INAF contribution to PHAROS2: Warm Section, signal transportation and iTPM digital backend

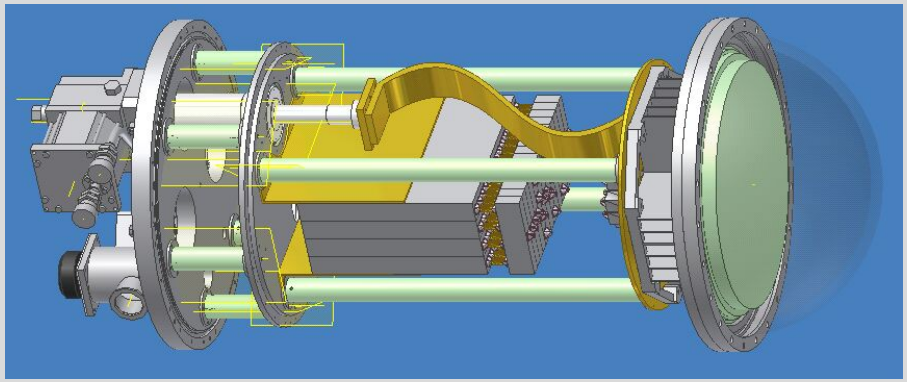
INAF PHAROS2 team:
A. Navarrini, J. Monari, A. Melis, F. Perini, R. Concu, A. Scalambra, P. Ortu, G. Naldi, J. Roda, G. Comoretto, M. Morsiani, A. Ladu, A. Maccaferri, S. Rusticelli, A. Mattana, L. Marongiu, M. Schiaffino, E. Carretti, A. Saba, F. Schillirò, E. Urru, A. Cattani

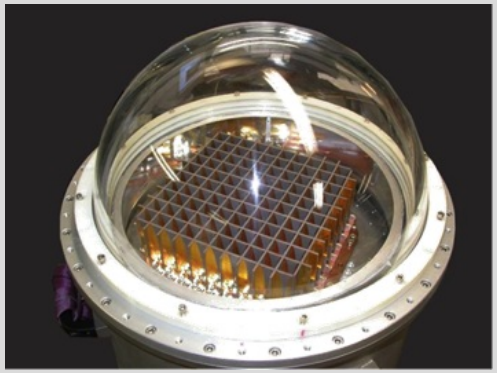
SKA Advanced Instrumentation Program

Italian contribution to PHAROS

INAF-Arcetri, Florence

Cryostat&vacuum window design, construction and test (thermal and mechanical)

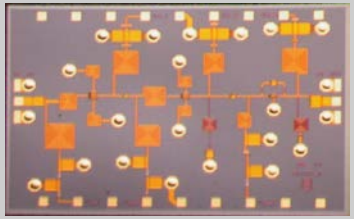




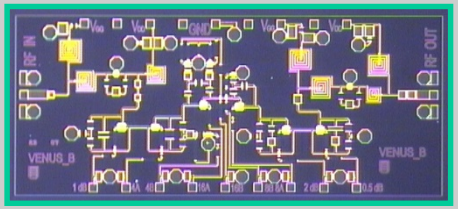
MECSA, Rome

- MMIC LNAs (operated at 20 K);
- MMIC VGAs (operated at 70 K);
- Phase shifters (operated at 70 K);
- Controlled attenuators (operated at 70 K);

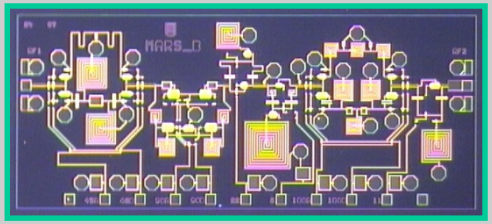
MMIC LNA



MMIC VGA



MMIC Phase shifter



0.18 μm PHEMT technology from OMMIC

INAF FTEs and budget for PHAROS2

Name	Institution	FTE 2017	FTE 2018
Navarrini Alessandro	OAC	0.7	0.7
Melis Andrea	OAC	0.6	0.6
Concu Raimondo	OAC	0.6	0.6
Ladu Adelaide	OAC	0.2	0.2
Saba Andrea	OAC	0.1	0.1
Marongiu Lino	OAC	0.1	0.1
Ortu Pierluigi	OAC	0.2	0.2
Urru Enrico	OAC	0.1	0.1
Carretti Ettore	OAC	0.1	0.1
Schillirò Francesco	OACt	0.3	0.3
Comoretto Gianni	OAA	0.05	0.05
Naldi Giovanni	IRA	0.25	0.25
Perini Federico	IRA	0.1	0.1
Monari Jader	IRA	0.1	0.1
Rusticelli Simone	IRA	0.5	0.5
Roda Juri	IRA		
Cattani Alessandro	IRA		
Mattana Andrea	IRA		
Scalambra Alessandro	IRA		
Schiaffino Marco	IRA		
Morsiani Marco	IRA		
Maccaferri Andrea	IRA		
Total		**4.0**	**4.0**

INAF representative on the PAF Consortium Board: Zerbi Filippo

Total Budget: 150 kE (75 kE in 2017 and 75 kE in 2018)

