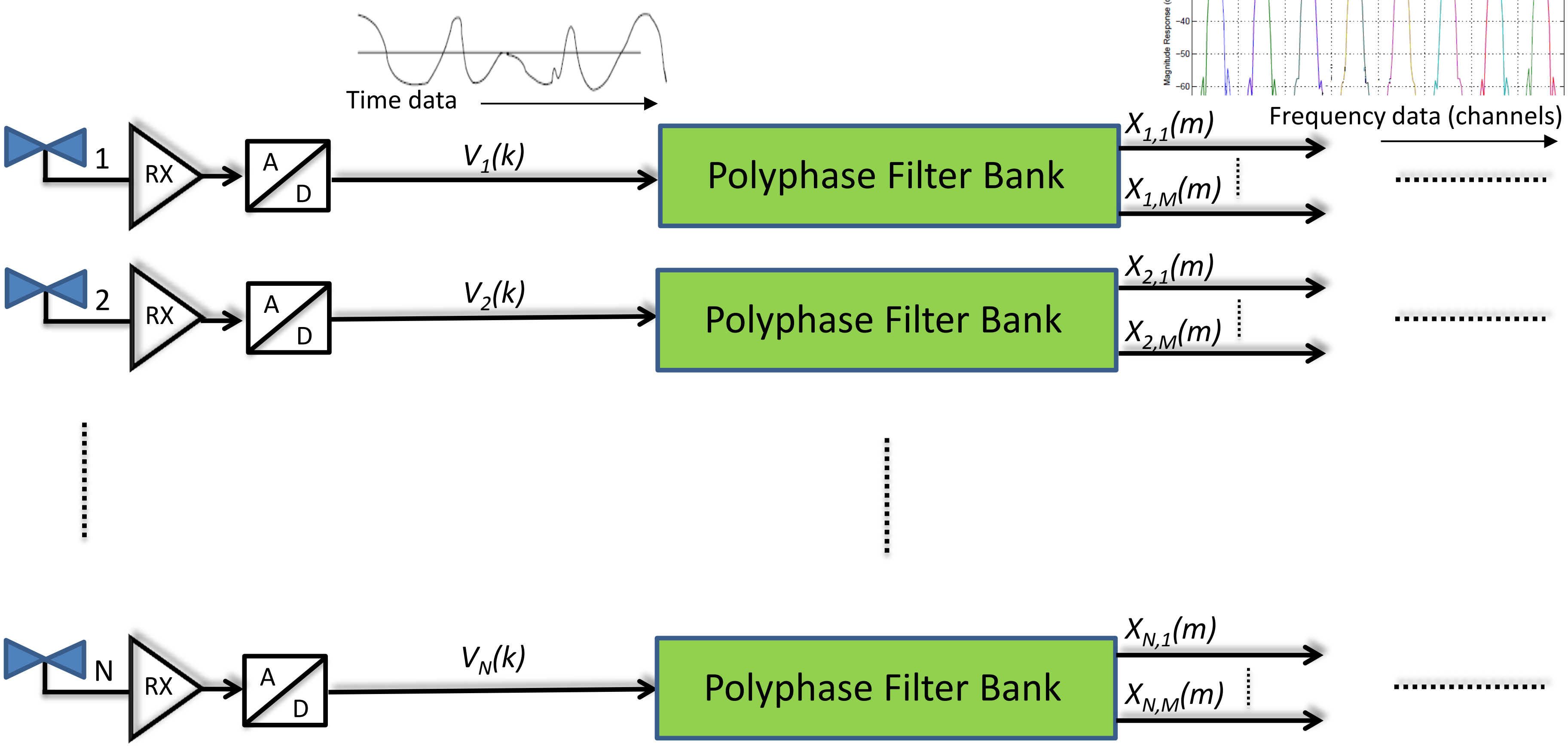
Medicina Digital Back End Rack



FX Correlator …

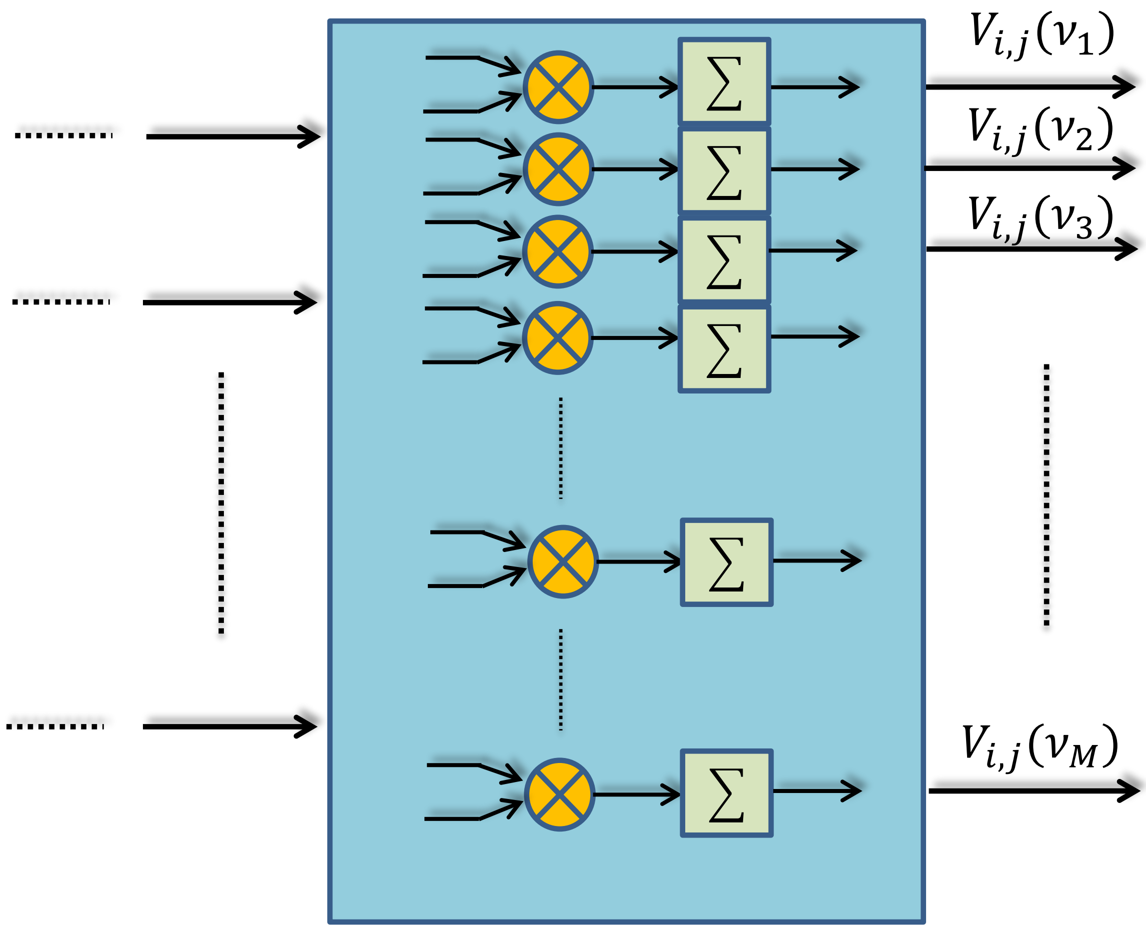
Channelizer (“*F-Engine*”)

