MCCT-SKADS Technical Workshop
The SKA and Digital Signal Processing
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BEAMFORMING AND CALIBRATION ARCHITECTURES USING THE *CASPER* SYSTEM

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Presentation outline

- The IRA/INAF Medicina Radio Observatory
  - The "Northern Cross" Radio Telescope
- Italian SKA pathfinder: BEST
- Medicina Digital Back-end
- BEST beamformer
- BEST calibration design
- Results

The IRA/INAF Medicina Observatory

The Observatory is addressed at:
Via Fiorentina n. 3508/B - 40059 Fiorentina di Medicina (Bologna)

Lat. Nord 44° 31' 13.8" Long. Est 11° 38' 48.9" Elev. 28m

The IRA/INAF Medicina Observatory

The "Northern Cross" Radio Telescope

E/W arm

Single antenna
560 mt x 35 mt
(1536 dipoles)

N/S arm

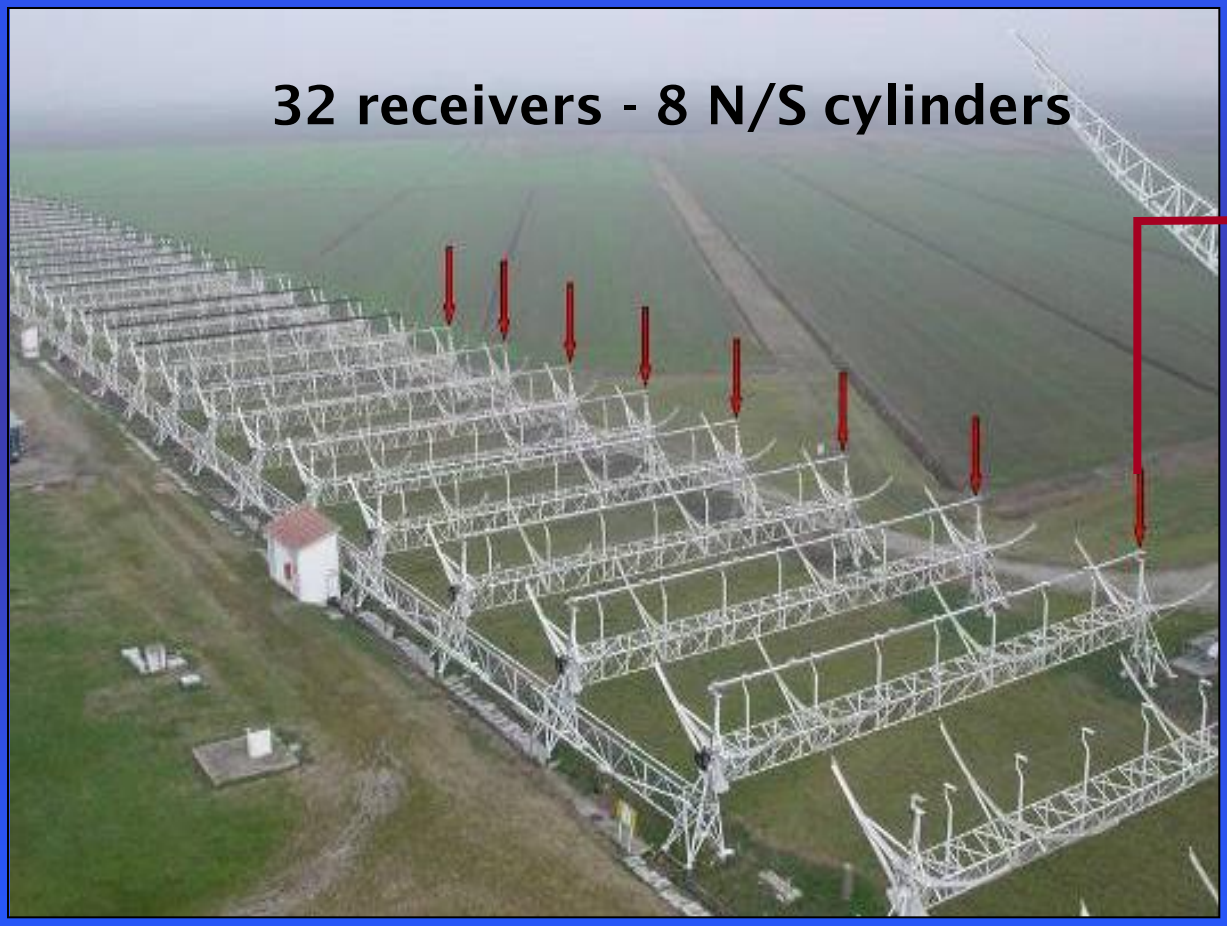
Array of 64 antennas
640 mt x 23.5 mt
(4096 dipoles)

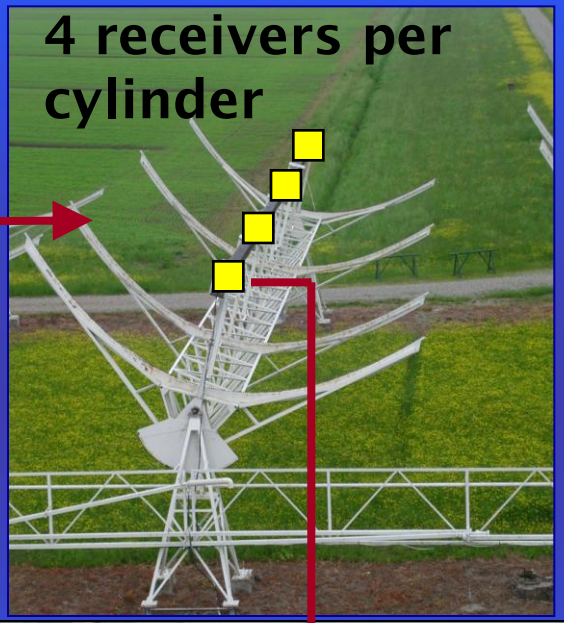
Collecting area:
$30000 m^2$

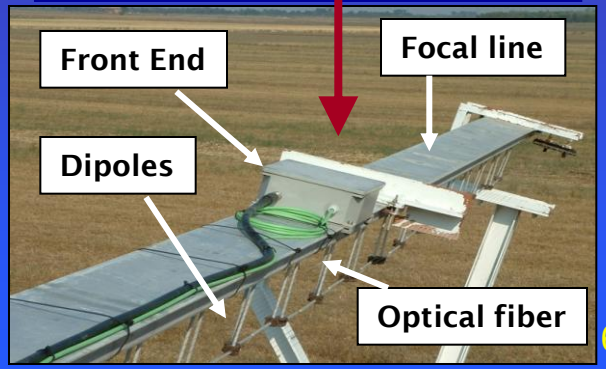
Working bandwidth: 2.7 MHz @ 408 MHz

BEST2

Part of the Northern Cross array has been used to obtain a pathfinder for SKADS







BEST2 main features

- System temperature: 86 K
- RF Central frequency: 408 MHz
- Frequency BW: 16 MHz
- IF: 30 MHz
- Instantaneous BW: 16 MHz
- Instantaneous primary FOV:
  - 37.62 deg^2
  - FOV-Declination: 5.7 deg
  - FOV-Right ascension: 6.6 deg
- Synthesized beam size: 0.9 deg^2
  - Declination: 31.1 arcmin
  - Right ascension: 104 arcmin
- Independent beams within FOV: 21

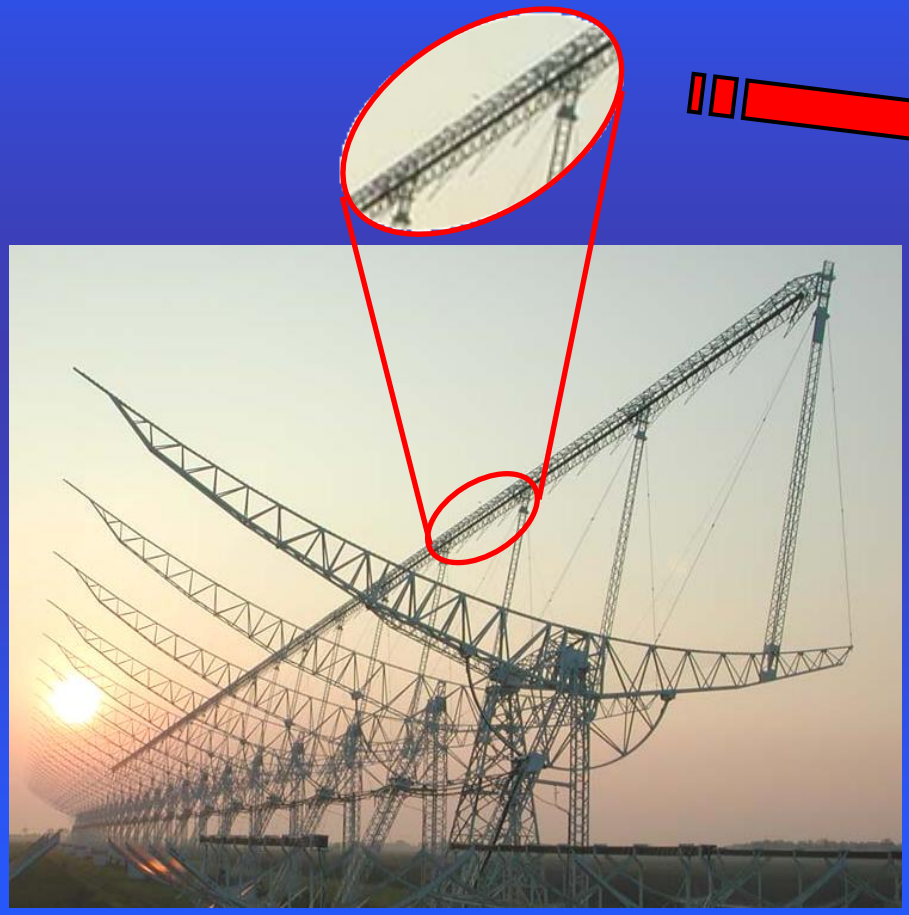
Continuum sensitivity
BW: 16 MHz
Integration Time: 30 sec

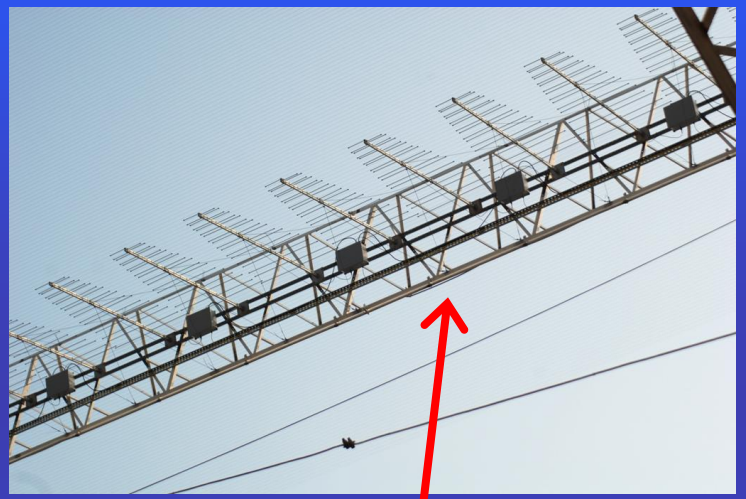
Total power mode (full array)
RMS noise / Sensitivity: 5.4 mJy
RMS noise / Sensitivity: 2.0 mK

