SKACH

Square Kilometer Array Swiss project (SKACH)
Disrupting … without disturbing
MID band 6 instrument presentation and Status
Swiss SKA Days 2023-09-07

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Haute Ecole Spécialisée de Suisse occidentale
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Mid-band 6: presentation outline

- Disrupting without disturbing
  - Bringing a new feature in a project
  - New vs existing features
  - Boundary conditions and system issues
- Road map of project(s) and features:
  - EBB Elegant breadboard (project SKACH)
  - Engineering model (EM) and beyond (further project TBD)
  - Other projects
- Status of EBB work packages
  - Project management and documentation
  - System design and requirements
  - Front-end
  - Digitizer
- Next actions
  - SKAO collaboration
  - PDR

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Disrupting…

- A potential multiband receiver vs existing/foreseen single band ones
  - Digitize any 2.5GHz BW over 0 to 40GHz range (as per spec) (Nyquist regions 2-7)
  - 1^{st} Nyquist region: baseband 0-5.2GHz sampling (Bands 1-4+)
  - Dynamics ~8bits@28GHz, 5bits@40GHz (as per spec)
  - Optional 4x on-chip direct digital converters (DDC) for extracting narrower sub-bands within main frequency band
  - Flexible architecture of 11 output data lines (62/64bit coding)
  - Extensive setting of delays to ease setup of “long” interfaces (optical fibre)
  - Very low power (<3W/ADC)
  - Small size (single package, dual chip)
  - Low cost (enables application in Phase Array Feeds)
  - Standard form factor evaluation board ➔ easy prototyping with FPGA boards
  - Available to HEIG-VD 4Q23
  - HEIG-VD has exclusivity thanks to long-time collaboration with manufacturer
  - EU manufacturer, non-ITAR
  - Available off the shelf 1Q25
- ADC constraints
  - 1 ADC per 2.5GHz (pass-)band (12.8GS/s max)
  - Band 5b or 6 : 2 ADC required for dual data streams at separate frequencies
  - Variable bass-band filter needed for antialiasing ➔ challenge!
  - VERY challenging to design with:
    - 40GHz+ bandwidth on signal and data lines, need to have flat pass-band
    - Femtosecond phase noise on sampling clock

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… without disturbing

- Only MID bands 1,2,5 are in SKAO roadmap
  - SKAO busy with commissioning the first SKA-MID dishes
  - Little “bandwidth” to give to SKACH EBB esp. for answers about requirements
  - So: be nice and persuasive…
- Data bandwidth constraints
  - 100GB ethernet from dish: max throughput 4bits x 12GSamples/s x 2 streams=96Gbits/s (requires selection of most significant 4bits out of ~7/8)
- System architecture constraints
  - Use existing Talon DX board (dish pedestal) without HW modification (would be pointless and wasteful to add an FPGA board only for band 6)
  - Interfacing enabled by optical switching between 2 groups of lines
    - Band12(34)5 optical fibres
    - Band 6 optical fibres
    - Just add a slow control output from the Talon DX
  - Add functions for band 6b in FPGA HDL (HW description language) and SW, define an internal interface (ICD interface control document) to existing features
- Size Weight and Power
  - Limited footprint available on indexer platform ➔ “small” box
  - Limited weight budget (ideally zero…) ➔ optimized mechanical and thermal design
  - Limited power budget (ideally zero…) ➔ compliance possible due to low ADC power consumption
- Control of MID-band 6 receiver
  - Use all the interfaces and protocols defined for MID-band 1,2,5.
- **All this eases integration of MB6 into SKA**

Wideband vs narrowband

- SKA-MID observatory architecture: "narrow" band
  - Based on less than octave bands (f_H/f_L<2)
  - Enables "classical" single waveguide circuit per ban: proven technology
  - Feed Aperture efficiency can be optimised: e.g. ~95% proportion of main dish illuminated over frequency band
  - Rigid band limits, one band operated at a time (mechanical selection with indexer rotation)
- Challenge: Wideband 4:1 coverage (e.g. 6-24GHz ~bands 5+6)
  - Wideband feed aperture efficiency limited to ~75% (state of the art)

    ➔WB Need ~25% longer observation time vs NB
  - Digitizers technology was not available for this BW when system design decision was made
    - Baseband digitizer for 6-24GHz) would require´~64GS/s sampling in baseband ("Brand" receiver)
    - Extremely high cost
    - Enormous data throughput ~256Gbits/s with 4 bits ➔ need 3x100GbE
    - SKA-MID Correlator/Beamformer cannot "digest" that!
  - Difficult to keep low noise in active devices (LNA…) over >2:1 bandwidth (noise matching)
  - However:
    - A 8-channel digitizer made of 16 pass-band ADC with 16 filters can cover a wide band (20GHz in 8 arbitrary bands) ➔ <u>needs octave variable filters</u>
      - "blow" the **100GbE limit per dish**! (8x100GbE needed!)
      - Also exceeding Correlator &BF capabilities by a multiple
  - Still: would allow observing two widely separated 2.5GHz bands imultaneously
  - **SKA1 dish 100GbE throughput limits simultaneous observable BW to 5GHz**