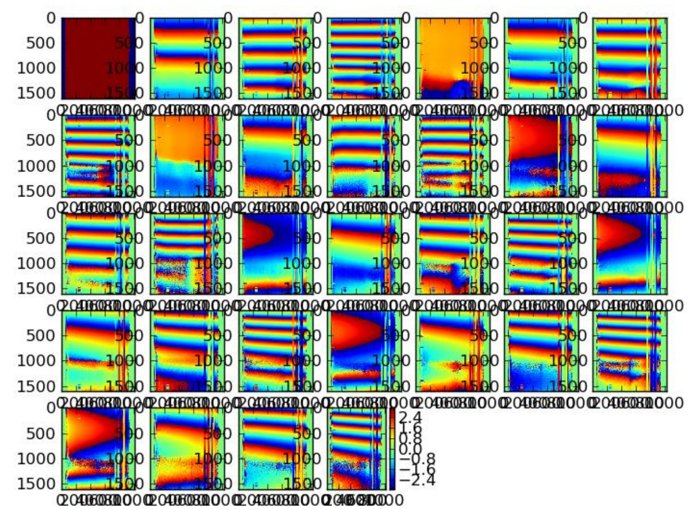




… FX Correlator

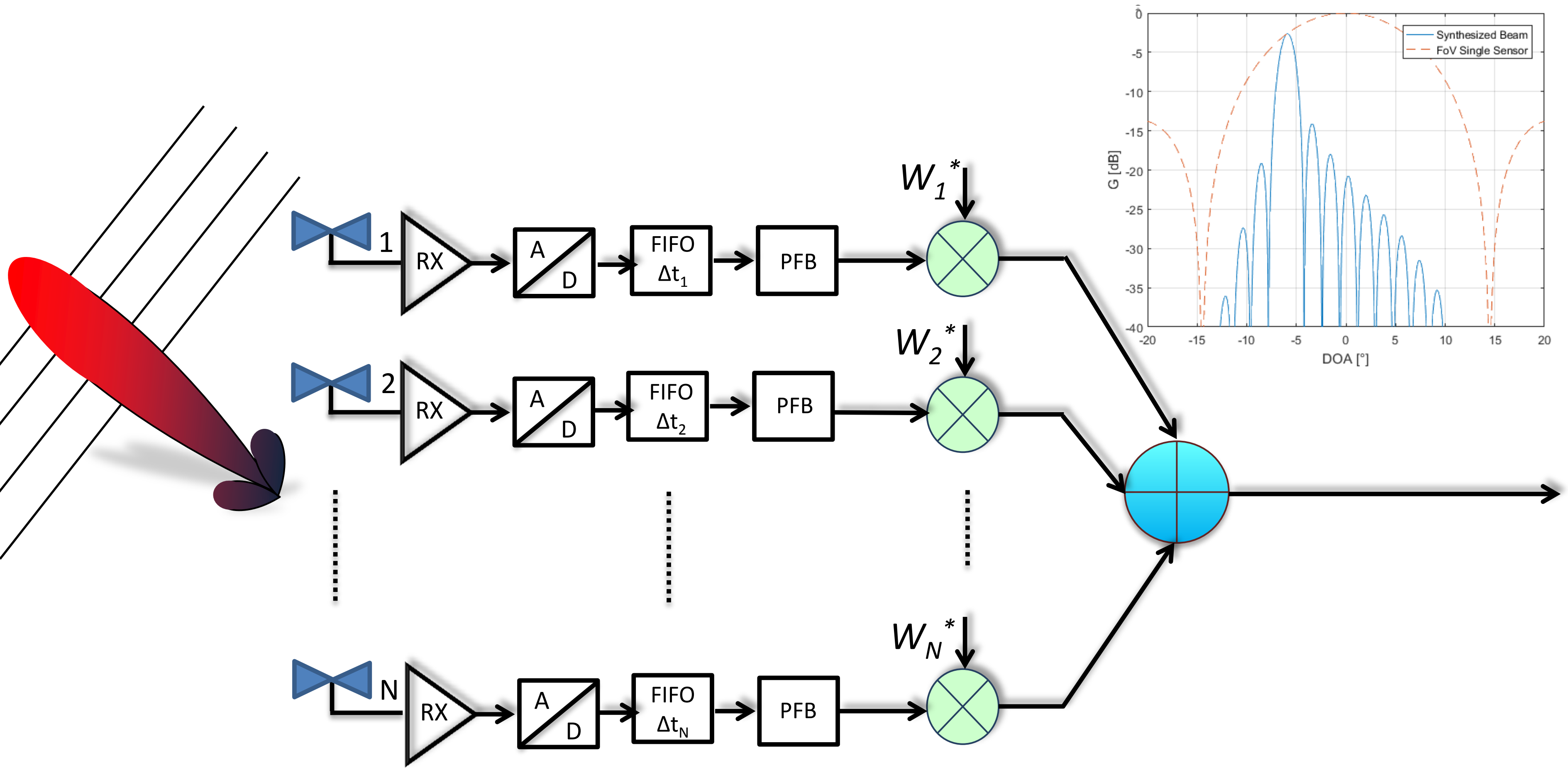
Correlator (“*X-Engine*”)