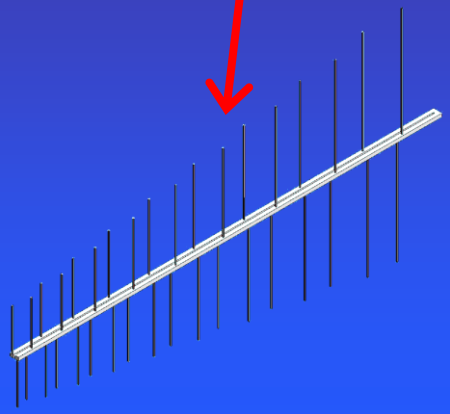
Correlation (full array)
RMS noise / Sensitivity: 43.3 mJy
RMS noise / Sensitivity: 2.8 mK

BEST3-Io

- Array composed by 18 log-periodic antennas (16+2 dummy elements)
- Frequency bandwidth: 120-240 MHz
- ~400m^2 effective area (estimated)







Medicina Back End

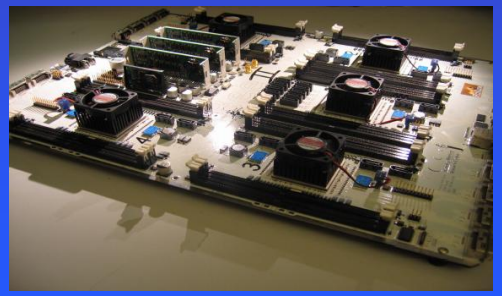
Medicina Digital Back End:

- 8 IBOBs + 16 A/D boards
- 1 BEE2
- 1 10 GbE Fujitsu switch
- 1 PC equipped with a 10GbE network card

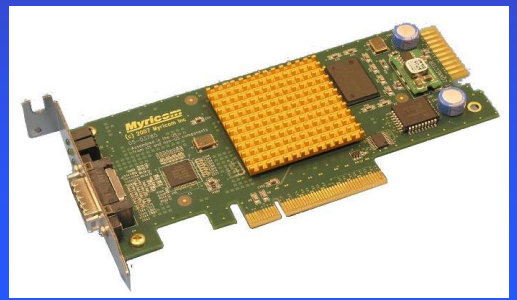
- IBOBs

- 10 GbE Fujitsu switch

- BEE2

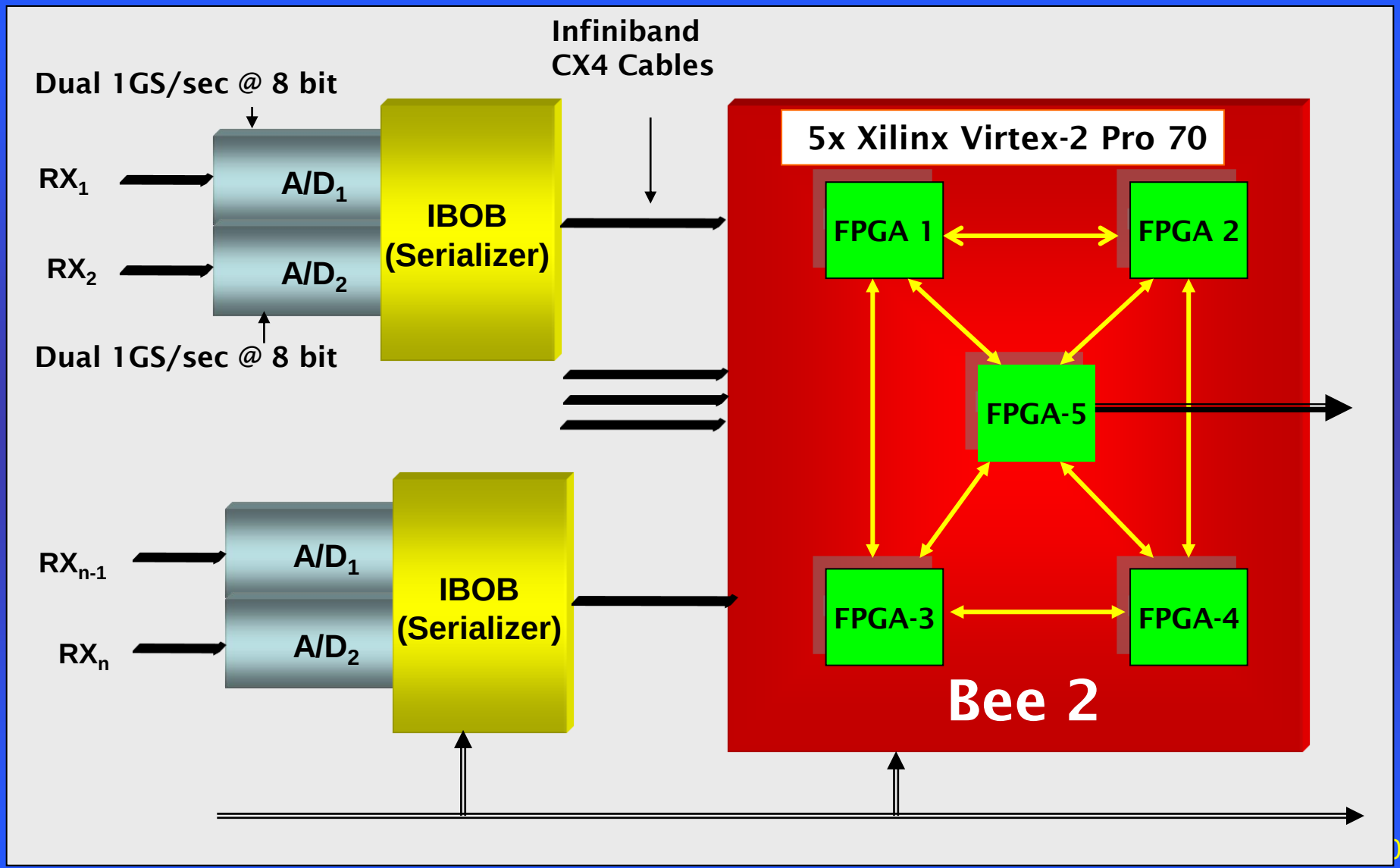


- 10 GbE network card



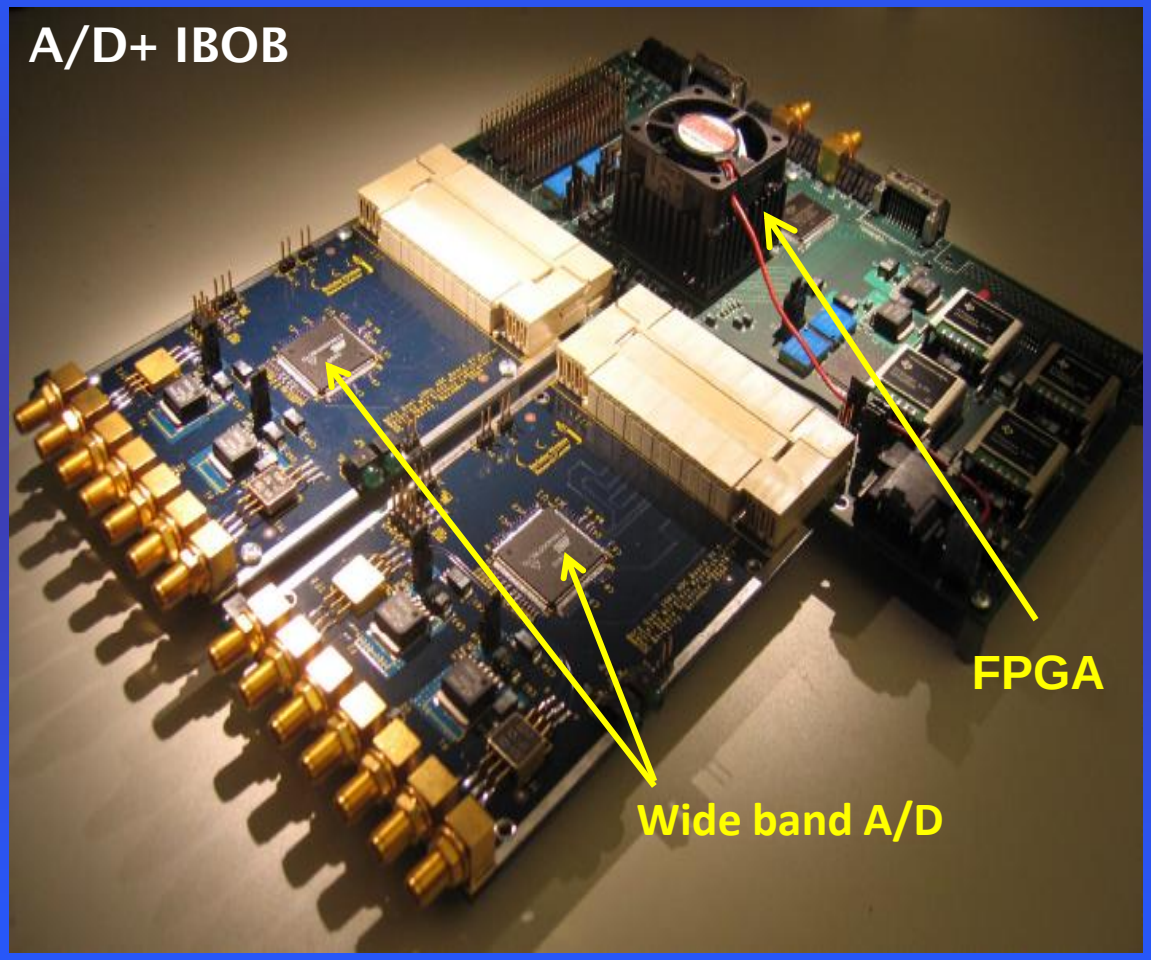
- Rack

Medicina Back End



Medicina Back End

A/D and data Processing



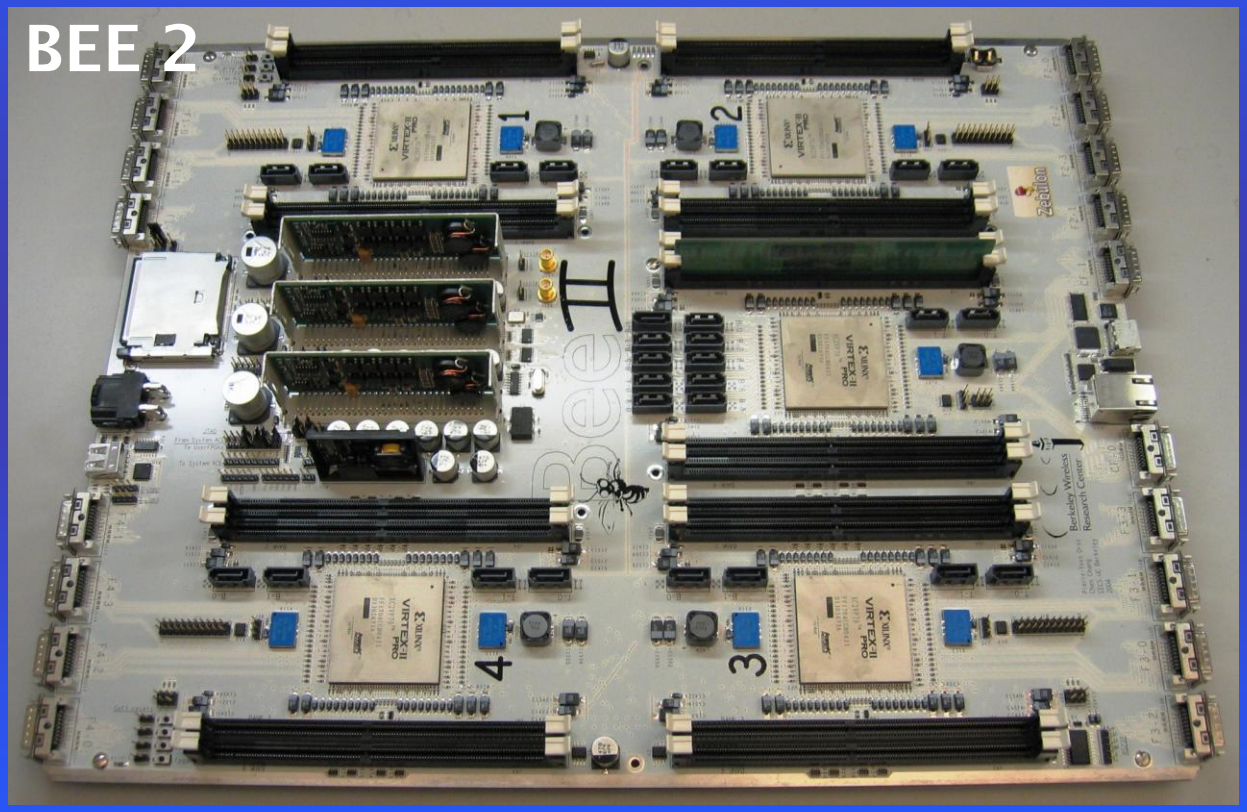
CASPER system :
A/D + IBOBs + BEE2

Our collaboration is starting with South Africa and Berkeley

Wide band A/D converter: dual 8 bits @ 1 GS/Sec (2 dual A/D for each IBOB packetizer board)

Medicina Back End

A/D and data Processing



Xilinx Virtex 2 Pro 70 (100 as well)

One Bee2 board can deliver 500 GOps/sec with a 400 W power supply.