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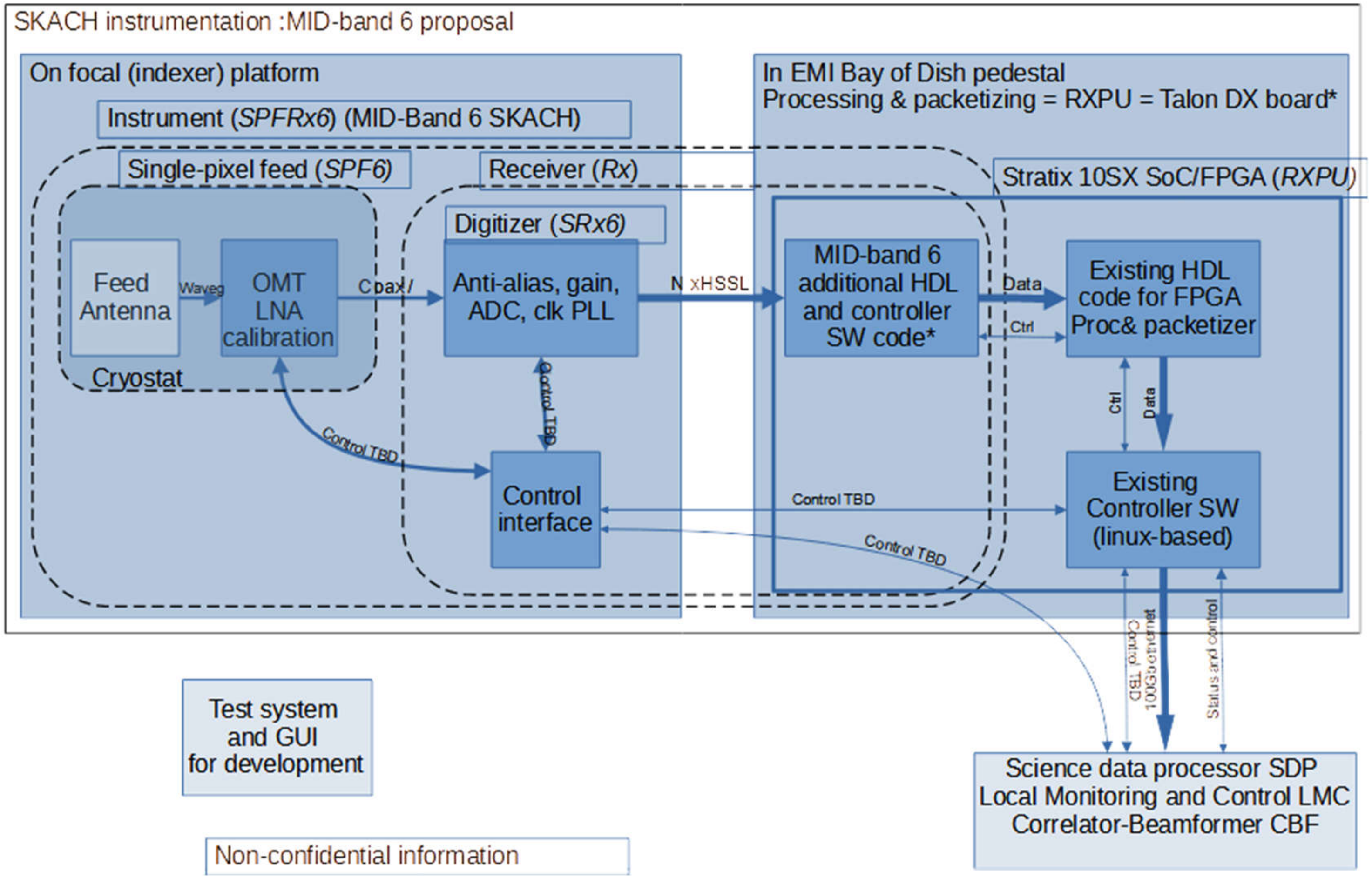
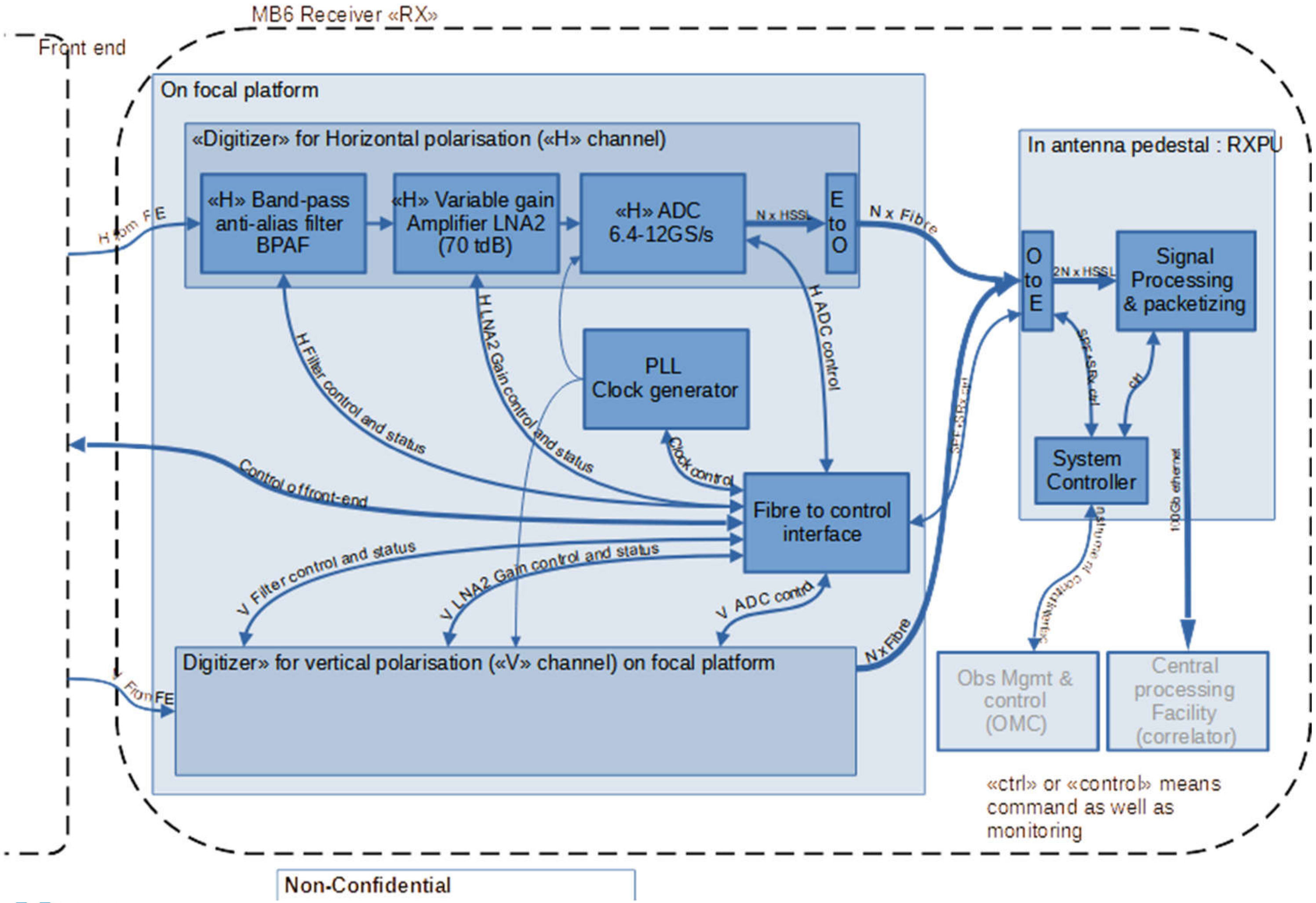
Block diagram: overall