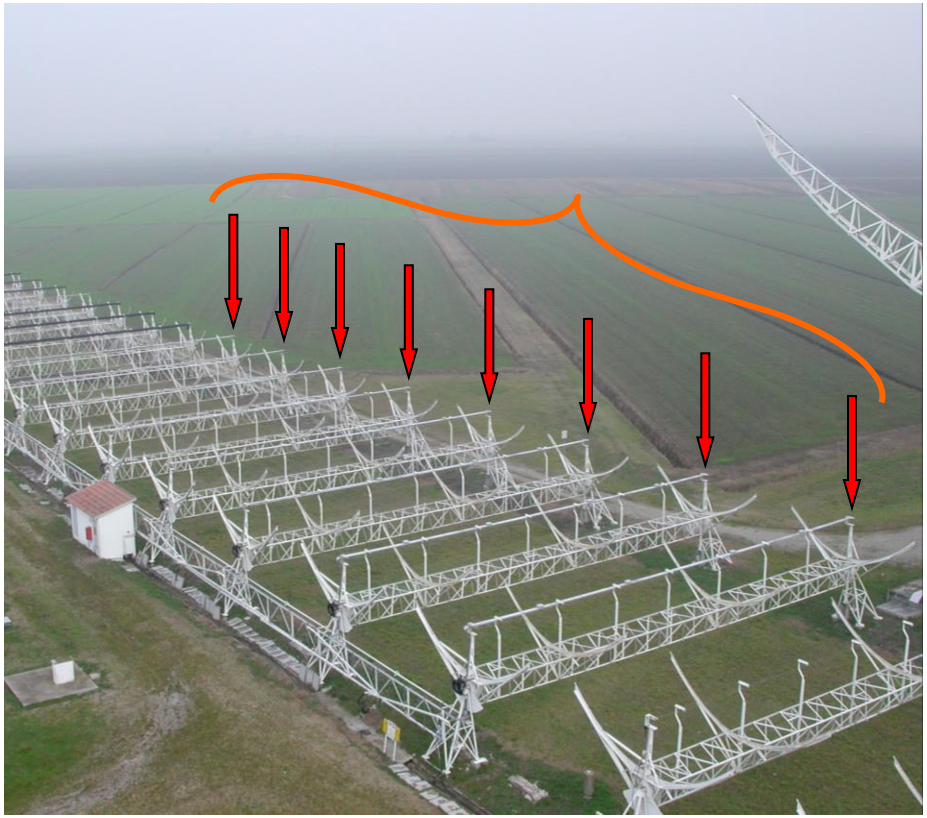
Beamforming

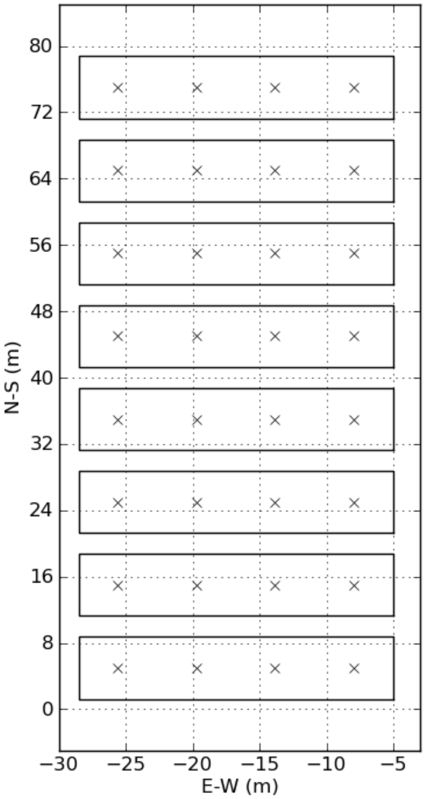
Adjusting gain and phase (through beamformer coefficients) in each path, the antenna is electronically “steered” within the FoV (single antenna pattern).



BEST-2 Array (SKA Demonstrator)

- *Planar array*
- *32 receivers installed in 8 cylinders of the North-South Arm (4 rx per cyl.)*
- *Single polarization*
- *RF bandwidth: 400-416 MHz*
- *Optical fiber links from the antennas to the receiver room*