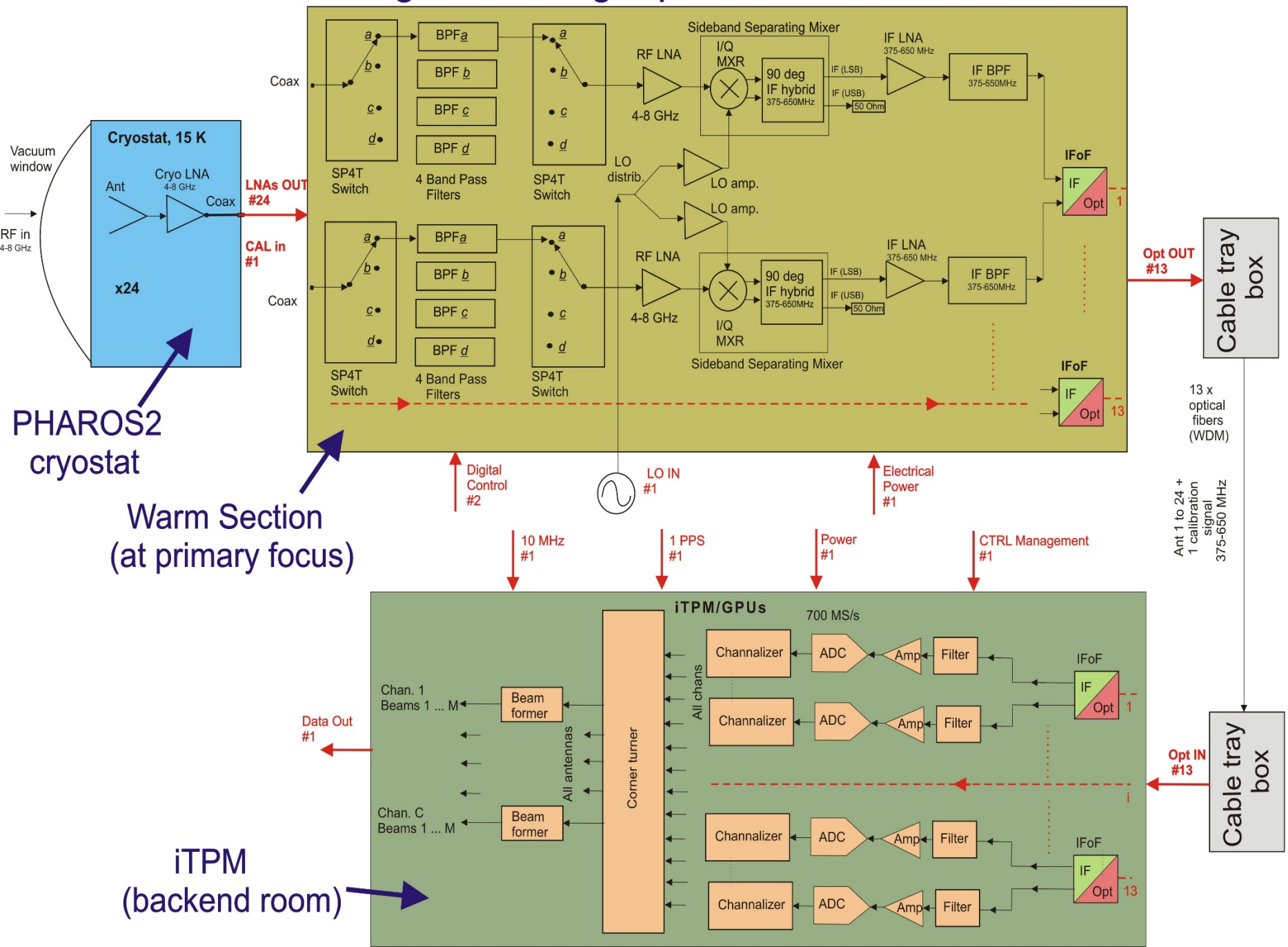
(Non comprehensive) science possibilities at C-band with cryo PAF

- Fast C-band continuum surveys, and polarization meas. in particular in the Galactic Plane (to improve existing surveys to ≈2.5’ resolution);
- CMB foregrounds;
- Gamma Ray Burst and Gravitational Wave event follow-ups;
- FRB search;
- Flat spectra transients/pulsars, like magnetars;
- Excited rotational states of OH near **6.03 GHz**: Zeeman effect, star formation;
- CH_3OH (**6.7 GHz**): survey of methanol masers, gas kinematics, UC HII region;
- Formaldehyde line emission at **4.8 GHz**;
- Confusion limited polariz. mapping of Galaxy Clusters and Supernova Remnants;
- Hydrogen recombination lines around **5 GHz**;
- High Dispersion Measure pulsar searches toward the Galactic Centre and inner Galaxy;