Block diagram: receiver



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Project roadmap 1 of 2

- EBB Elegant breadboard (project SKACH instrumentation) **TRL3-4**
  - 15-25GHz covered in 4 fixed sub-bands (15-17.5, 17.5-20GHz,…), BP filters switched one at a time
  - 2 ADC (1 stream H+V), 2 sets of 4 sub-band filters, 1 PLL clock generator (~15 femtosecond phase noise)
  - 2x 11=22 optical data lines (may be less as control lines are needed) to FPGA
  - Same FPGA as in SKAO, different HW board (Altera/Intel Stratix 10 SX)
  - Run Linux on processor core in FPGA (4x Cortex A53)
  - Linux control SW taking in account SKA interface requirements and protocols
  - 300Kelvin front-end (mechanically compatible with Oxford B56 cryostat) and COTS feed horn
  - No mechanical, thermal, DC power constraints

- Engineering model and beyond (further project TBD) **TRL5-6**
  - Decide on frequency range: 15 to 30/40/50GHz? 20-35GHz?
  - 2 simultaneous H+V streams at arbitrarily selectable frequencies (as Band 5b)
  - 4 ADC (2 streams x 2 pol), 2 PLL clock generators and 4 variable filters
  - Up to 4x11=44 optical data lines:
    - not all can be interfaced to Talon DX
    - absolutely need to select/combine data bits in FPGA to comply to maximum SKA ethernet throughput
  - Serialising/processing/interfacing/control in FPGA of Talon DX
  - Use control SKA control SW running on the processor core inside FPGA
  - Compliant to all SKAO requirements for installation on dishes