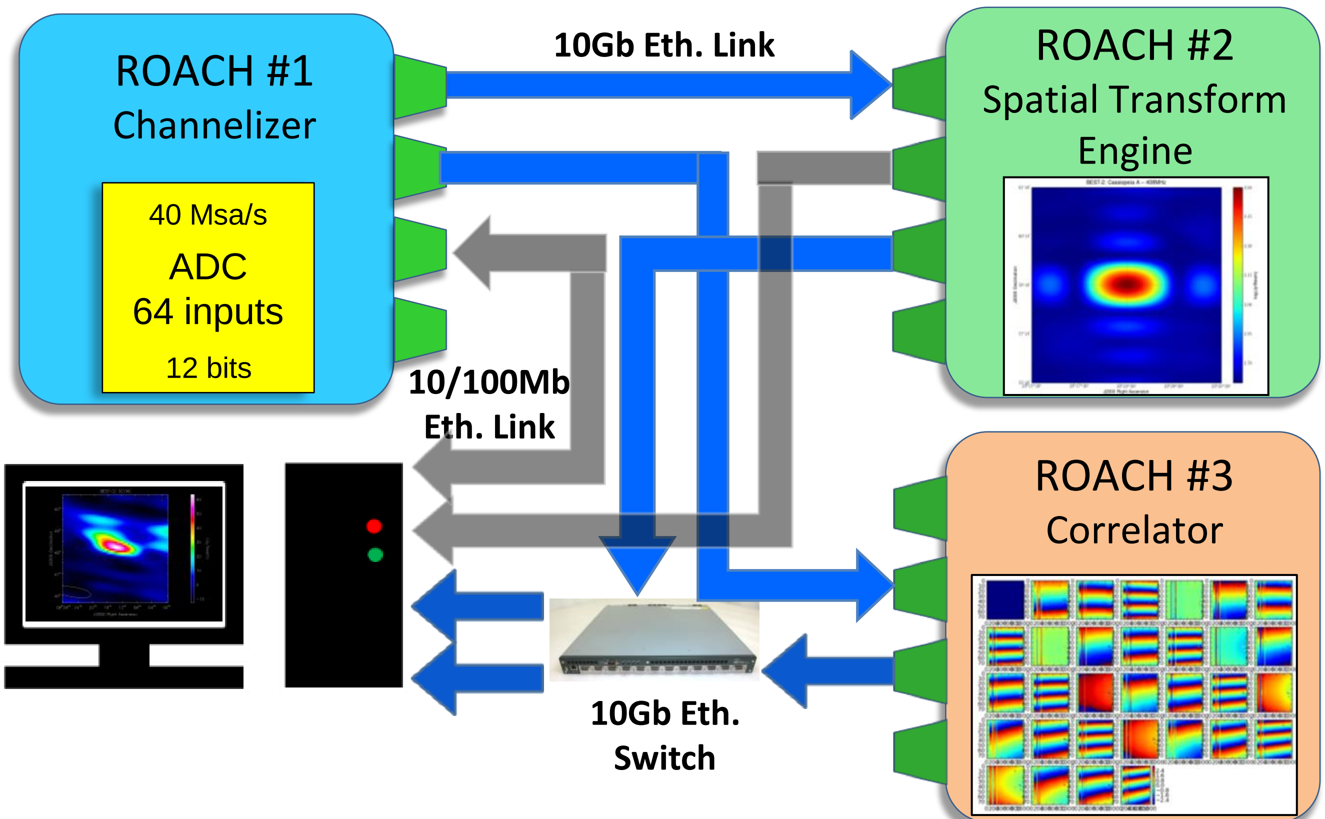
BEST-2 Back End

ROACH #1

- Bandwidth: 20 MHz
- 1024 Frequency Channels
- Resolution Bandwidth: 19.5 KHz
- Amplitude and Phase Equalization

ROACH #2

- Direct Imager
- N. Beams Generated: 128
- N. Beams Output at full data rate: ≤8
- Throughput: 5.12Gb/s

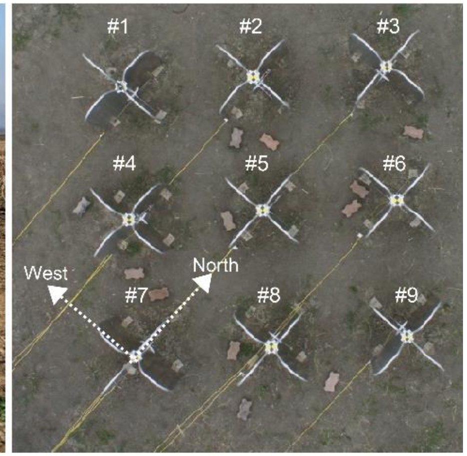


ROACH #3

- FX Correlator
- N. Baselines: 528
- Full Correlation Matrices
- Calibration Coefficients extracted in Software

In collaboration with Jack Hickish, Griffin Foster, Kris Zarb Adami and Andrea Mattana