- ***6.7 MOps/€***
- ***1.25 GOps/W***

Medicina Back End

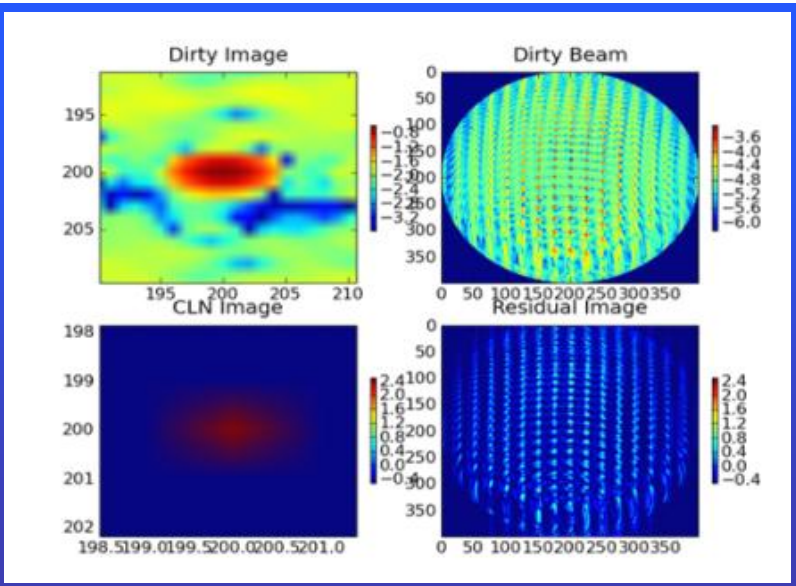
Why CASPER Hardware?

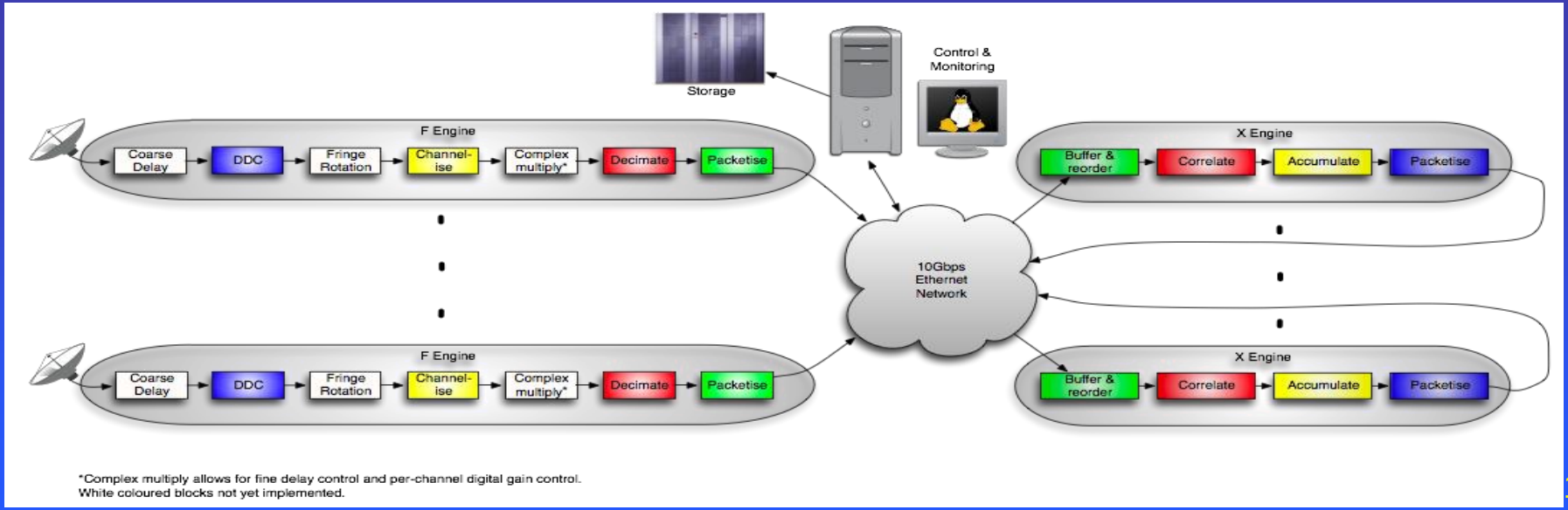
- CASPER (Center for Astronomy Signal Processing and Electronics Research): **open source** international consortium, founded in Berkeley, that includes many countries e.g. India (GMRT), South Africa (MeerKat), USA (ATA, NRAO),…
- Multi-purpose and reconfigurable Hardware (based on FPGA): the same Hardware for many different applications

  ⇒ saving in costs
- Scalable platform: Ethernet network protocol and packetized architectures allow to connect many boards through network switch
- Software and Firmware easily reusable in the next generations of Hardware
- Rapidity in development: CASPER development platform is a high-level design tool that provides a graphical Matlab/Simulink design environment quite user-friendly
- Widespread and very active community: it's easy to receive technical support (wikipage, mailing list …)

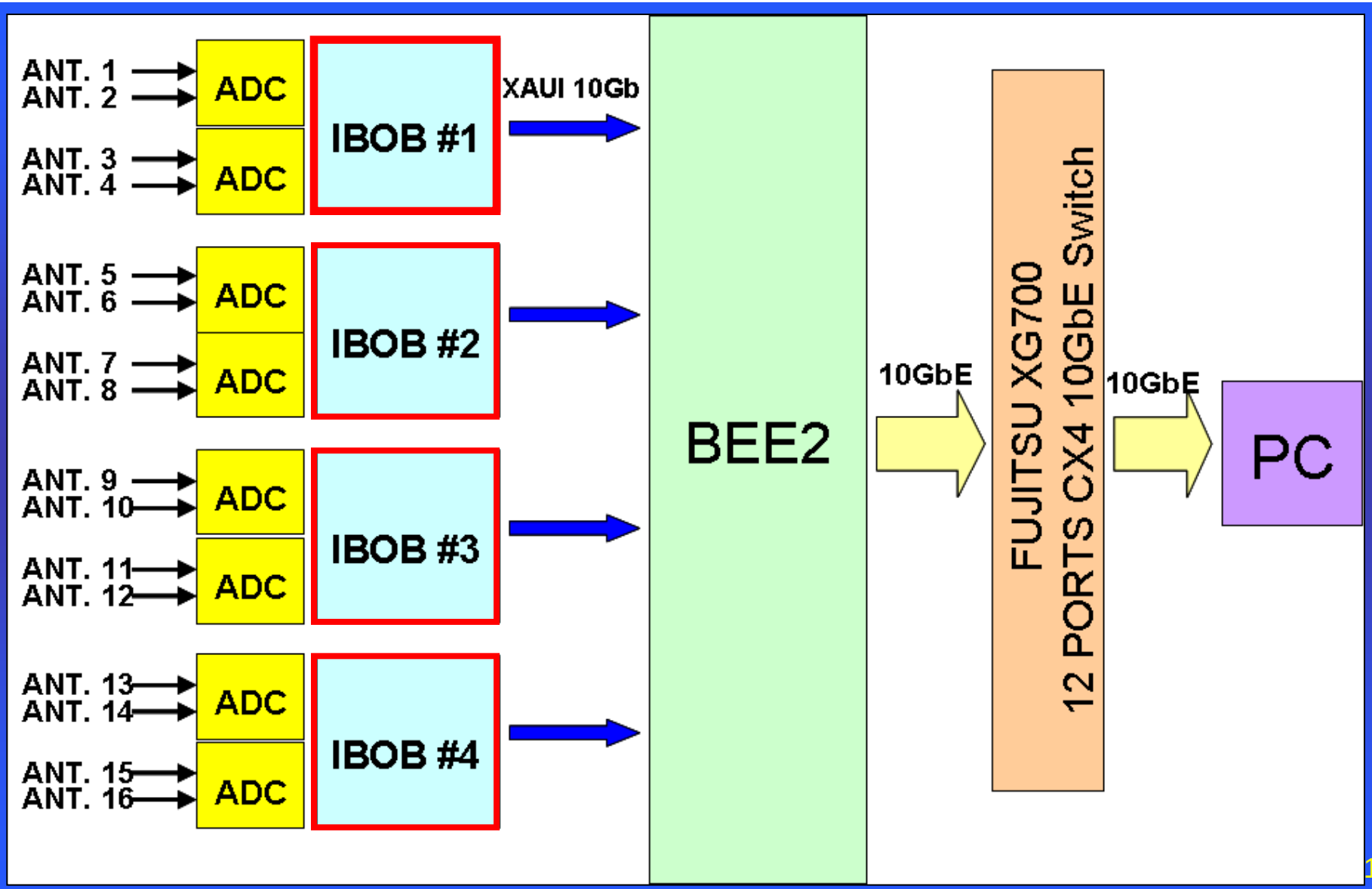
BEST packetized correlator

- A 32 receivers FX packetized correlator (2048 ch.) has been programmed in the frame of a collaboration with Cape Town University (Alan Langman, Jason Manley), IRA/INAF and Berkeley University (Dan Werthimer, Aaron Parsons).