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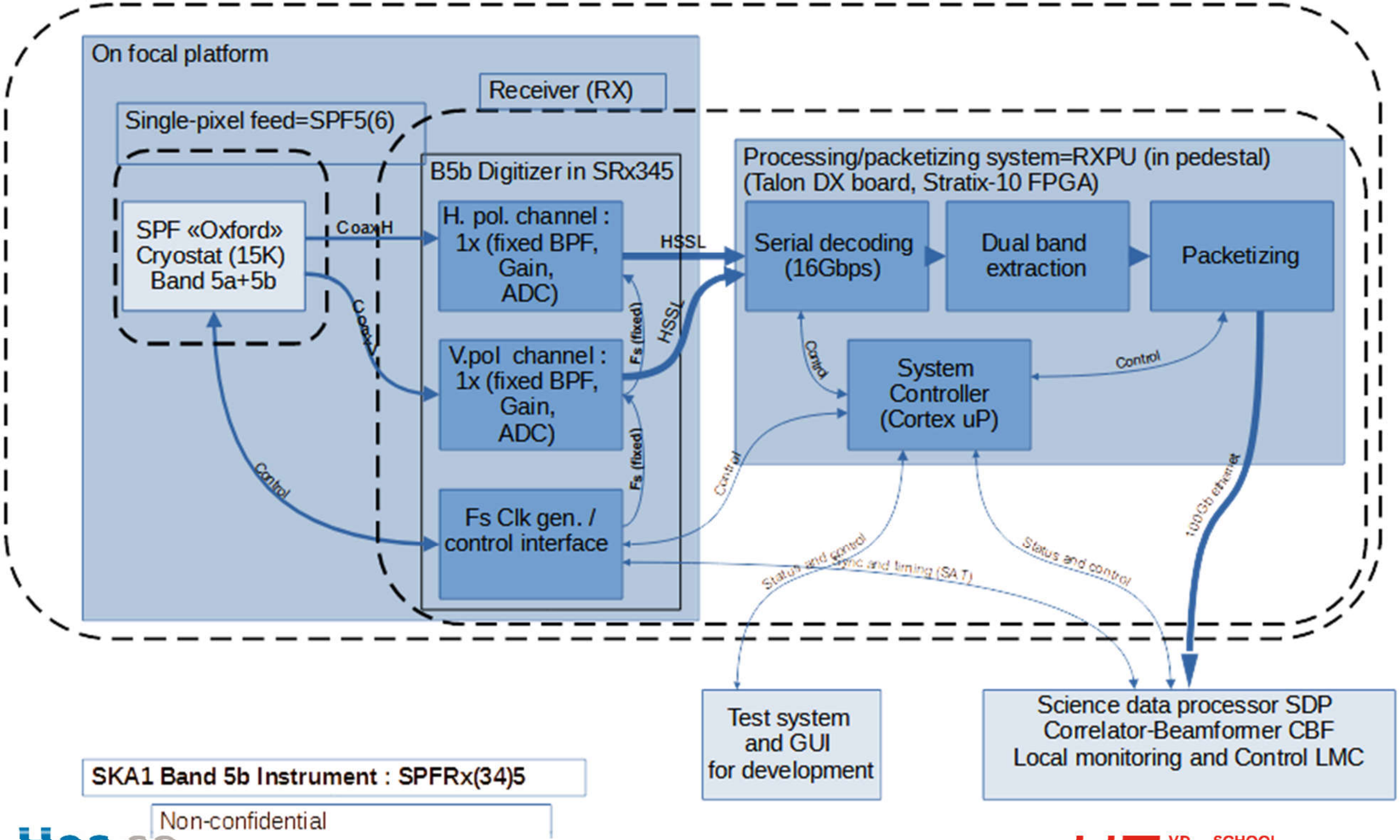
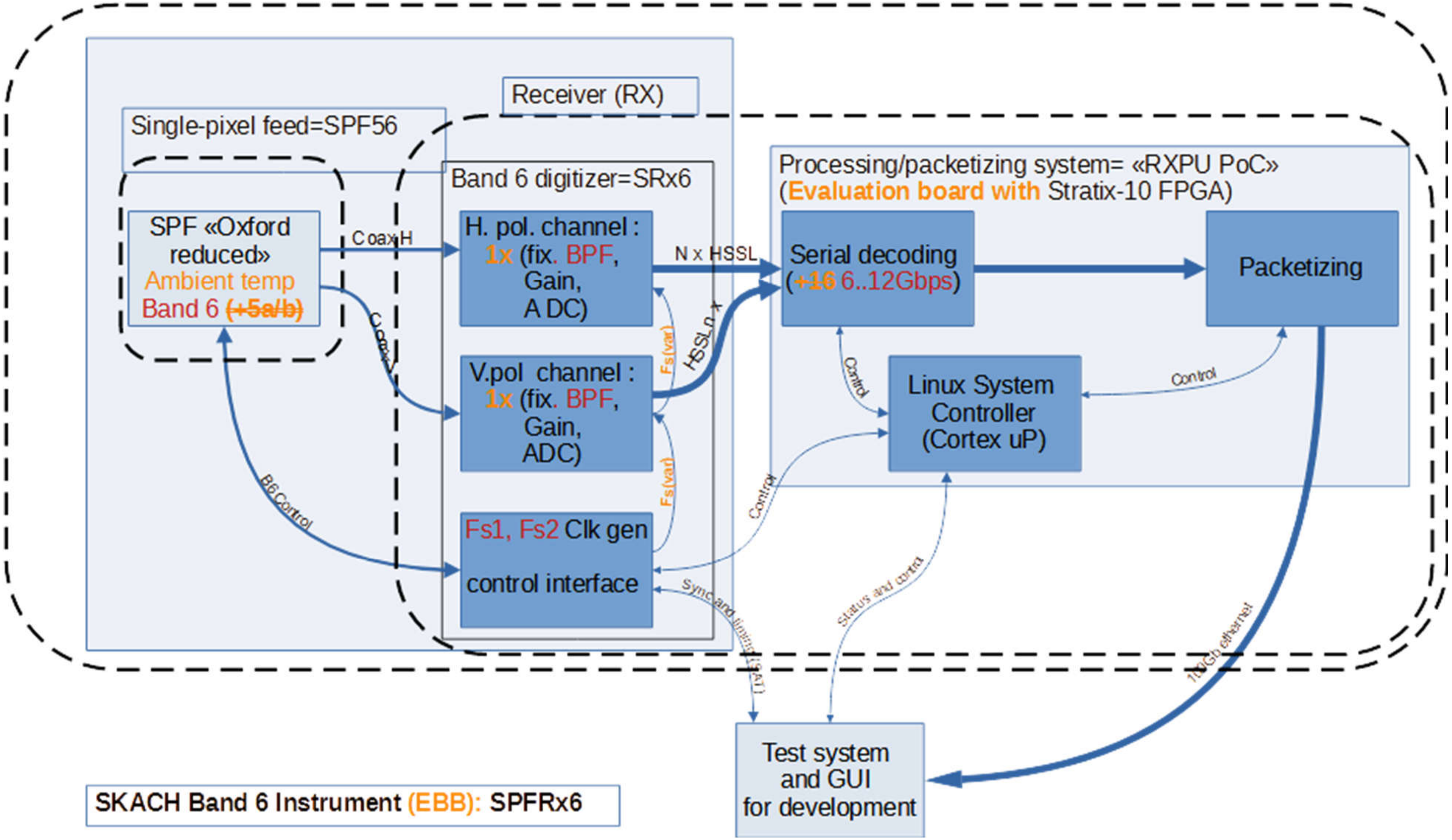
Block diagram: MID-Band 5 receiver