MAD: Medicina Array Demonstrator

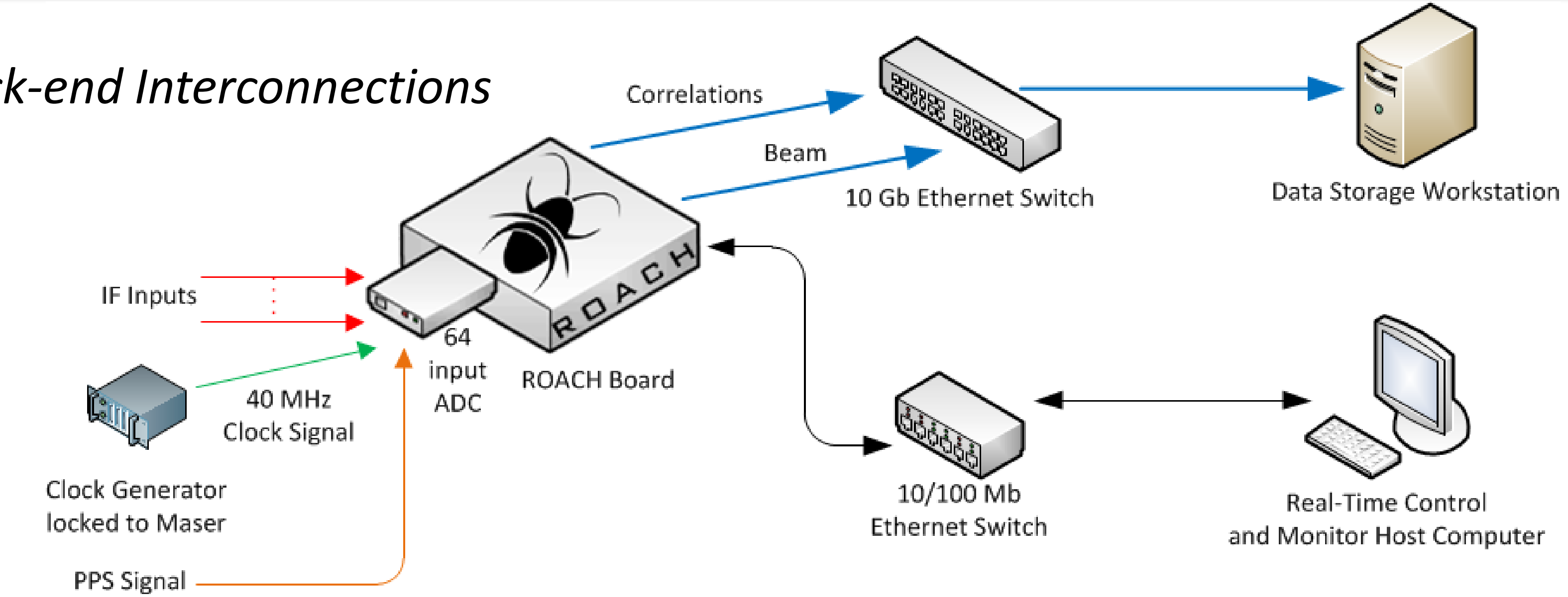


- MAD is a 3 x 3 regularly spaced antenna array
- Test bench for antenna characterization and array calibration techniques in its operative conditions
- Novel procedure based on a flying artificial test source

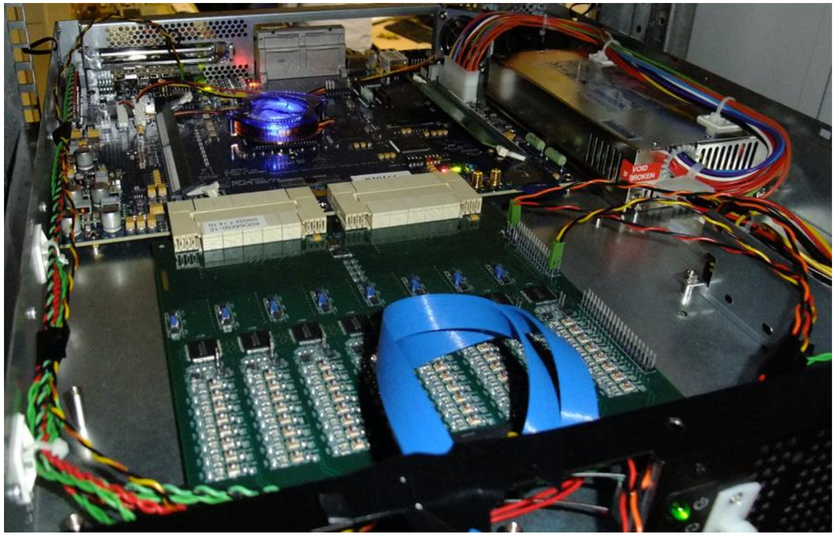
- Each array element receives a RF signal from a transmitting Unmanned Aerial Vehicle (UAV) (hexacopter)
- A digital FPGA-based back-end is responsible for both data-acquisition and signal processing
- Test of new calibration algorithms are performed in post-processing