BEST Beamformer



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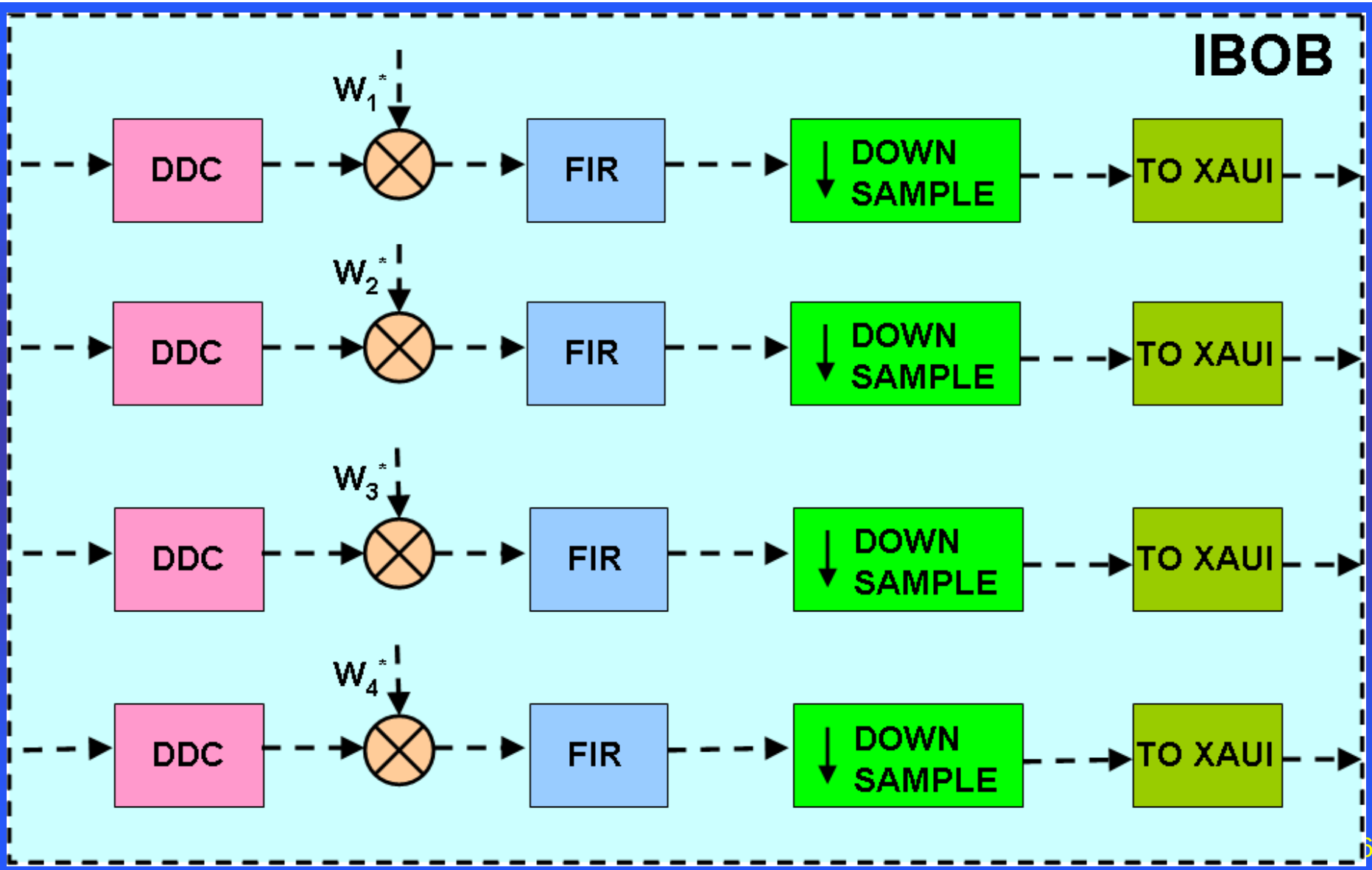
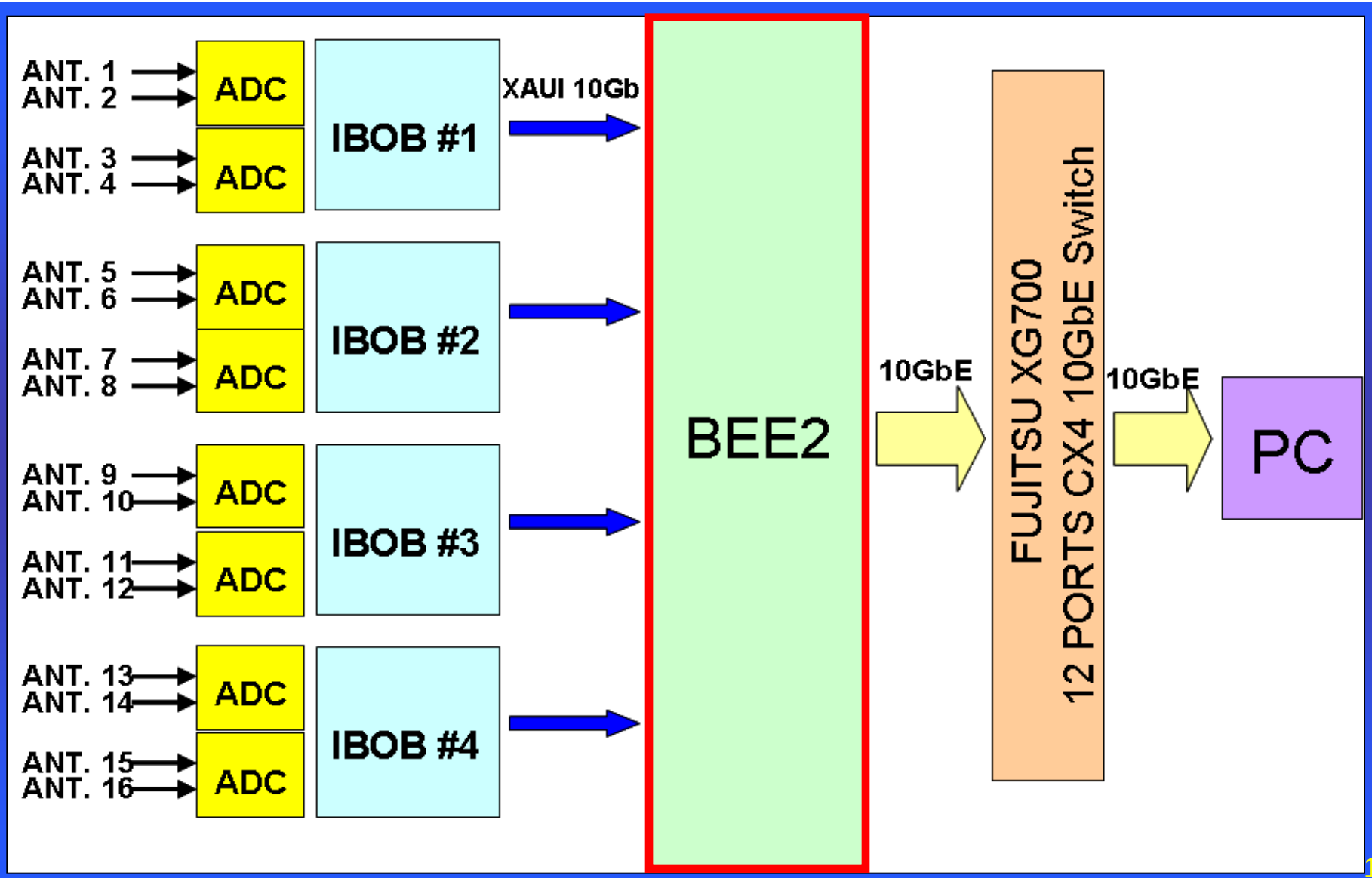


BEST Beamformer



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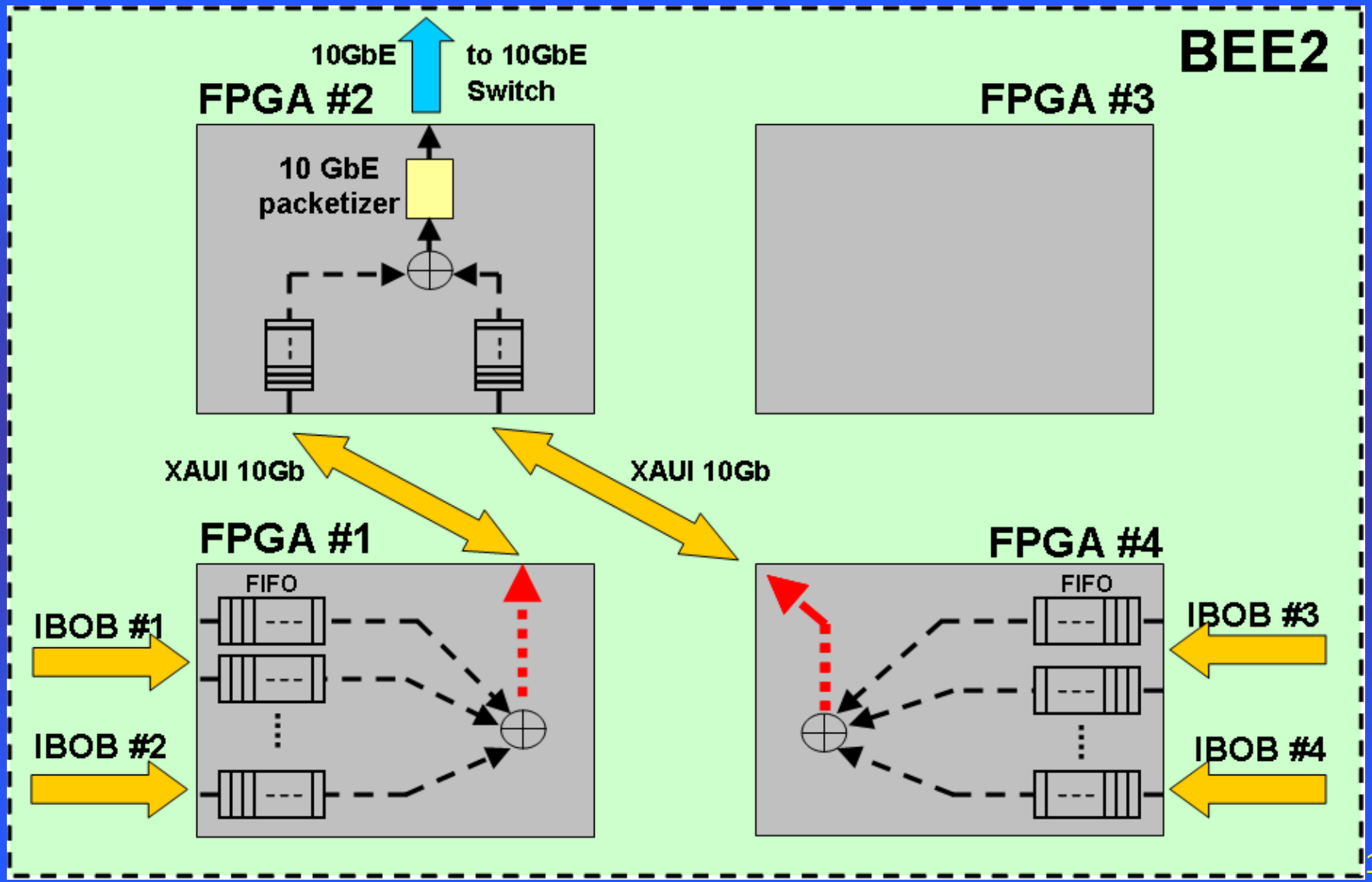
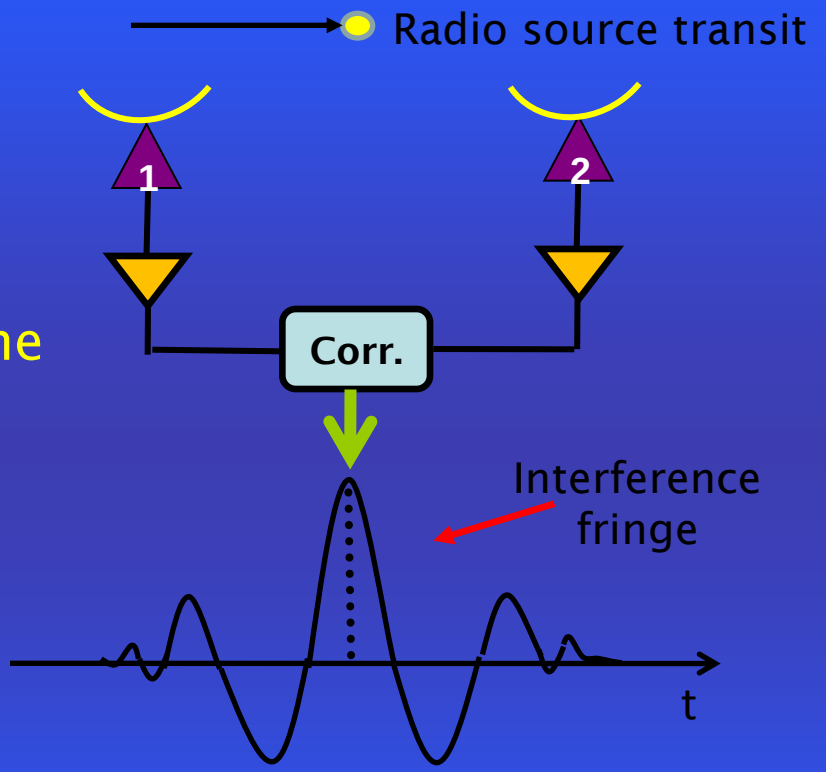