Block diagram: Mid-band 6 receiver EBB



Project roadmap 2 of 2

- Some parts of future EM **explored** in Horizon Europe “Radioblocks” project
  - “Scaled” variable pass-band filter as first step
    - Operating at f_H = 2~3GHz (5 or 7 cavity)
  - Miniaturised centimeter-wave variable pass-band filter
    - Operating at band similar to mid-band 6 but depending on EVN requirements
  - Filter setting algorithms
    - “Smart” tuning and calibration algorithms in fundamental mode
    - Tuning of upper/harmonic cavity modes?
  - Cryo LNA
    - Cryo compatible substrate (cryo-to-ambient operation)
    - Adaptive polarisation vs temperature
    - Diramics InP MMIC

- Innosuisse or SNF
  - Project idea with application to:
    - Radio-astronomy
    - Quantum computing
    - Time and frequency standards

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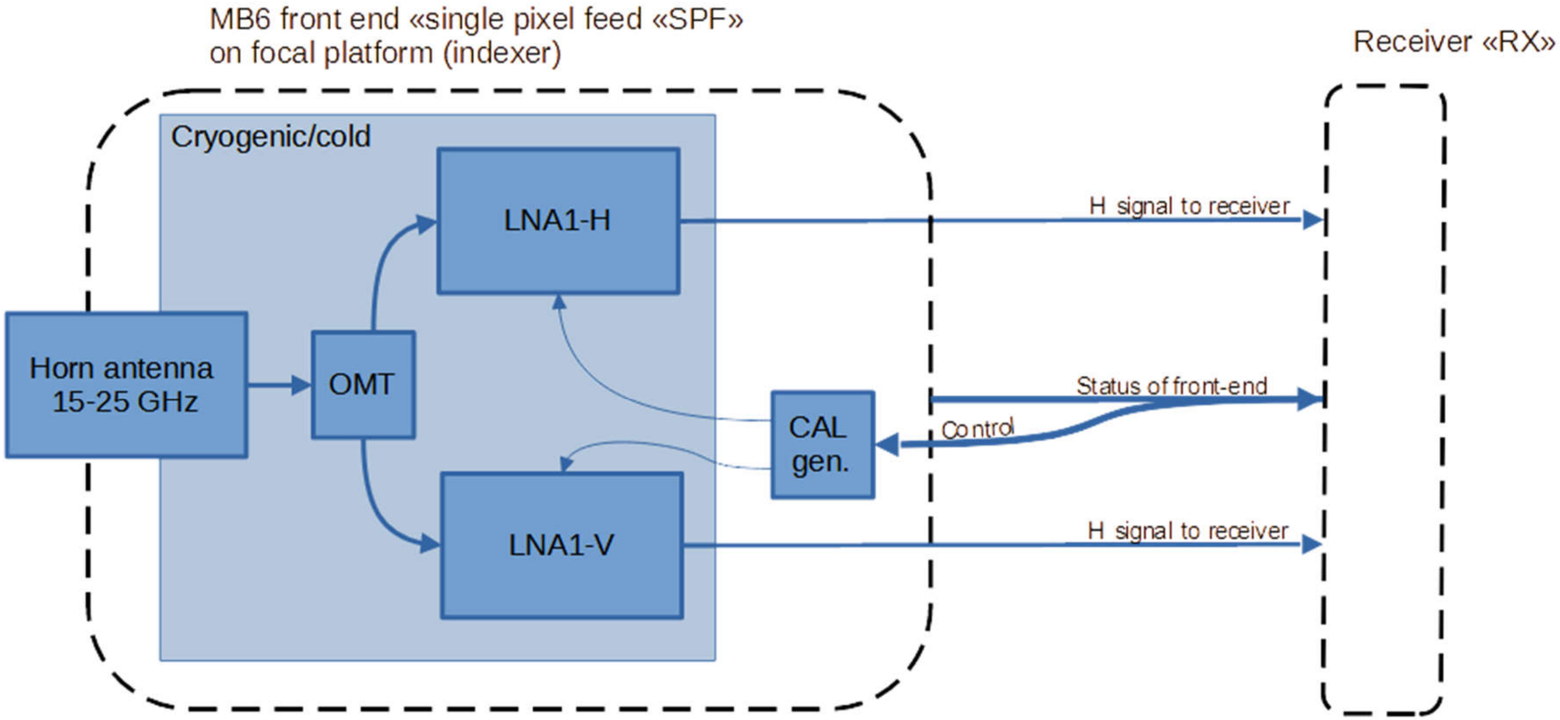
And the front-end («SPF6»)?