MAD Digital Back-end

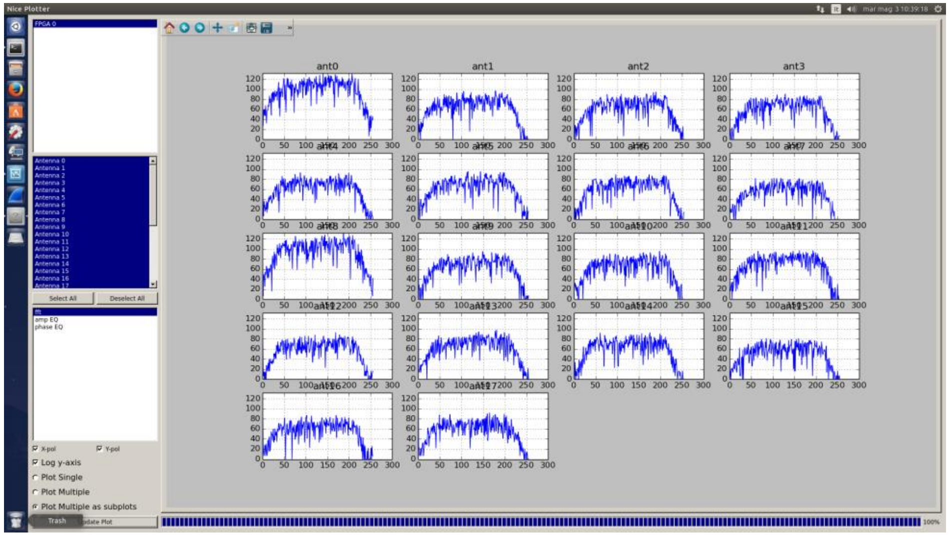
Back-end Interconnections



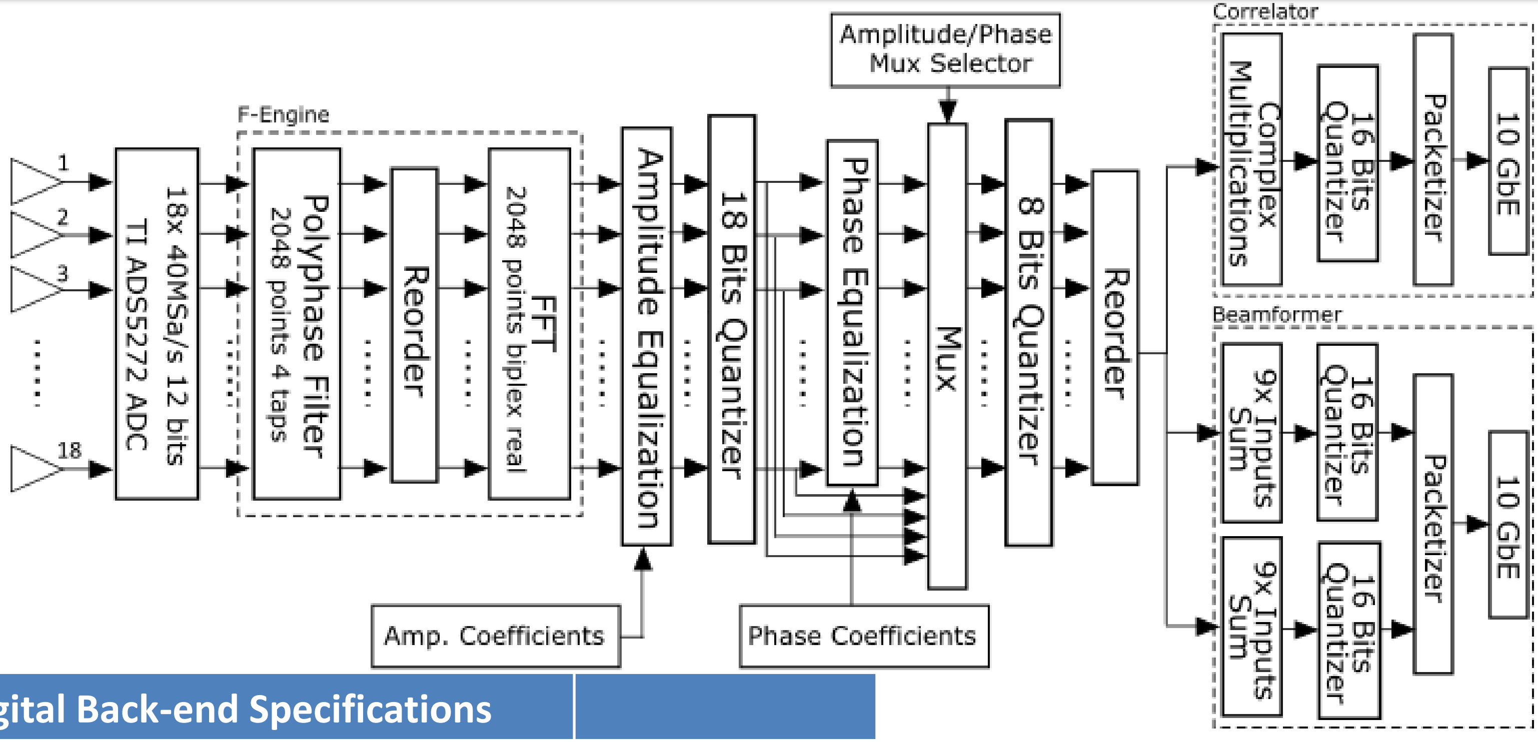
Roach Board (https://casper.berkeley.edu/)



Software Tools for Real-Time Monitoring



MAD Digital Back-end

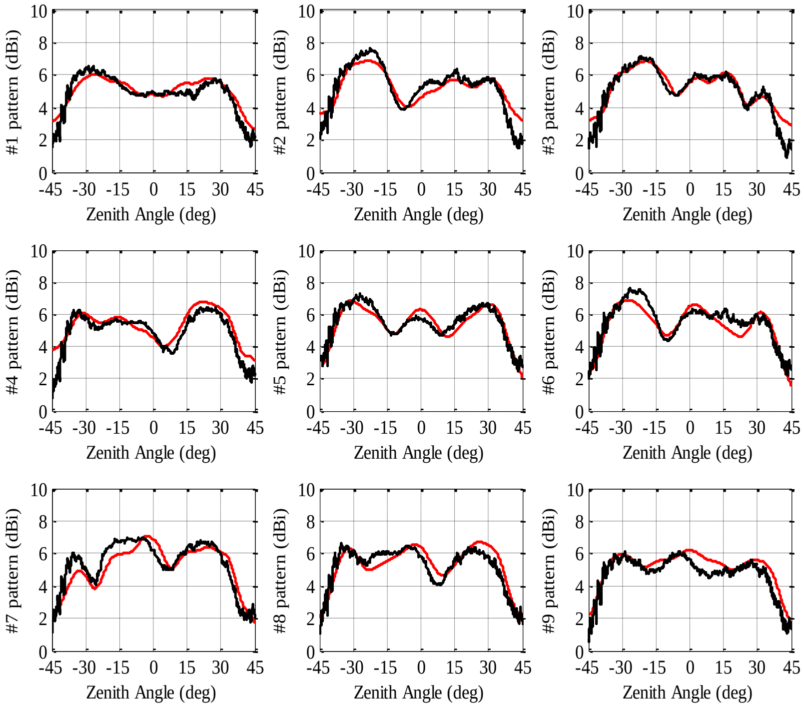


MAD Digital Back-end Specifications	
FPGA clock	160 MHz
ADC sampling clock	40 MSa/s
ADC sampling precision	12 bits
Frequency Resolution	19.5 kHz
Time resolution	51.2 µs
Auto Correlations	9
Cross Correlations	8
Correlator and Beamformer Output	10 GigaBit Ethernet

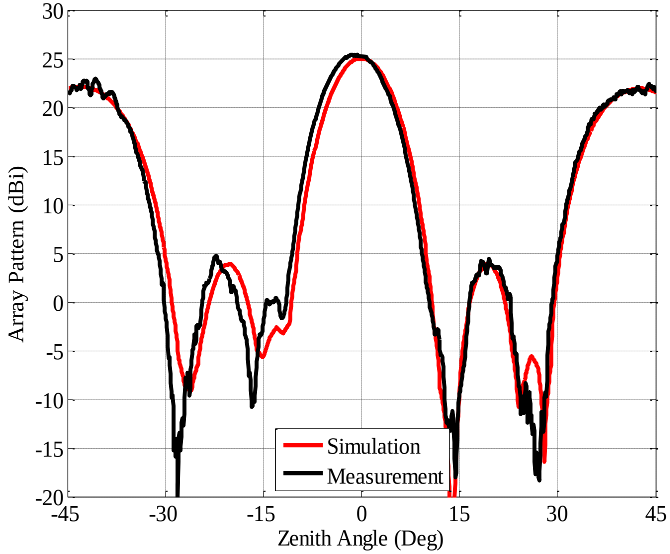
- **Digital architecture implemented in a single ROACH Board**
- FPGA: Xilinx Virtex-5 SX95T
- Correlator and Beamformer works in parallel
- Amplitude and Phase Coefficients written in FPGA through software interface