Calibration

- Before the beam can be formed, the array has to be calibrated
- With calibrated receivers ($\Delta\phi=0$): maximum occurs at the source transit
- If $\Delta\phi < 0$ (1 is delayed respect to 2) maximum occurs after the transit of the source
- If $\Delta\phi > 0$ (2 is delayed respect to 1) maximum occurs before the transit of the source



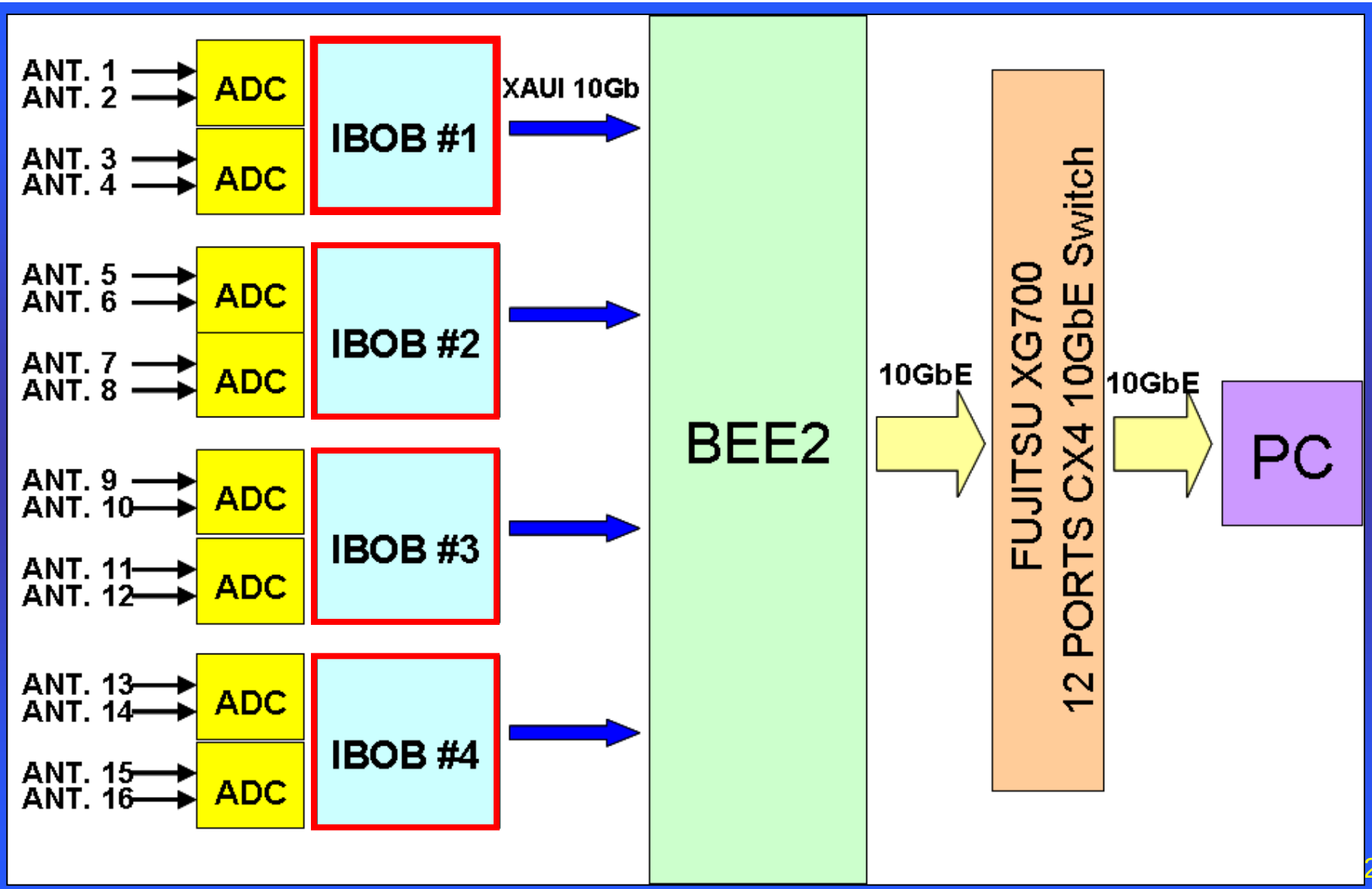
$$\Delta t = t_{\max} - t_{trans} \quad \text{(sideral seconds)}$$

$$\dot{\theta} = \frac{2\pi}{86400}\cos(\delta)$$

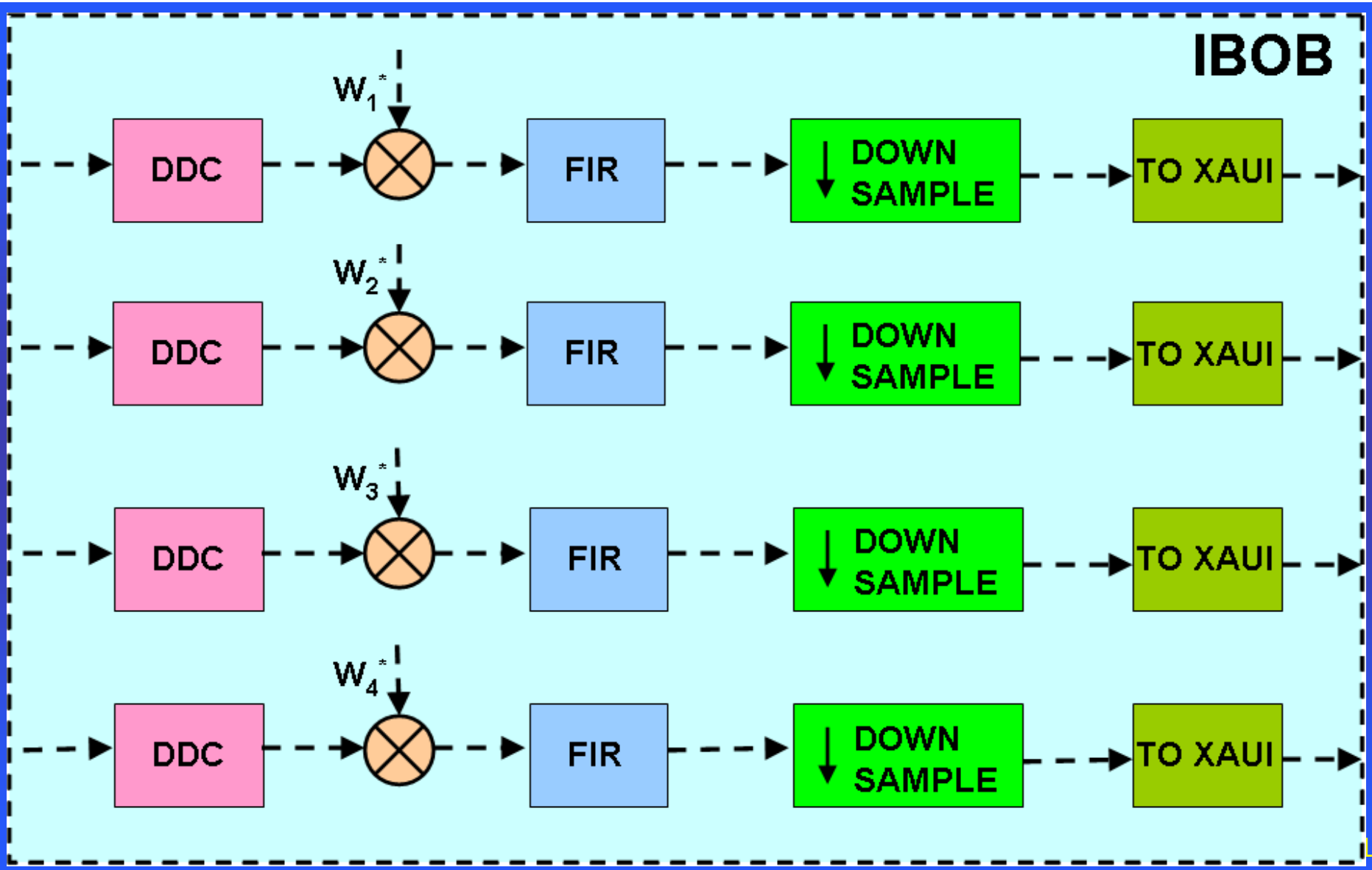
$$\theta = \dot{\theta} \cdot \Delta t$$

$$\Delta\phi = -2\pi \cdot \frac{baseline}{\lambda} \cdot \sin\left(\frac{2\pi \cdot \cos(\delta) \cdot \Delta t}{86400}\right)$$