- EBB Elegant breadboard (project SKACH instrumentation)
  - 300K front-end mechanically compatible with Oxford B56 cryostat
  - LNA with Diramics InP MMIC
  - COTS horn
  - Less effort than on receiver/digitizer

- Engineering model and beyond (further project TBD)
  - Upper frequency?
  - Cryo 15/70Kelvin front end in fully operational B56 "Oxford" cryostat
  - Cryo Diramics LNA modules (15K)
  - Cryocooled (70K?) Horn designed by TBD (wideband?)
  - OMT designed by TBD (if required)
  - Auxiliary functions co-design HEIG-VD+Oxford
  - LNA: Wideband front-end would need several LNAs anyway, e.g. 15-50GHz coverage would require 3 bands covered by e.g. by 3 different Diramics LNA with couplers etc.
  - Wideband front-end (post-horn) challenging but appears to be feasible using:
    - 3D printed Waveguide technology

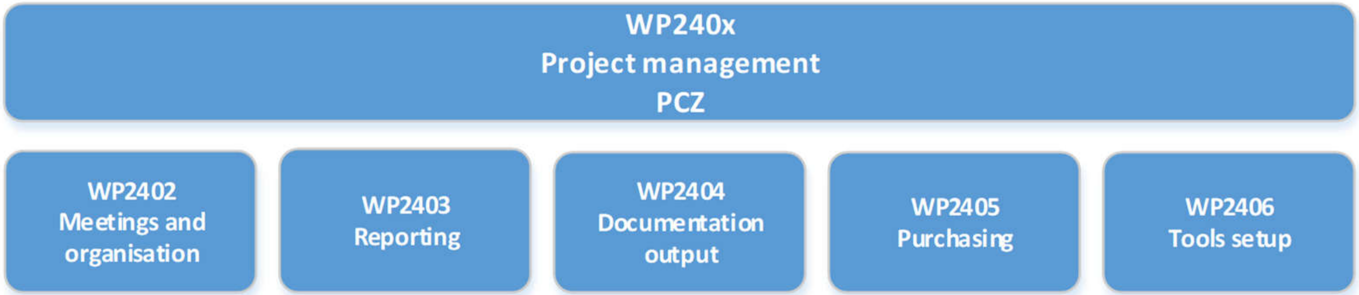
      OR
    - Advanced PCB technology with innovative substrate (cryo-compatible)
  - Horn+OMT+LNA is a single unit and internal interfaces will need to be defined before collaborating