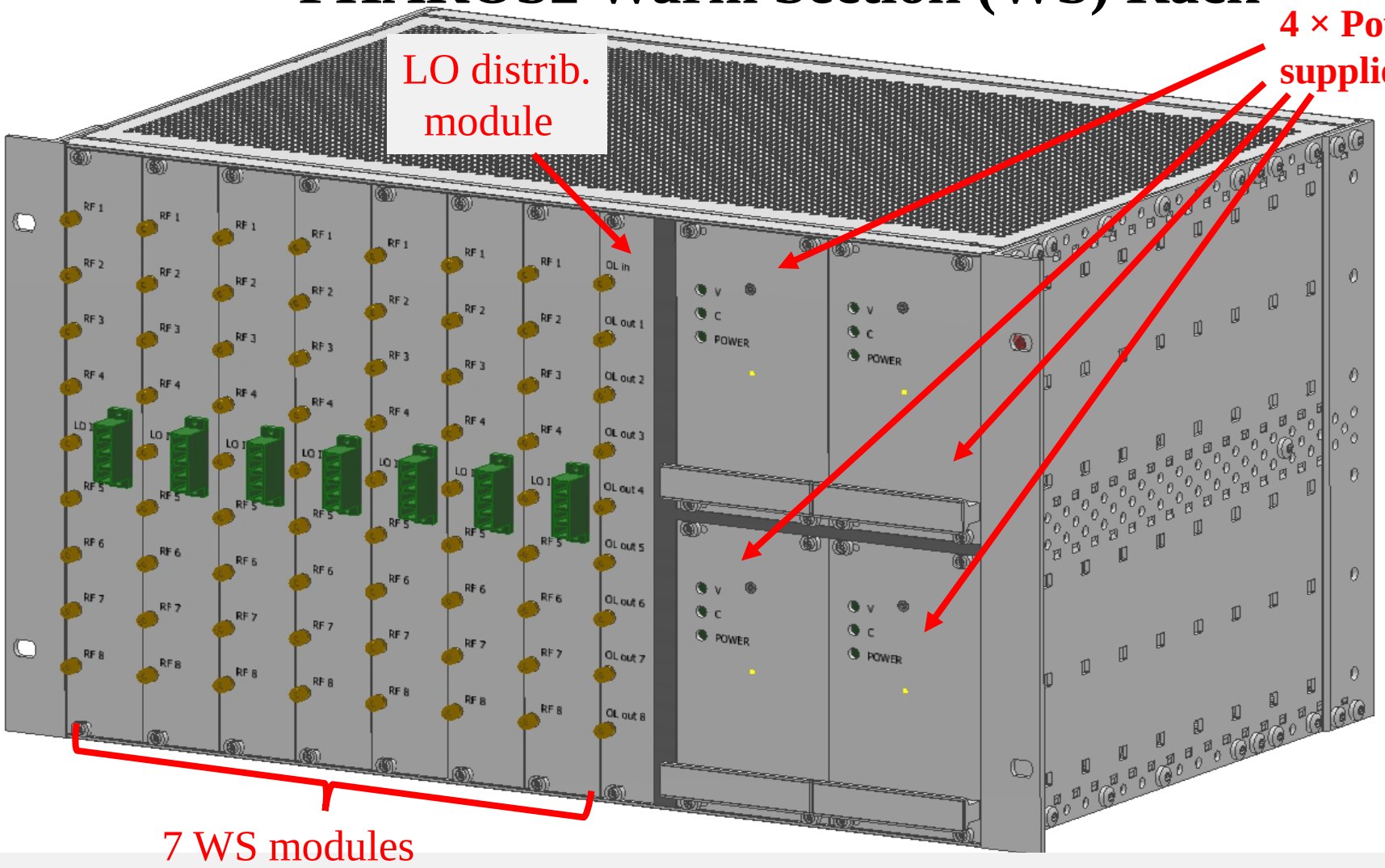
PHAROS2 main specifications

Radio Frequency (RF) range:	**4000-8000 MHz**
Frequency down-conversion type:	**Single**, with sideband separation mixer (2SB)
Local Oscillator (LO) freq. range:	**4650-8375 MHz** (LSB tuning)
Intermediate Frequency (IF) range:	**375-650 MHz** (275 MHz instantaneous bandwidth)
Number of active antenna elements:	**24** (out of a dual polarization 11x10 array of Vivaldi ant.)
Number of compound beams:	**4** (13 ant.→1 beam, 24 ant.→ 4 beams, 37 ant.→ 9 beams)
Number of polarizations:	**1** (single-polarization)
Selectable RF filters, frequency ranges and LO tuning frequencies:	**4** selectable band pass filters (BPF): *a)* 4000-8000 MHz; LO tunable anywhere across 4650-8375 MHz *b)* 4775-5050 MHz; LO fixed at 5425 MHz (Formaldhyde at 4800 MHz and H recombination lines); *c)* 5780-6055 MHz; LO fixed at 6430 MHz (Excited rotational states of OH near 6003 MHz); d) 6445-6720 MHz; LO fixed at 7095 MHz (Methanol maser line at 6668.5 MHz); When options *b)*, *c)* or *d)* are chosen the mixer image sideband rejection is increased by the filter rejection (total expected> 40 dB);
IF signal transportation:	**Two IF signals transported over a single optical fiber** (IFoF) using Wavelength Division Multiplexing (1270 nm and 1330 nm)
Backend and beamforming:	**Digital backend with one iTPM** (Italian Tile Processing Module) capable of digitizing 32 inputs, 512 frequency channels

Schematic diagram of single-polarization PHAROS2 PAF



PHAROS2 Warm Section (WS) Rack

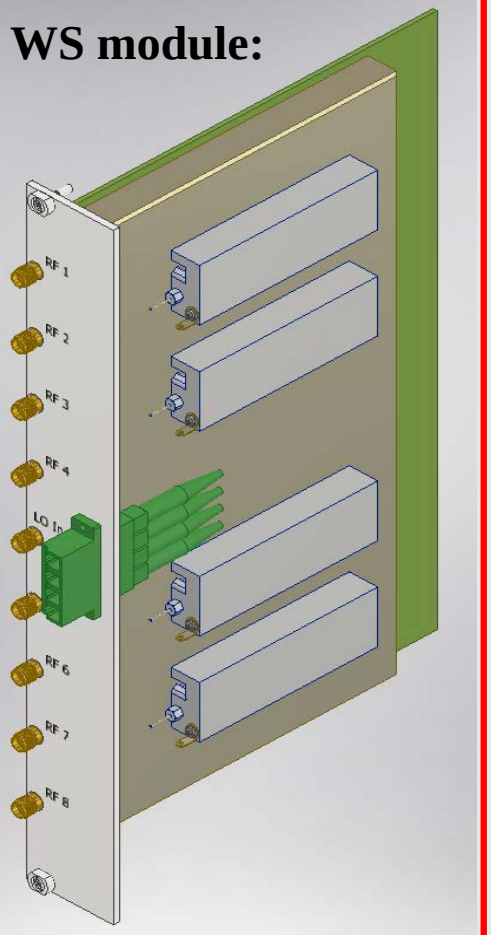


- A 6U rack (19”) can contain 7 WS modules, 1 LO distribution module and 4 power supplies. It will be capable of handling up to 56 input signals;
- The rack for the single-polarization PHAROS2 instrument will contain 4 WS module, 1 LO distribution module and 2 power supplies, capable of handling up to 32 input signals (24 from cryostat + 1 calibration from noise source =25 inputs to be used; 7 unused);

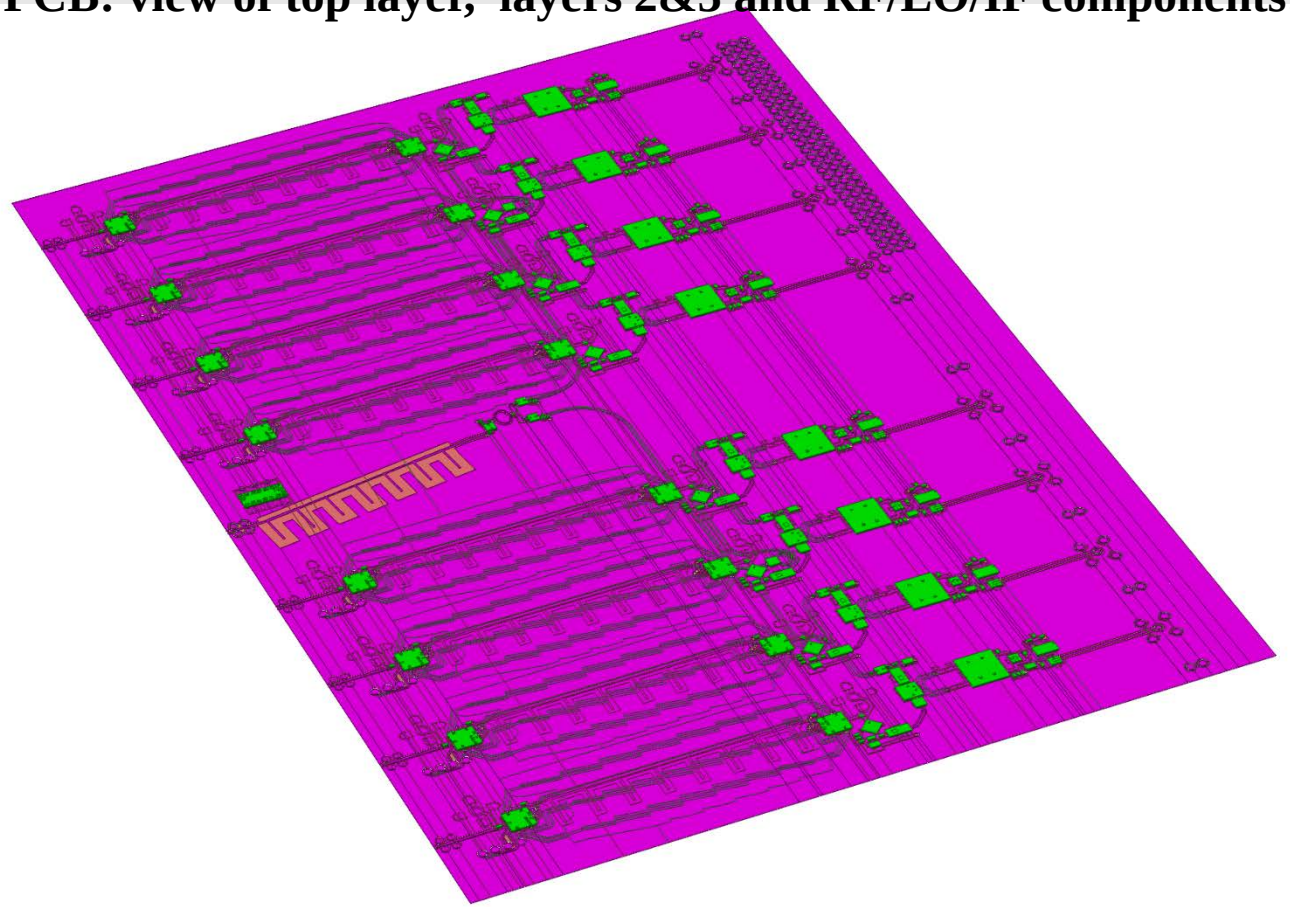
One of the PHAROS2 Warm Section (WS) modules:

- One WS module has 8 RF inputs, 1 LO input and 4 WDM IFoF outputs (4 laser transmitters);
- Four-layer RF/IF PCB board with commercial surface mount components (no bonding, easy assembly, low-cost, bias voltages 5 V and 3.3 V);
- 1 LO input internally distributed with 8-way splitter (+filtering section and LO amplification);

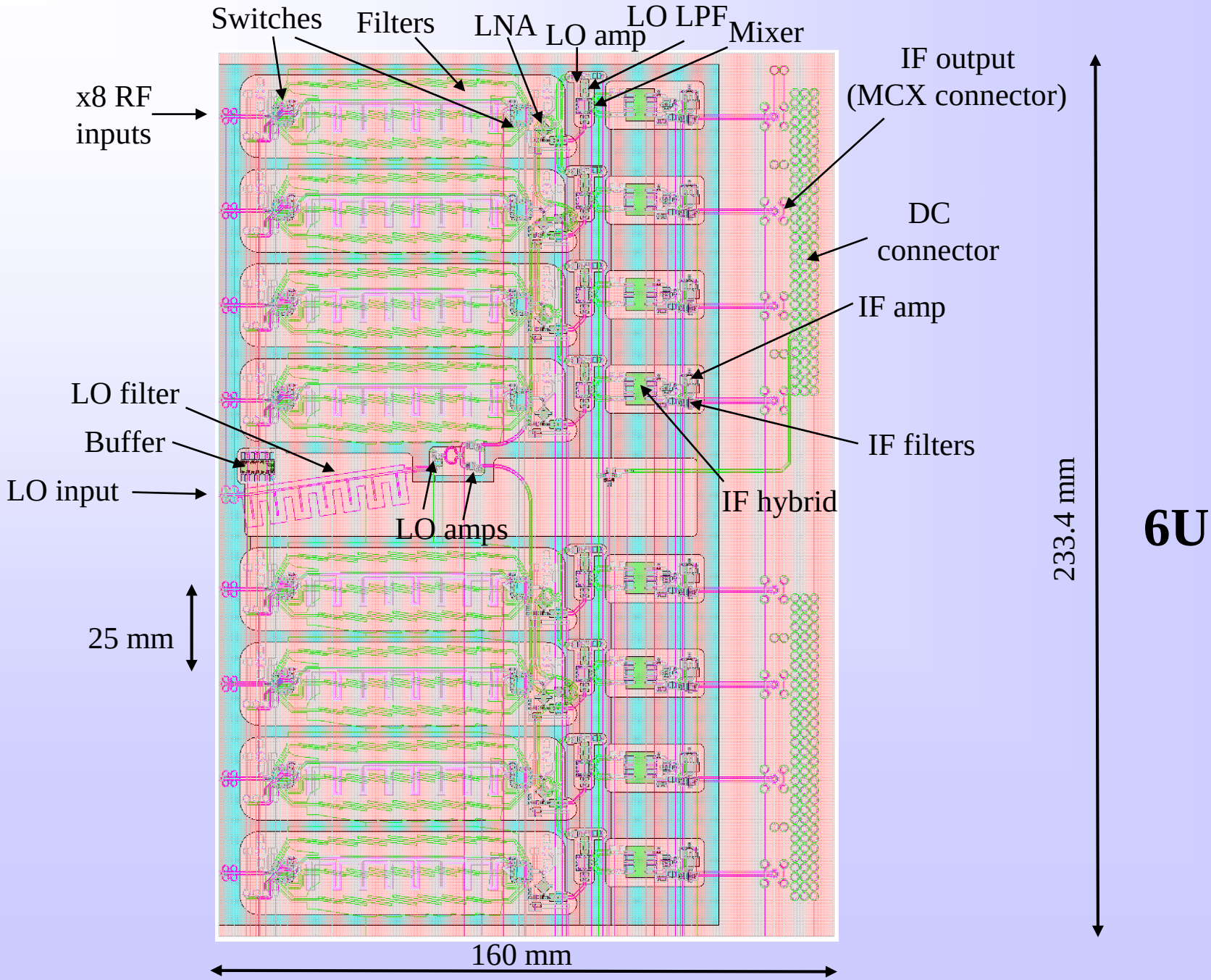
WS module:



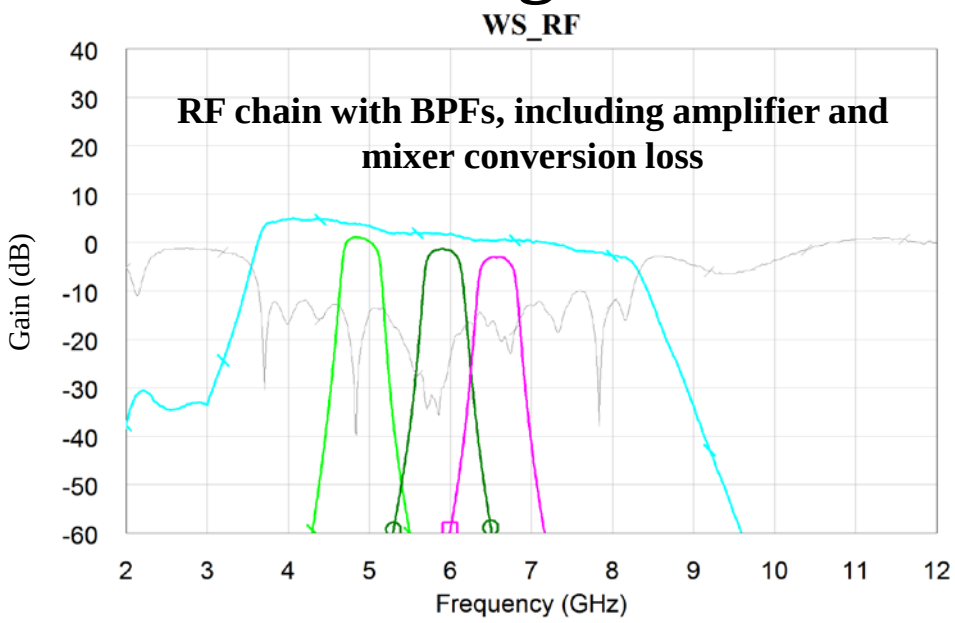
PCB: view of top layer, layers 2&3 and RF/LO/IF components:

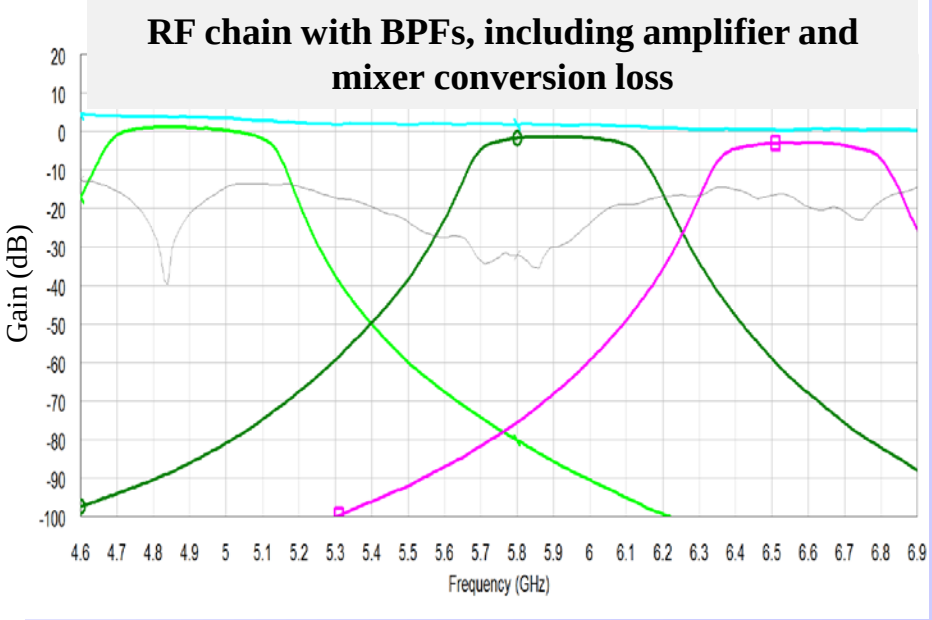


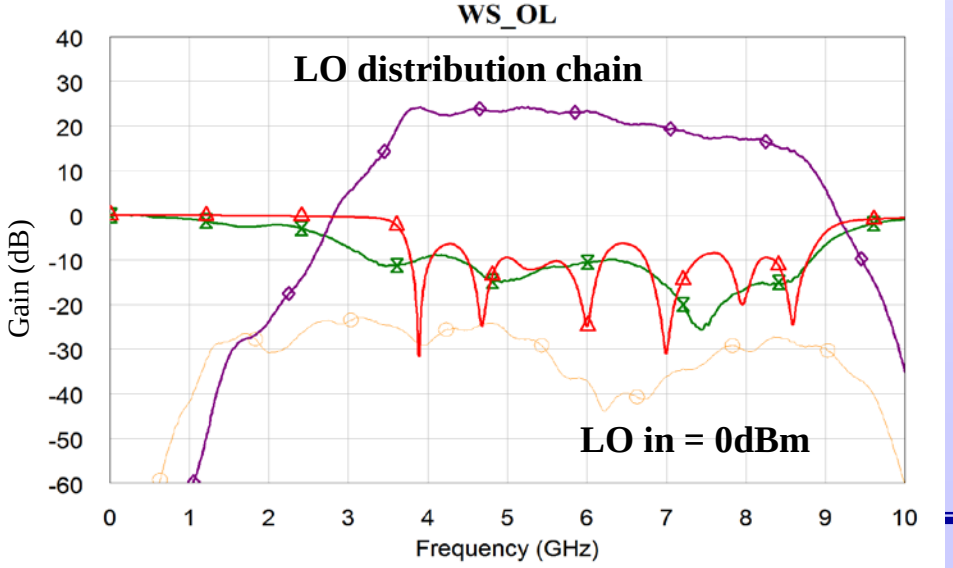
PCB of WS module

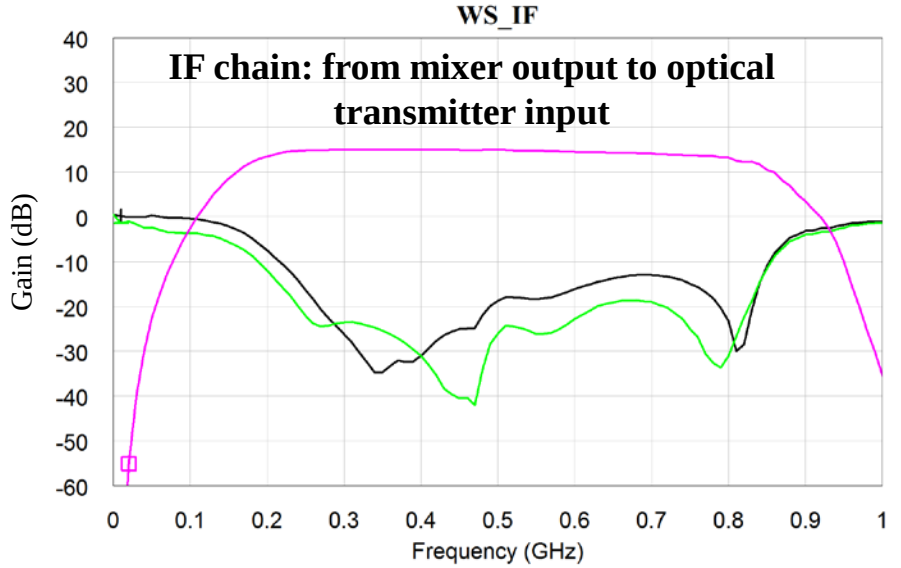


Electromagnetic simulation results of WS module

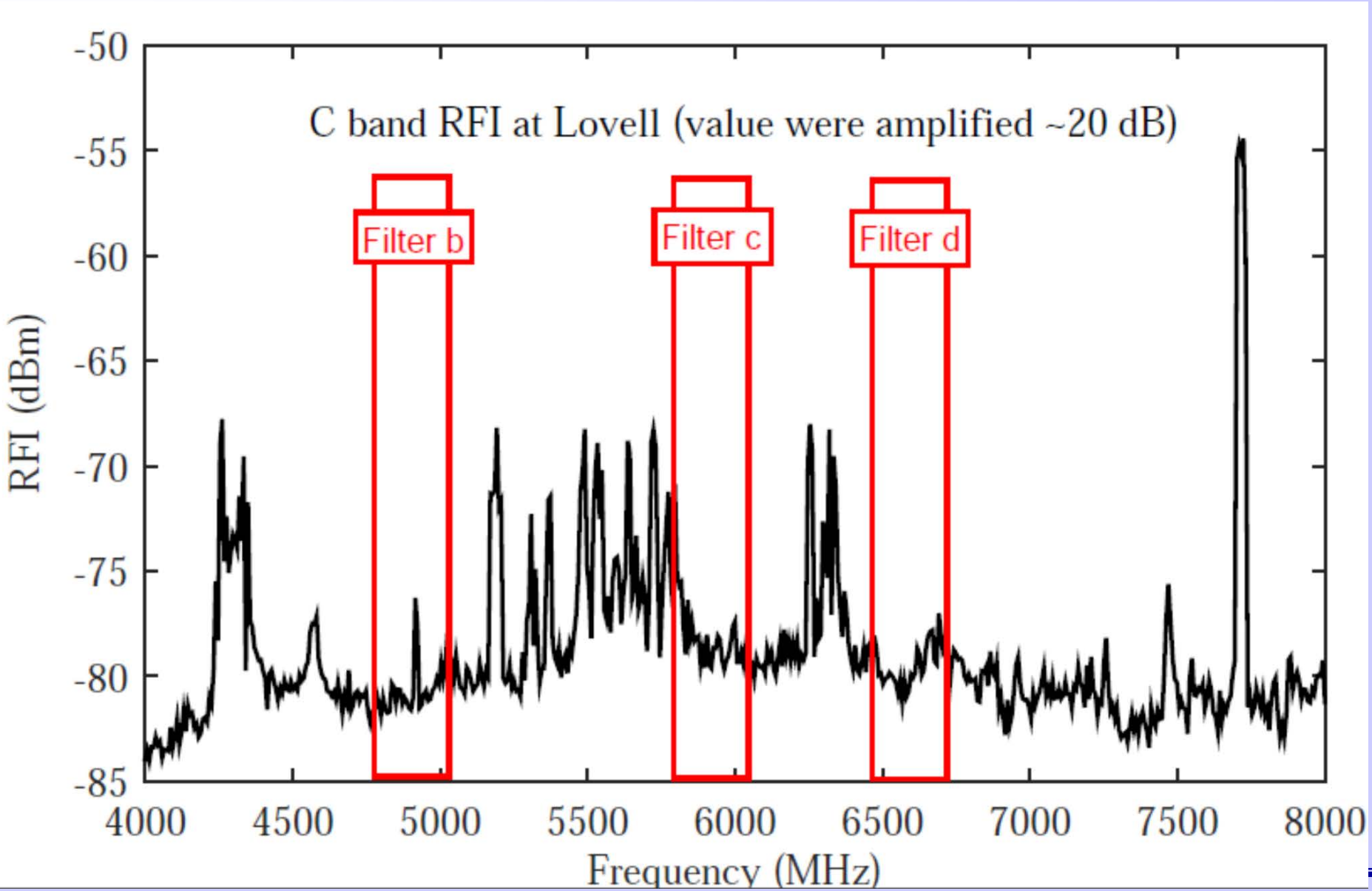