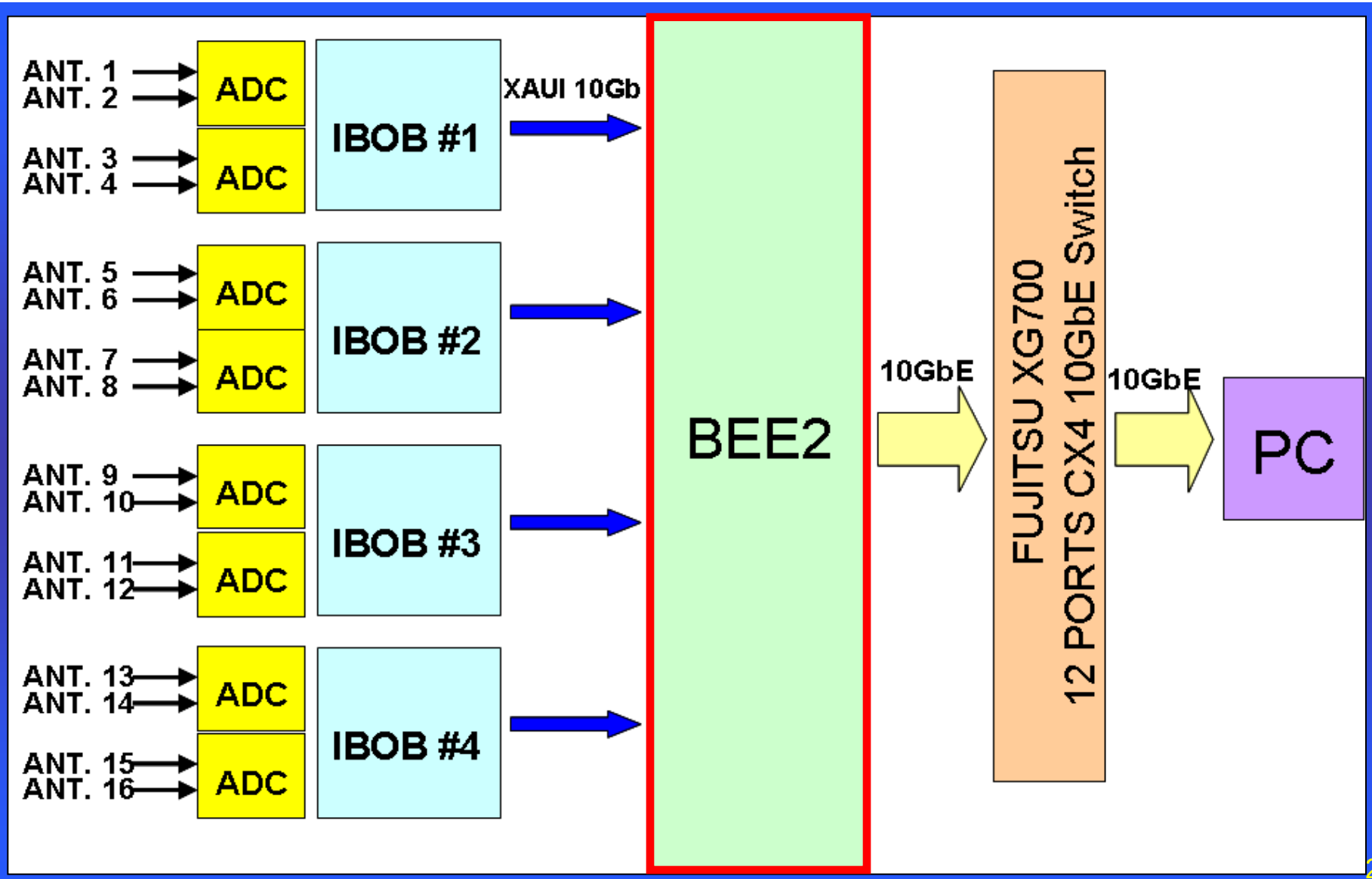
BEST calibration design



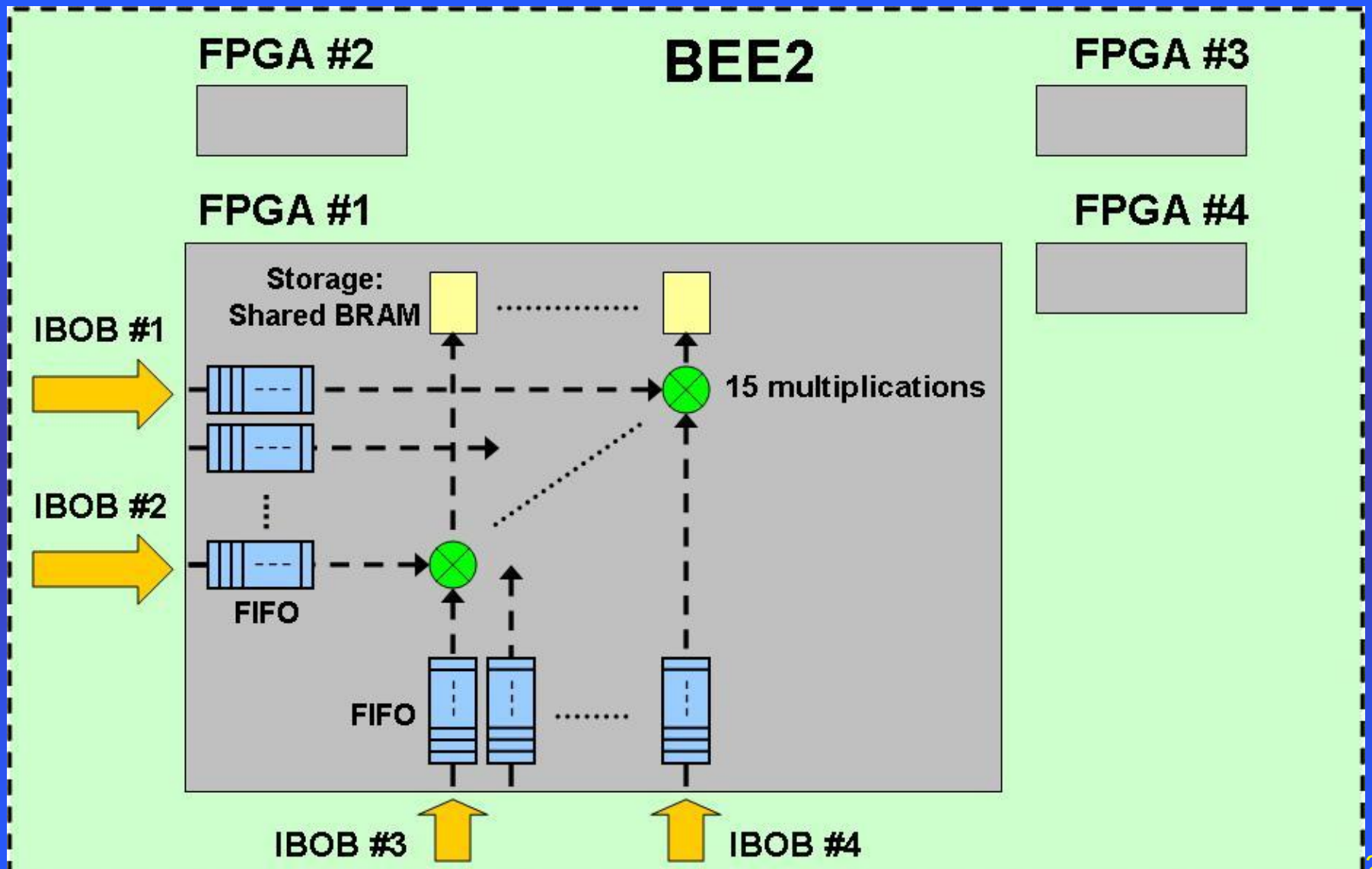
BEST calibration design



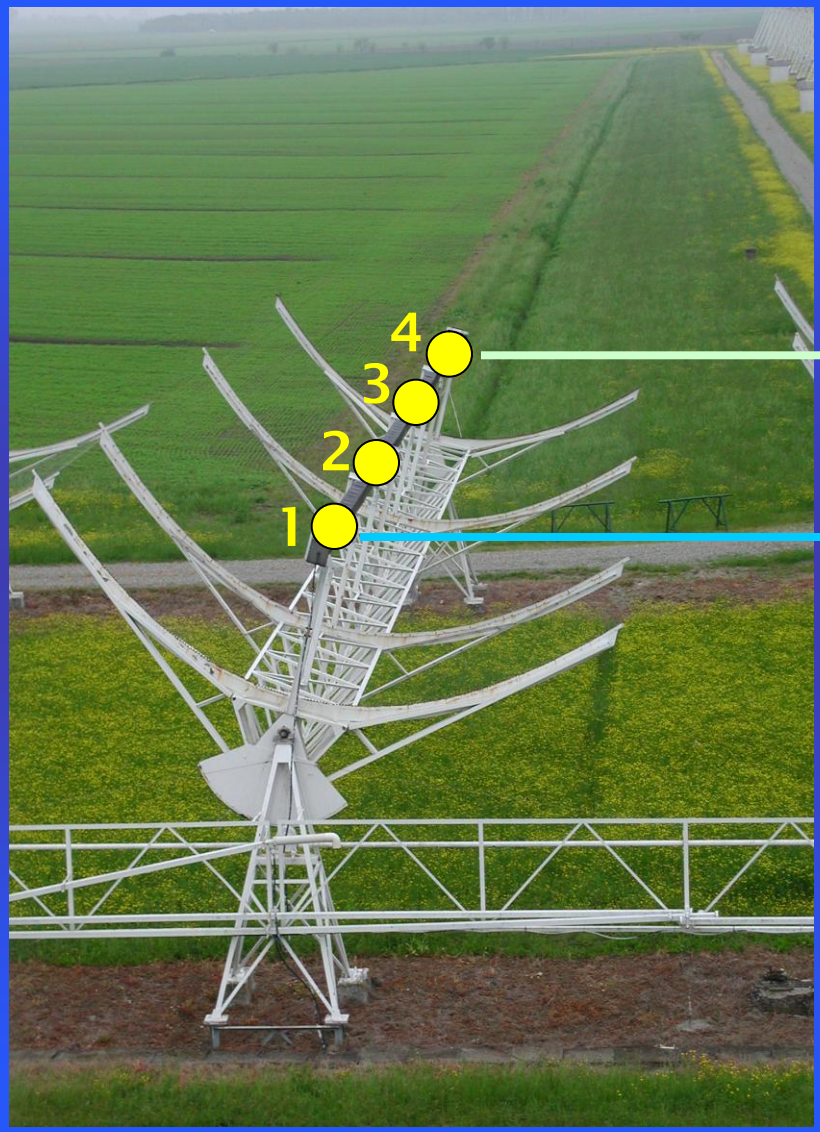
BEST calibration design



BEST calibration design



Calibration Results



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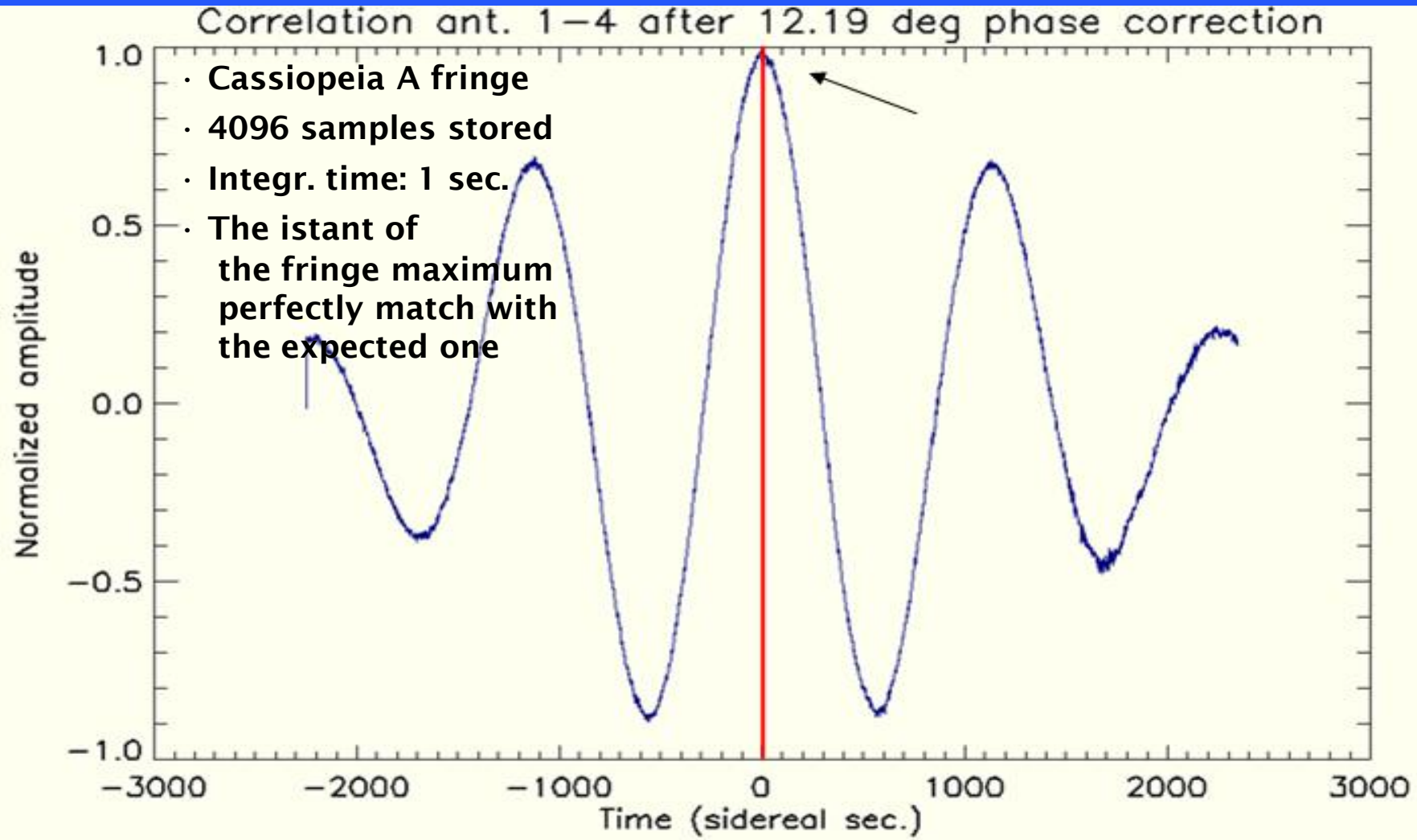