Front end block diagram



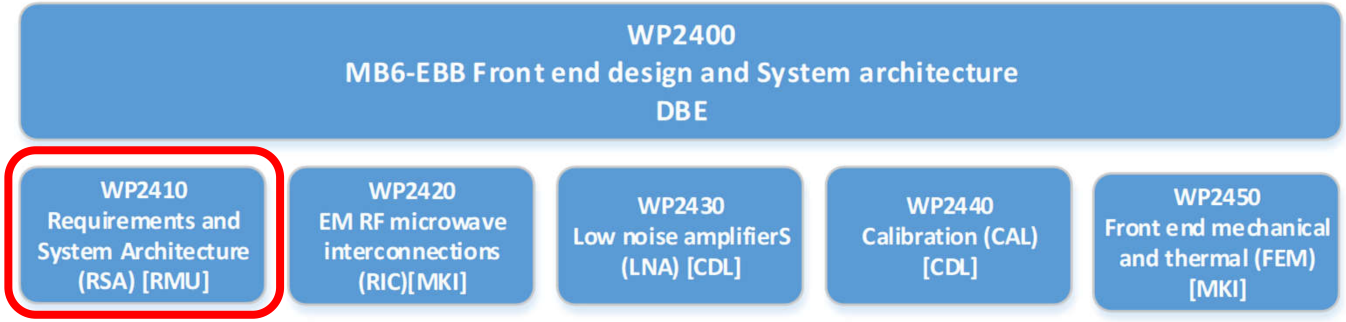
Non-confidential

EBB Work breakdown: WP240x PM



- **WP2404:** Documentation:
  - ☑ **Project management plan (PMP)**
  - ☑ **Design&development plan (DDP)**
  - ⚠ **Risk analysis**, in updating after SRR (will be including FPGA)
  - ☑ **Template for the "Stories" for the "agile" Sprints**
  - 🕓 EMC control plan for EM
  - ⚠ Master test plan (MTP) in update for "field tests"
  - 🕓 **Proposal: EBB as H_2O vapour radio-meter**
- 🕓 **WP2405**: purchasing is a critical activity in the current times of shortage of electronic components, establishing a Long Lead Item list
- **WP2406**: Cameo and git
  - ☑ setting up
  - ⚠ Maintenance
- ➔ next milestone: PDR (preliminary design review) dec 2023

EBB Work breakdown: WP2410 Req+Sysarch



- **WP2410:**
  - **System requirements review SRR→next slides**
  - **Noise model and analysis**
    - **Electronics (Horn output to ADC)**
      - **Rough model (excel file)**
      - **Fine model with frequency caracteristics of subsystems**
    - **Antenna noise**
      - **Sky and earth noise**
      - **Need geometrical model of full dish + imperfections**
      - **Collaboration needed**
  - **Science requirements**
    - **For EBB**
    - **For EM**

SRR = 2 reviews: «internal» and «external»

- System Requirements Review
- Based on «Observation & Action» templates and an organisation note
- SKACH pre-review for identifiying and selecting items to be discussed at SRR online meetings (2x3h)

THANKS to all reviewers!

- External review
  - Scientists from Oxford, INAF, Chalmers, ESO
  - PLUS internal reviewers, i.e. HES-SO, SKACH mgmt, SKAO Engineering
  - Worked on specifications (requirement list)

  ➔ 278 returns, of which 63 discussed during SRR external meeting, 42 remaining with actions
- Internal review
  - reviewed additional information such as
  - Design development plan
  - Risk register
  - Management plan and other plans

  ➔ 120 returns, of which 23 discussed during SRR external meeting, 15 remaining with actions

➔ Follow-up needed with SKAO-engineering

SRR status

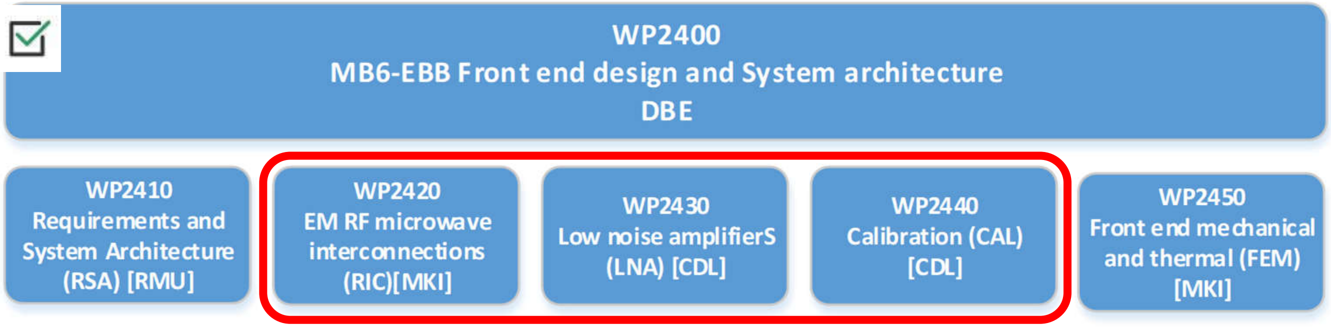
- «issues» about open/TBD requirements and features created on HEIG-VD git
- Mark Sargent and 2 SKAO engineering team members invited
- Other people may be invited
- Requirement update stalled (need responses from SKAO)
- Document update in progress

Open 10 · Closed 0 · All 10

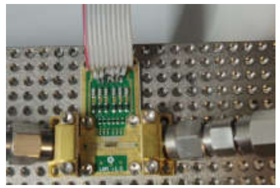
Search or filter results...