MAD: Some results

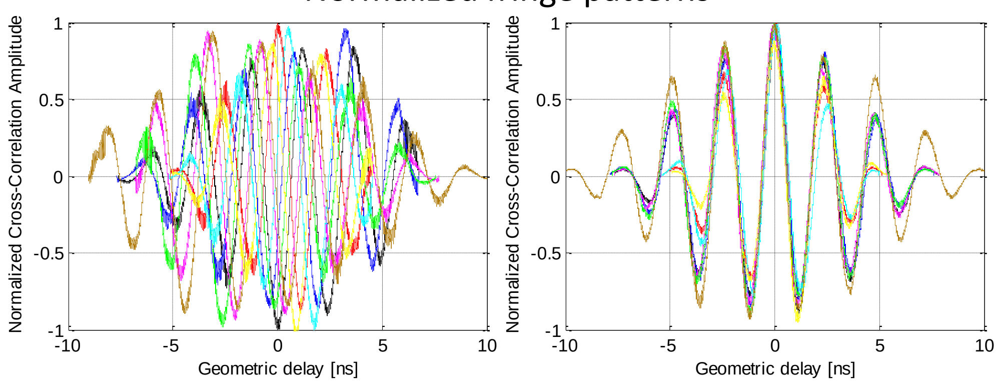
Embedded antenna pattern



Array beam pattern



Normalized fringe patterns

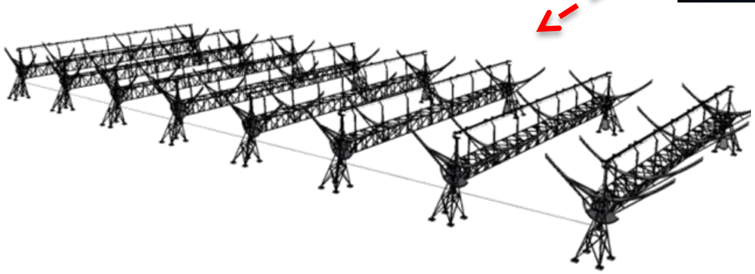


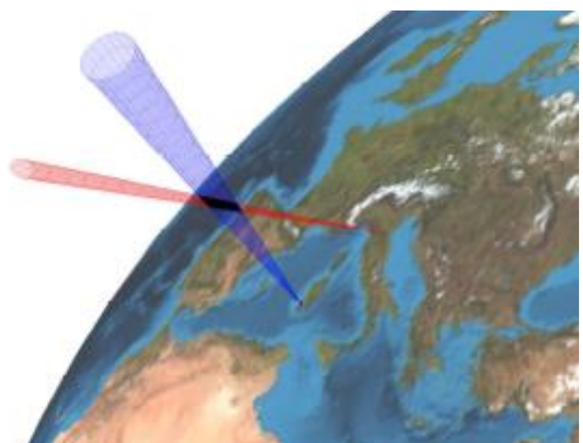
- Very good agreement between measurements and EM simulations both for the embedded element and the array beam pattern
  - Good accuracy in the array calibration
  - Validation of the calibration procedure

Northern Cross for Space Debris Observation

- SST (Space Surveillance and Tracking) European consortium (June 2015)
- EC funds (2015-2020) for the upgrade of existing assets, for construction of new facilities and for the operating cost
- Northern Cross (N/S arm) selected as the receiver part of a bistatic radar