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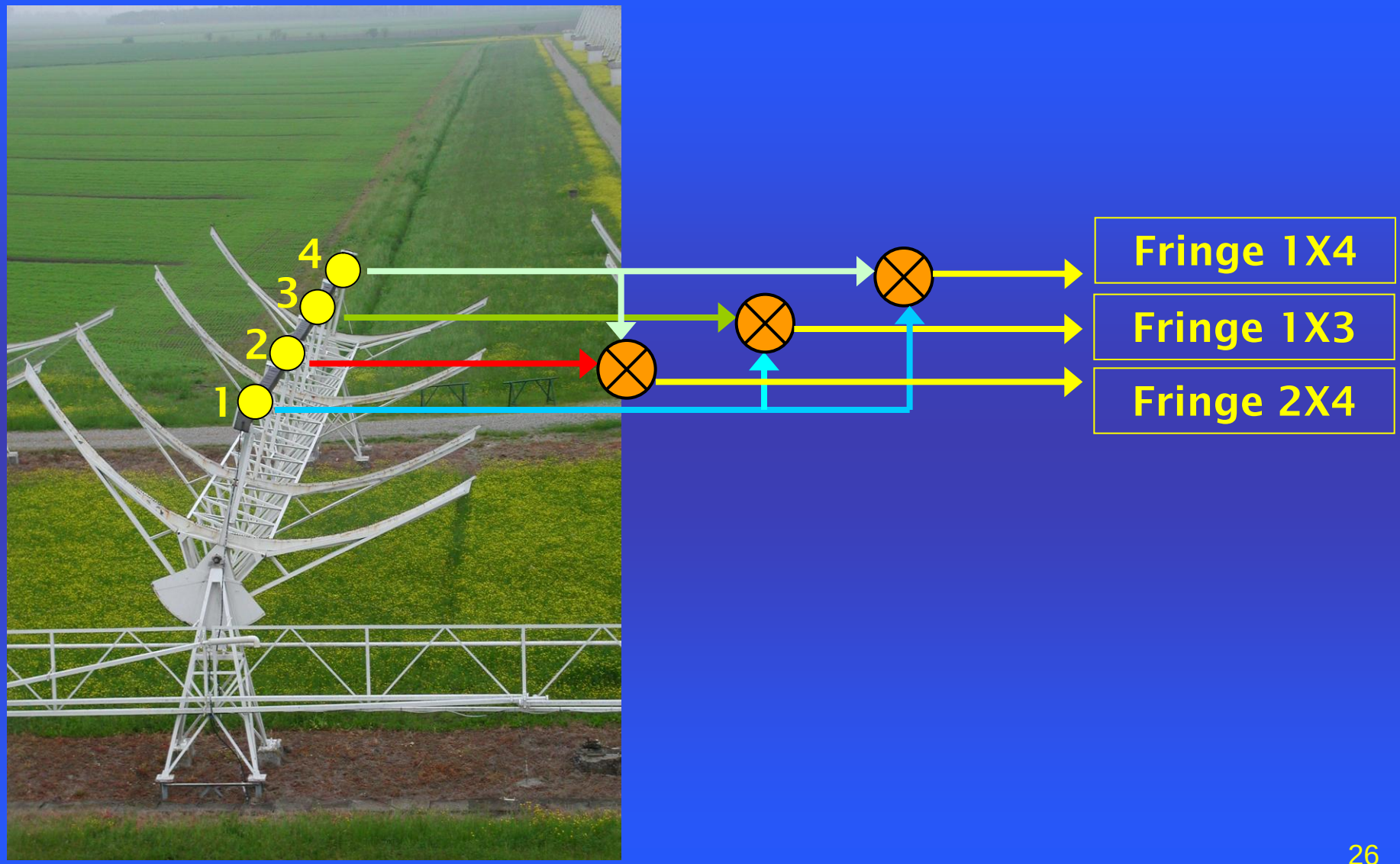
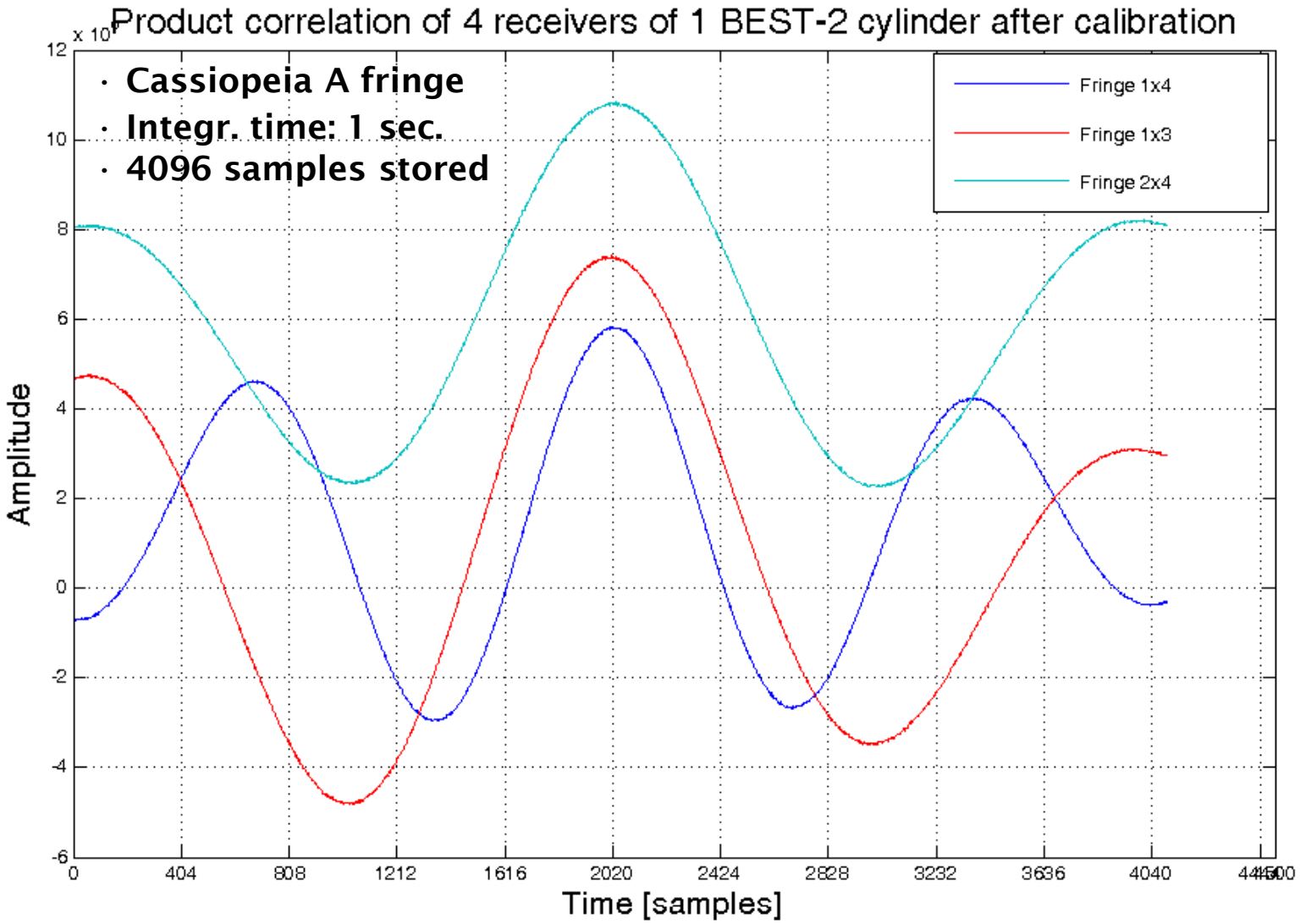
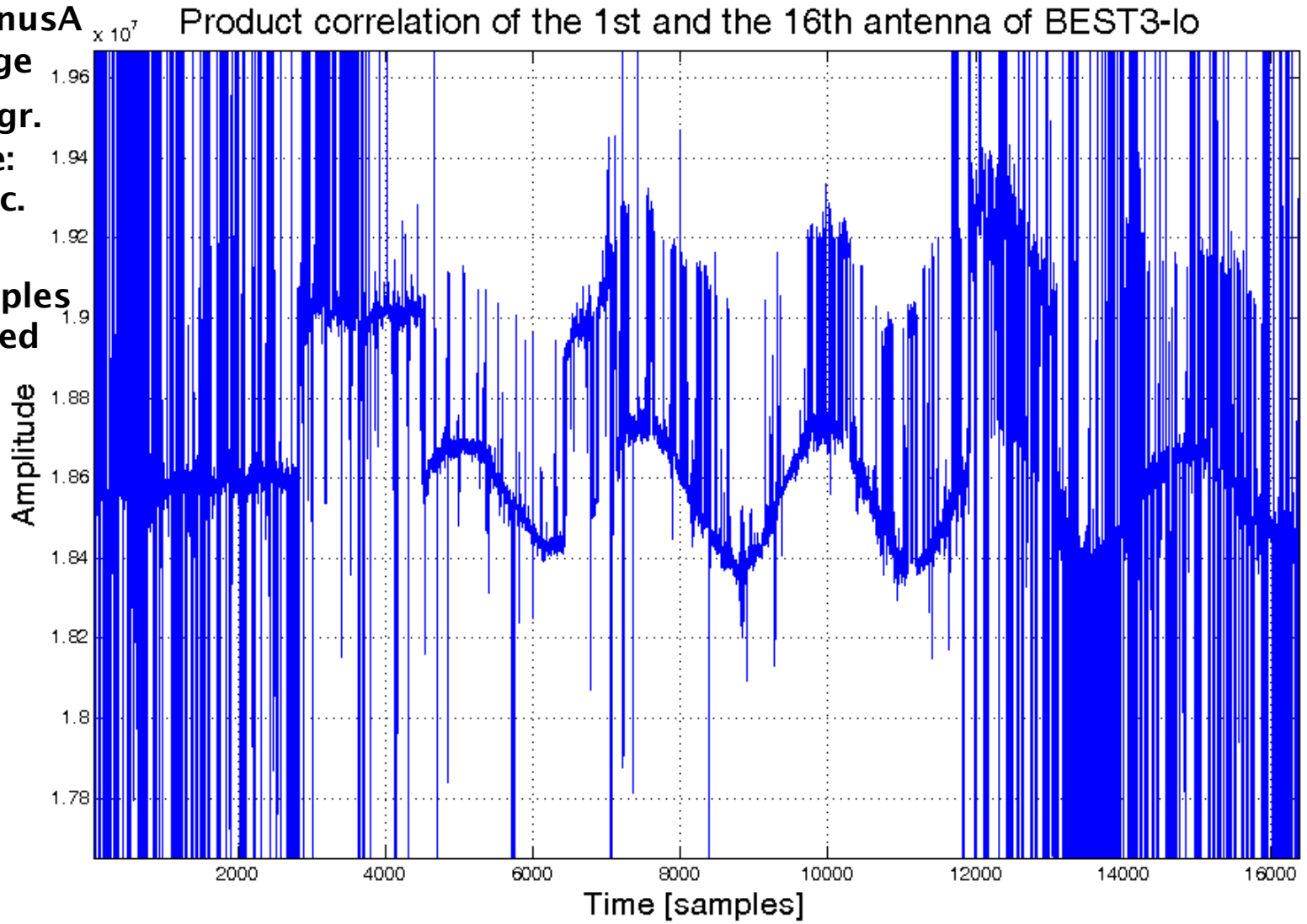