Band Pass Filtering of the C-Band at Lovell telescope



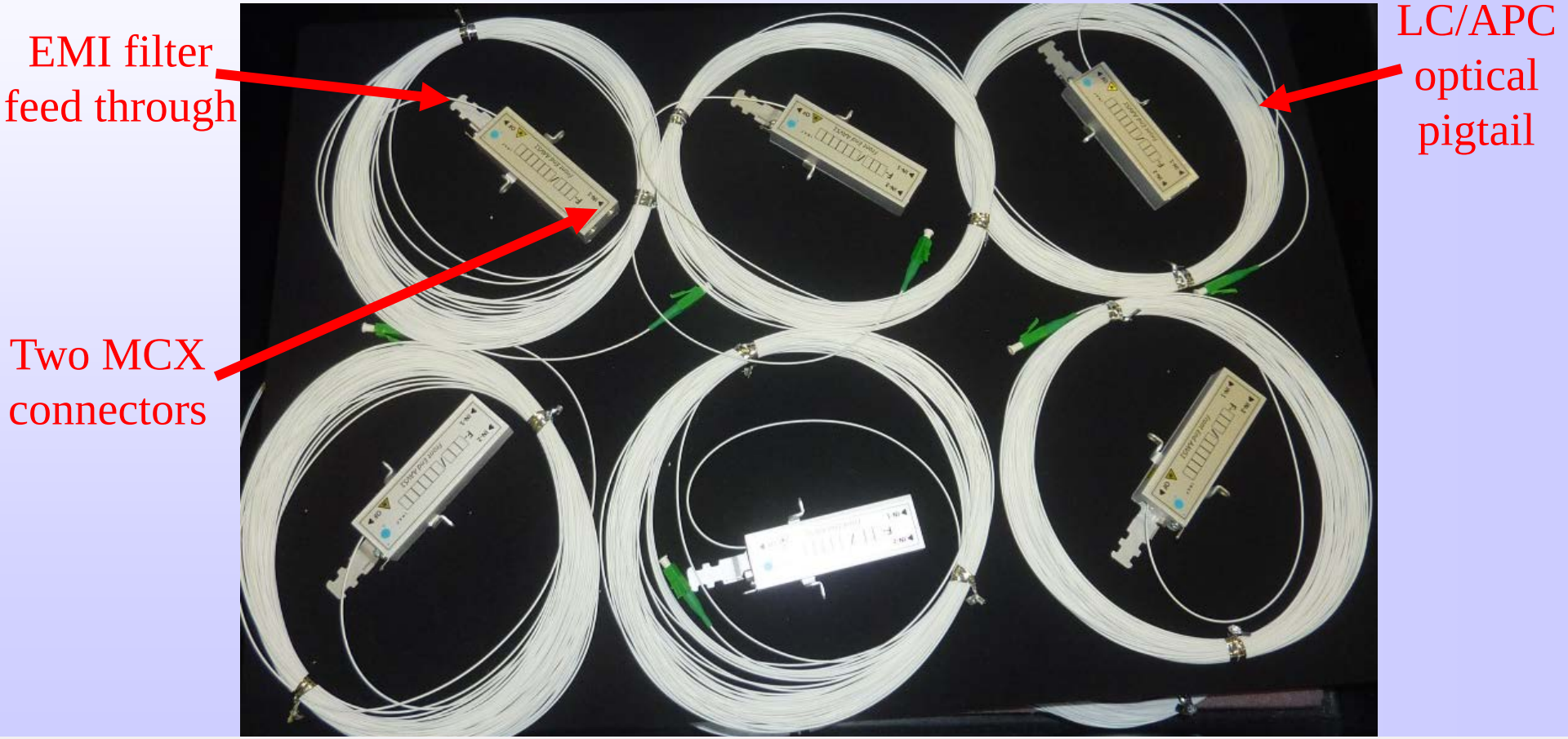
IF over Fiber (IFoF)

CWDM (Coarse Wavelength Division Multiplexing) for IF over fiber technology. Developed for SKA LFAA by INAF-led collaboration:

- Two different IF signals (from two different single-pol antenna elements) transmitted over same optical fiber using different optical carriers at λ=1270 nm and λ=1330 nm;
- Dual laser sources and dual photodiode detectors in single packages.
- RF isolation between channels: >30 dB up to 650 MHz;
- Demultiplexed at optical receiver side;
- Half FO, connectors, fusion splices, fibre joints (compared to more standard non-multiplexed links);
- Widely used in fiber optic communication systems → low cost;
- Input IF band in the optical transmitters: 375-650 MHz (for PHAROS2);

IFoF Links (AAVS1-SKAlow RX): Front End

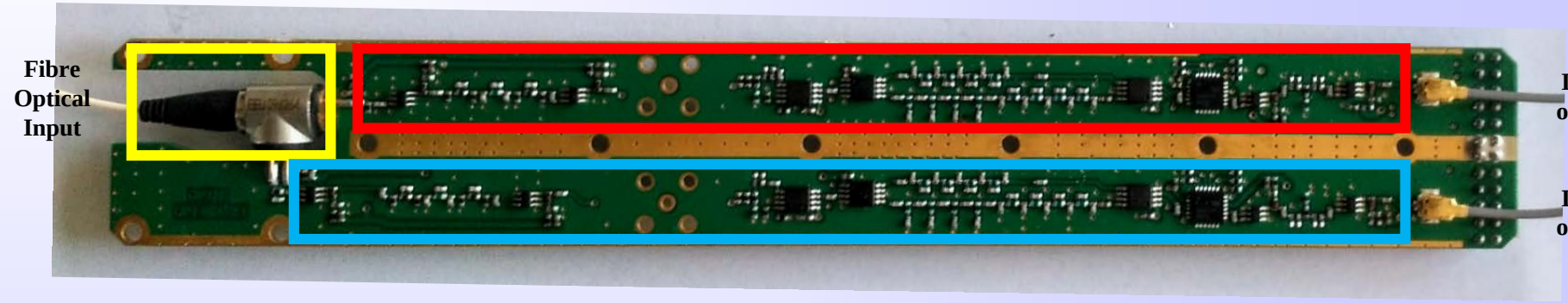
4 optical transmitters in each Warm Section module × 4 modules=16 optical transmitters (32 signals can be transfered, 24+1 used)



Two IF signals transferred from Lovell telescope primary focus to JBO backend room on same optical fibre. Optical wavelengths (1270 nm and 1330 nm): minimum of the dispersion of G652D optical fibre. Length of optical pigtail of approx. 1 m (to connect to WS front-panel).

IFoF Links (AAVS1-SKAlow RX): ORX/IF

Optical receivers:



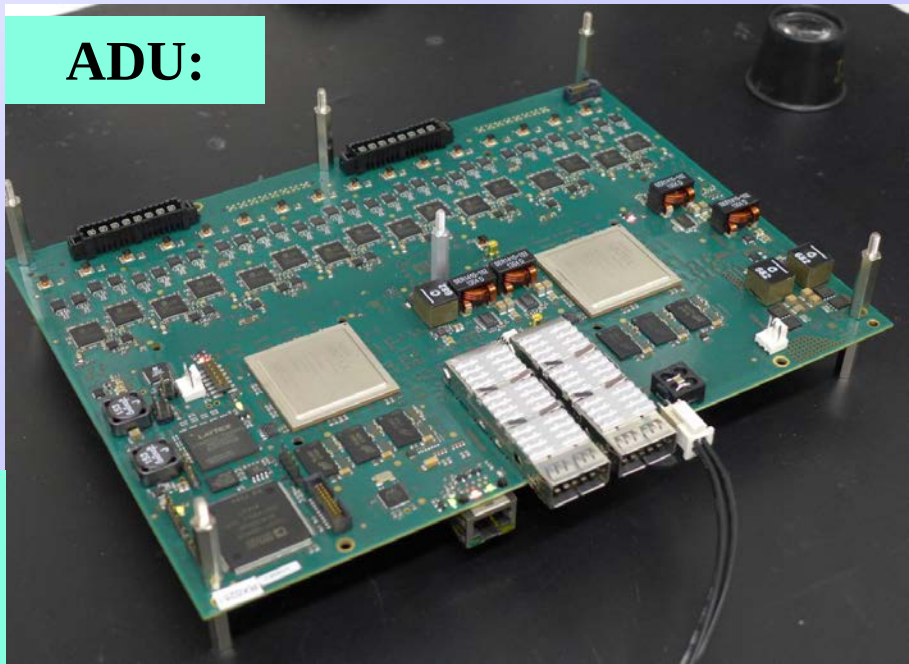
Two independent IF chains (red and blue). Each channel adapts the signal for the digital conversion by ADU: amplification, level adjustment (by means of a digital step attenuator, 31 dB range/1 dB step), band selector with a filter bank (low band, 50–375MHz, or high band, 375–650MHz) and a switch to close the IF input of any receiver on a 50 Ohm load for debugging procedures.
Receiver control with SPI bus from ADU board.

iTPM overview

TPM (Tile Processing Module): Digital platform developed for backend of new generation SKA Aperture Arrays. Collaboration between five INAF Departments. Supported by industrial partners.

- Convert analog optical fiber signals to electrical signals;
- ADCs: AD9680, JESD204B, 1 GS/s, ENOB=10.8;
- FPGAs: XILINX Ultrascale XCU40 20 nm;
- Digitisation at 700MS/s → 375-650 MHz sampled in second Nyquist zone; Note that in PHAROS2 the signals are reversed twice (LSB tuning, then second Nyquist) resulting in non-reversed passbands;
- Two 40Gbps Ethernet interfaces (QSFP);
- Amplification and bandpass filtering, ready for digitisation;
- Management of the clock distribution and of the memory storage;
- Channelization: 512 channels;
- Control and monitoring processor data;

ADU:

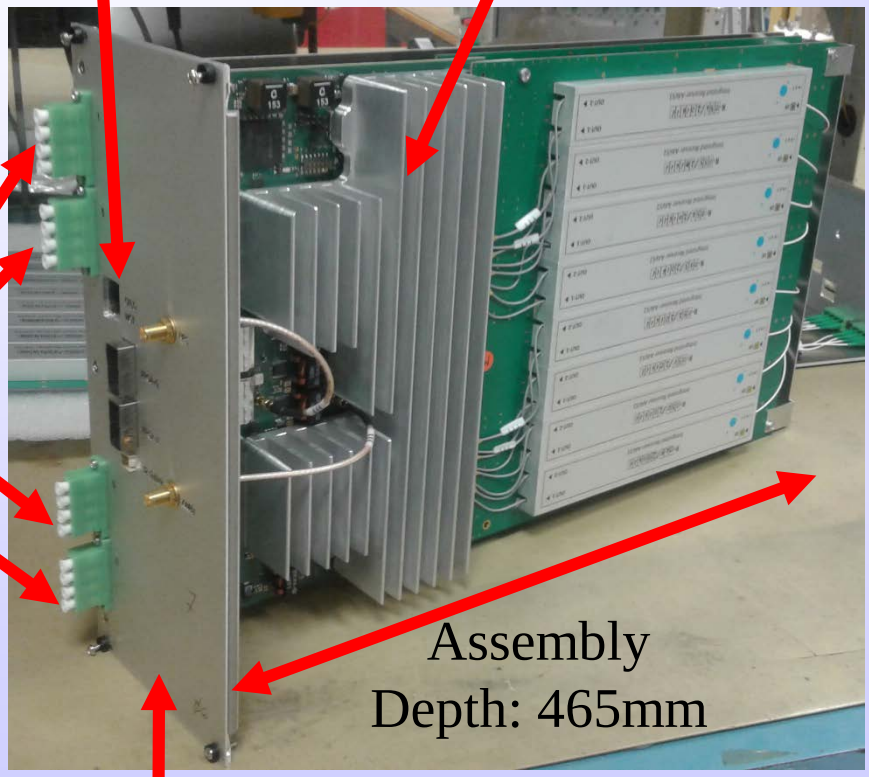


ADU: employs two FPGAs and 16 dual-ADCs capable of digitising 32 analog inputs, 500 MHz BW;

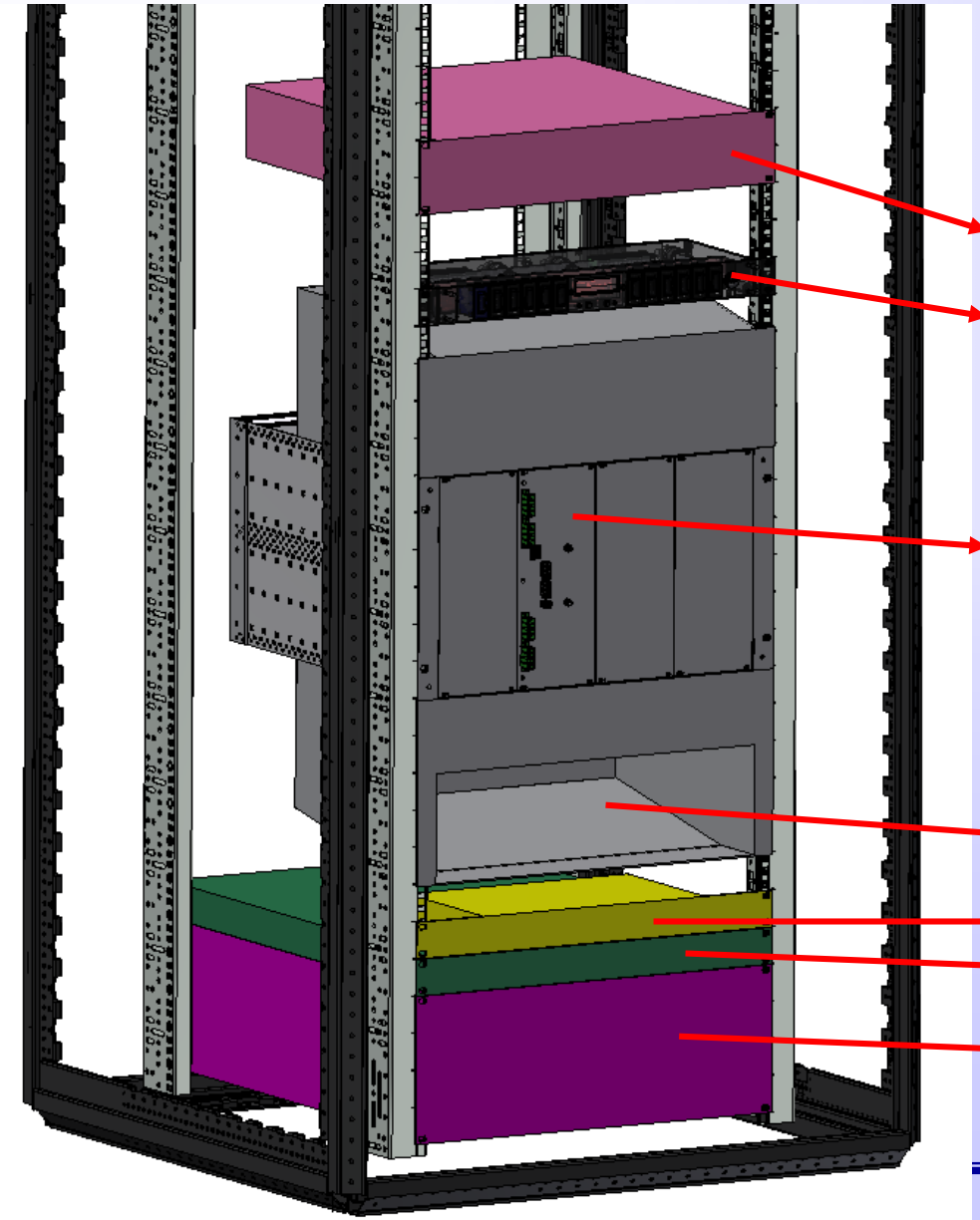
iTPM overview

- Includes one ADU and two preADUs;
- One preADU has 8 fiber optics receivers;

iTPM overview



PHAROS2 Backend Cabinet



Intellinet I-CASE EPX-4210BKX:
Standard 19″ racks, height 42U;
External dimensions: 800x1000x2057 mm^3;

Power supply (2U)

Power distributor (1U)

Subrack with 1 iTPM (6U)

Air deflector (3U)

Switch 1G (1U)

Switch 40G (1U) required for future upgrade

Server (4U)

Digital backend for PHAROS2

- 25 IF inputs (24+1 cal) across 375-650 MHz from IFoF to iTPM v. 1.2;
- iTPM initially used for digitization and channelization by 24 polyphase filter bank (PFB): 512 sub-bands (≈0.68 MHz/ch) in complex representation through FFT;

Three milestones for beamforming implementation:

Milestone 1: implementation of beamforming of one single channel, 0.68 MHz BW (350MHz/512) on CPU (GPU not required) with the Medicina software pipeline developed for space debris project. Use 24 elements single polarization to allow forming 4 beams (or more). Completed.

Milestone 2: Implementation of beamforming of 24 channels from 24 single polarization antenna elements, for a total of 16 MHz BW, using GPUs. Upcoming field tests on the Medicina Northern Cross BEST-2 telescope. It will be possible to form more than 4 beams. Requires to modify the firmware.

Milestone 3: Implementation of beamforming in the iTPM FPGAs for 24 elements, single polarization, 4 beams with ≈250 MHz BW.

Note: beamforming architecture with iTPM-FPGAs scalable to large BW (>2GHz) and large n. of beams (>30) is beyond the scope of this development plan.