agenzia spaziale italiana





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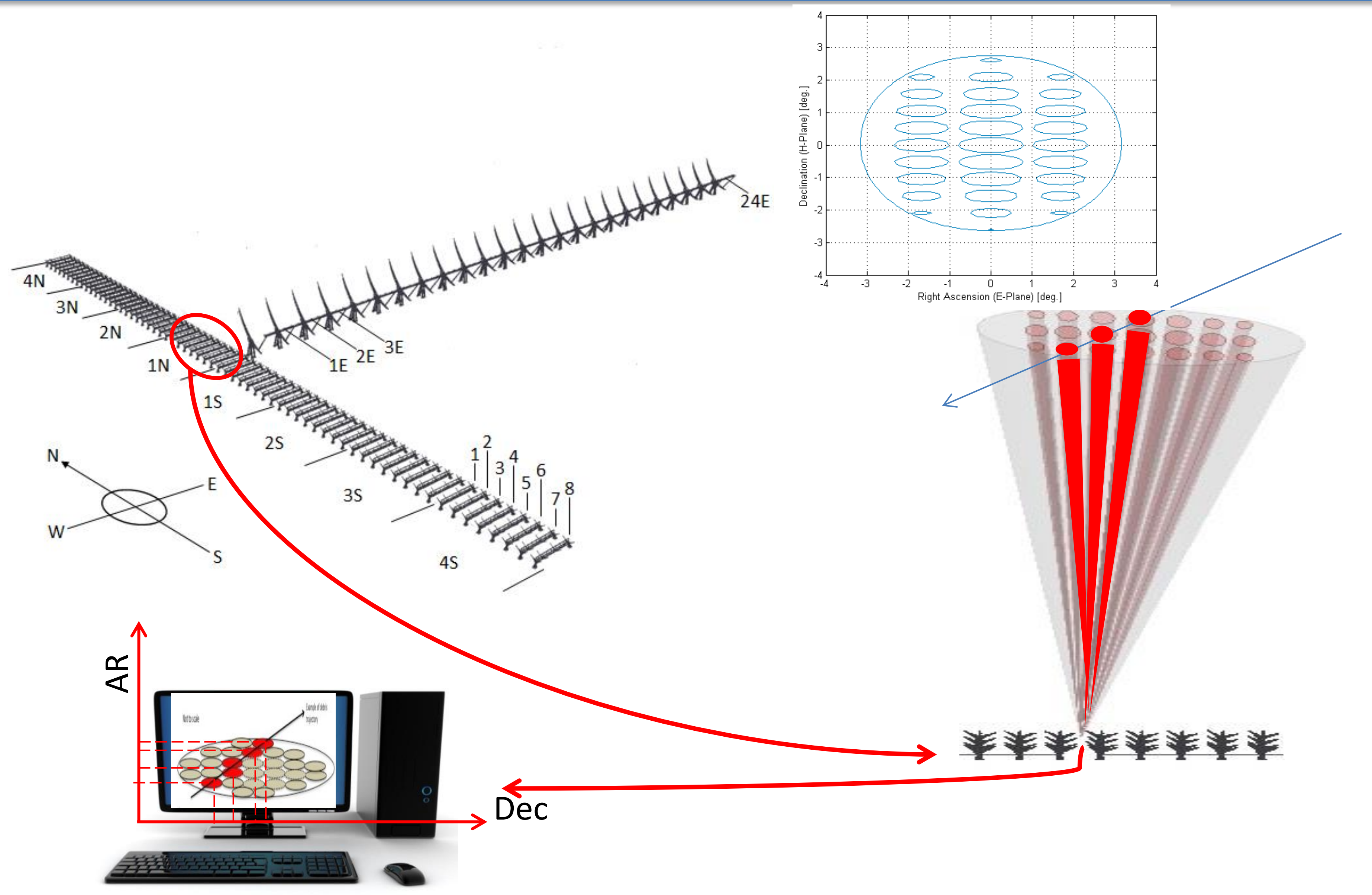
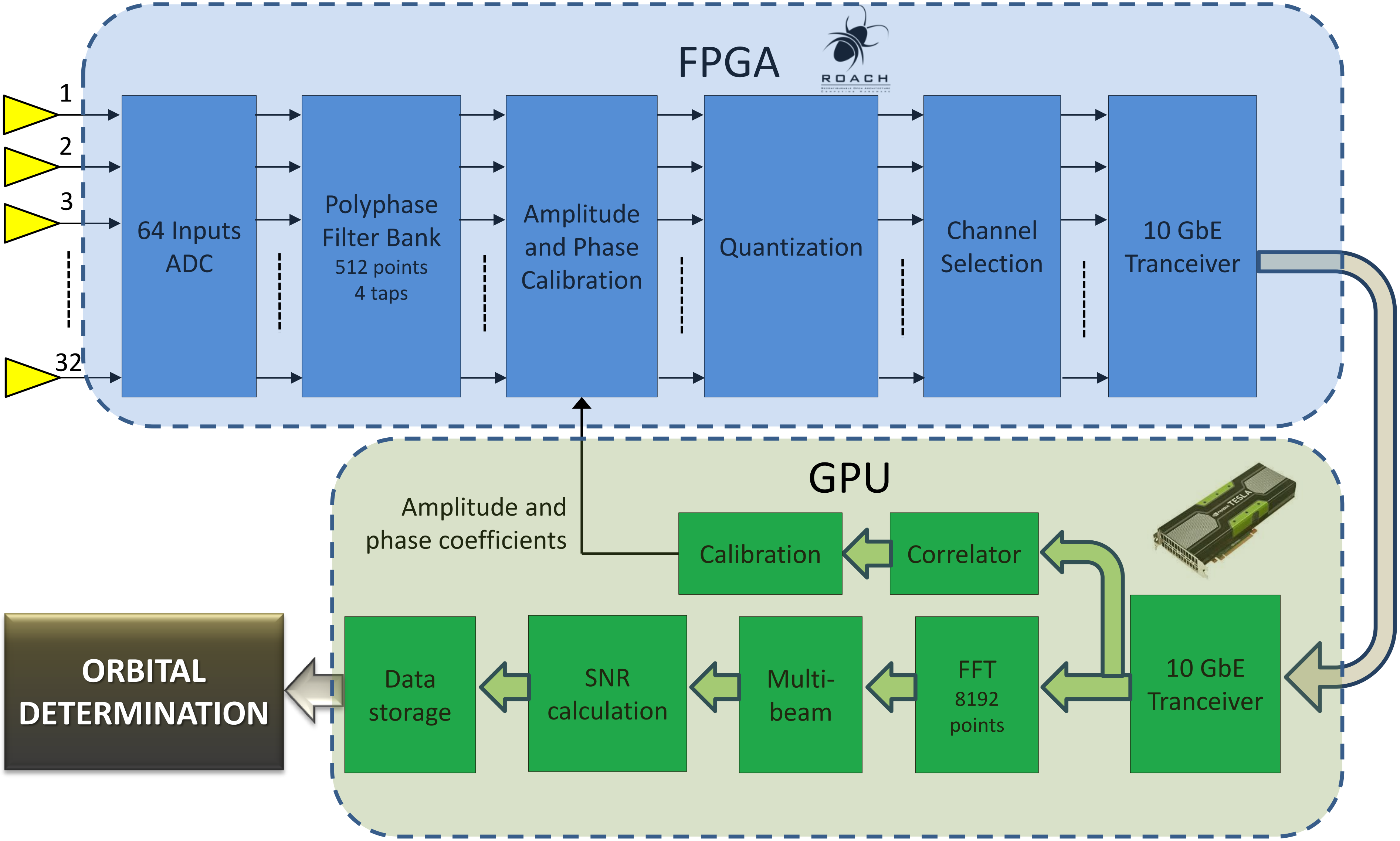
Electronic Multi-beam with BEST-2 Array



Back-end for Orbital Determination



In collaboration with Germano Bianchi, Andrea Mattana, Alessio Magro, Kris Zarb Adami

Conclusions

- Expertise in FPGA applications at Medicina
- Shared usage of reconfigurable hardware among many projects
- Exchange of knowledge and collaborations

Thank you.