Calibration Results



Calibration Results

- CygnusA fringe
- Integr. time: 1 sec.
- 16K samples stored

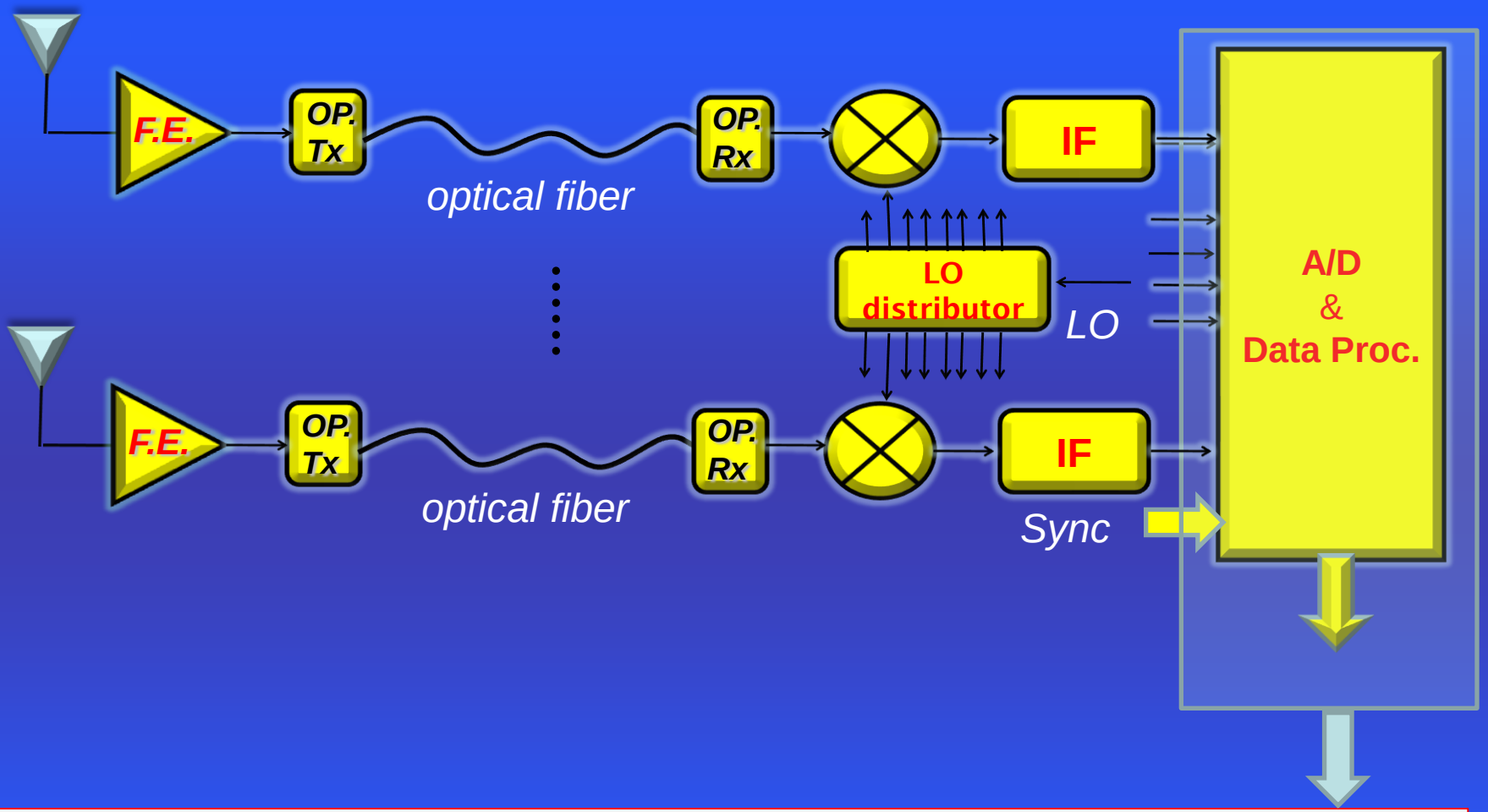


The End

THANK YOU

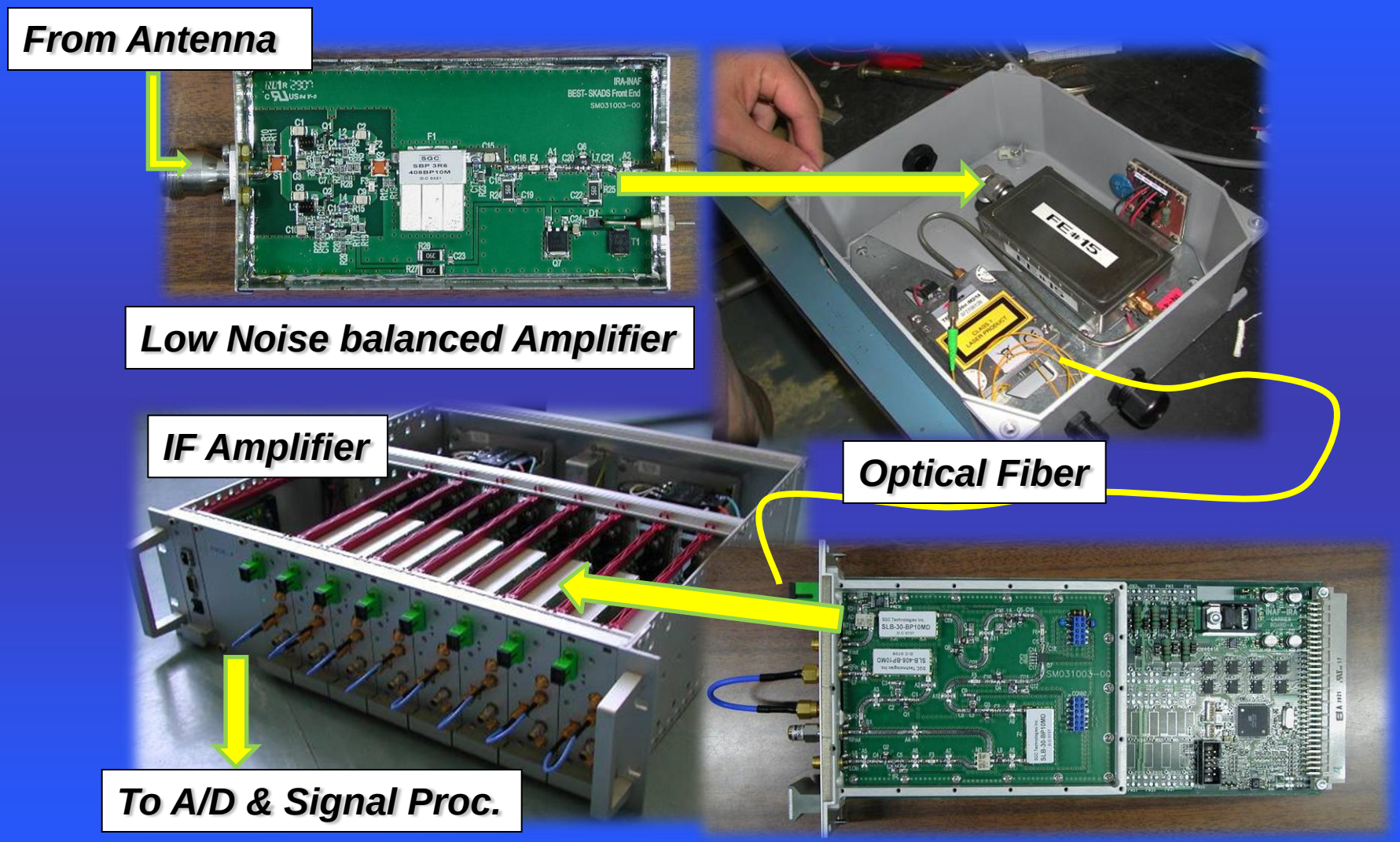
Spare Diapos

Medicina Back End

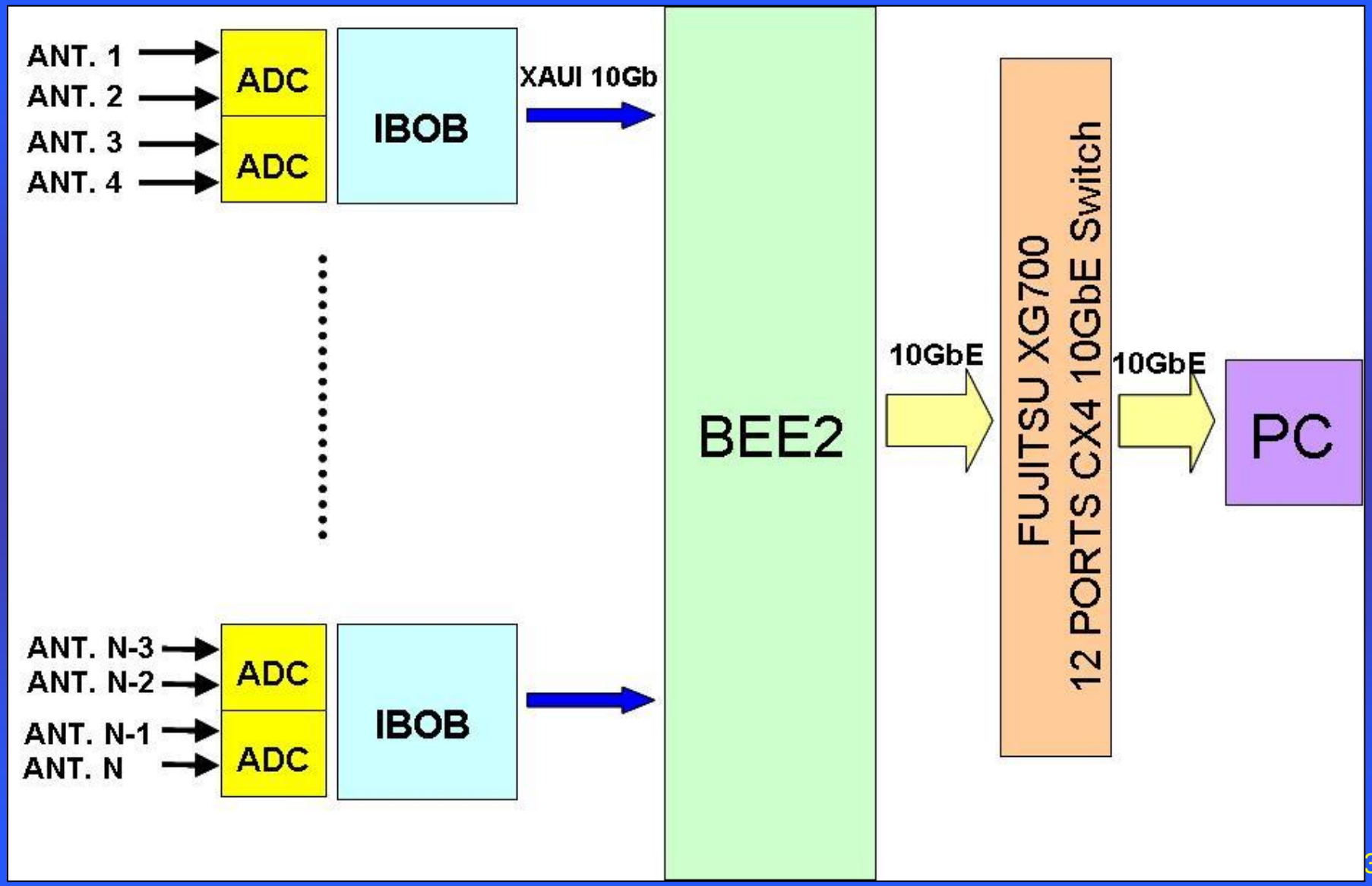


For the A/Ds and post processing blocks, the Berkeley-CASPER Boards have been used….

Medicina Back End



Medicina Back End



BEST calibration design

- First tests on IBOBs with 1 Cylinder of BEST2 system
- 2 signals product correlation (extreme antennas of 8th cylinder)
- Beamformer coefficients set up: RE1=RE2=1; IM1=IM2=0