- R.SRx6.027 - Out of band suppression budget
  #6 · created 1 week ago by Menth Gilbert
- R.SRx6.023 - gain roughness budget
  #5 · created 1 week ago by Menth Gilbert
- R.SRx6.004 - gain stability budget
  #4 · created 1 week ago by Menth Gilbert
- R.SPF6.010 - frequency range
  #1 · created 1 week ago by Menth Gilbert
- General - system / subsystem nomenclature
  #2 · created 1 week ago by Menth Gilbert
- General - sensitivity
  #3 · created 1 week ago by Menth Gilbert
- General - mass and footprint budget
  #9 · created 1 week ago by Menth Gilbert
- General - changes in existing SKA infrastructure to accomodate MB6
  #10 · created 1 week ago by Menth Gilbert
- General - band 6 availability on MeerKat
  #8 · created 1 week ago by Menth Gilbert
- General - access to SKAO documentation
  #7 · created 1 week ago by Menth Gilbert

EBB Work breakdown: WP2400 front-end



- **WP2420**: microwave **interconnections:**
  - prelim work on OMT v1, 1st PoC on OxU mockup
  - Horn with Built-in OMT in selection
- **WP2430**: LNA1 v1 is delivered and validated at ambient
  - Gain 27-28dB, Noise figure 1.8dB
  - Miniature polarisation ("power supply") circuit to be designed
- **WP2440**: A **calibration** source
  - is being selected (calibrated COTS noise diode)
  - Coupling mechanism (+switch) to be designed
- **WP2450**: **thermo-mechanical** issues which also have an impact on the noise performance are handled in this WP ➔ this is more for the EM



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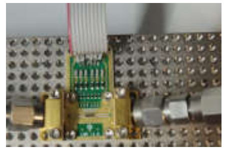
EBB Work breakdown: receiver 1/3

WP2300
MB6-EBB Receiver: digitizer, processing and system controller
DBE

WP2310 High-gain LNA2 [YDO]	WP2320 Band-pas antialias filter, fixed (BPAF-F) [YDO]	WP2330 Digitizer (ADC) [CDL]	WP2340 Internal optical interface (IOI) [EPO]	WP2350 FPGA processing [EPO]	WP2360 BPAF-V pre-study (BPS) [MKI]	WP2370 System controller (SYC) [RMU]	WP2380 digitizer mechanics (DIM) [APT]	WP2390 MB6-EBB Full system test platform (FTP) [RMU]

- **WP2310:** Second LNA needs a lot of gain (60..70dB)
  - ☑ Diramics MMIC selected (2x2)
  - ☑ Circuit architecture defined
  - X-MW based build



  - **WP2320**: fixed band pass **anti-alias** filter for selecting the 2.5GHz sub-bands (1 in 4)
  - ☑ ~~Specifications of filters defined, awaiting custom quotes~~
  - Started design of own design adjustable filters for sub-bands (“almost” single design for 4 bands, same principle of operation as for variable filter WP2360 but screw-adjusted
  - Mechanical drawings started
  - 4:1 Switches defined and ordered ➔ delivery normally sept 23

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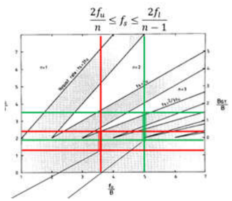
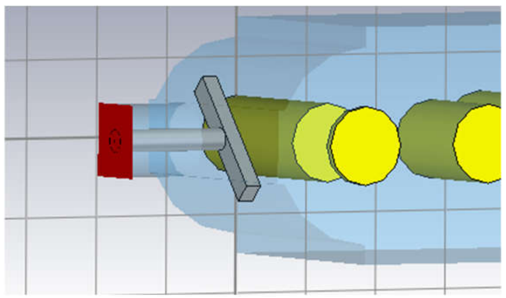
EBB Work breakdown: receiver 2/3 (WP2360)

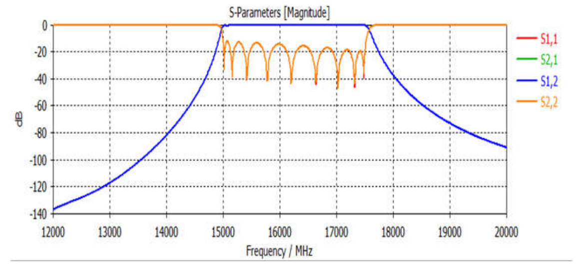
WP2300
MB6-EBB Receiver: digitizer, processing and system controller
DBE

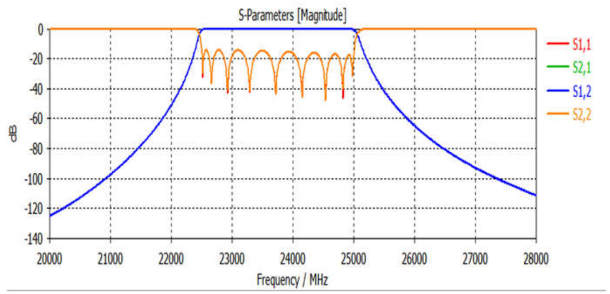
- WP2310 High-gain LNA2 [YDO]
- WP2320 Band-pas antialias filter, fixed (BPAF-F) [YDO]
- WP2330 Digitizer (ADC) [CDL]
- WP2340 Internal optical interface (IOI) [EPO]
- WP2350 FPGA processing [EPO]
- **WP2360 BPAF-V pre-study (BPS) [MKI]**
- WP2370 System controller (SYC) [RMU]
- WP2380 digitizer mechanics (DIM) [APT]
- WP2390 MB6-EBB Full system test platform (FTP) [RMU]

- See following presentation by M. Khalvati and M. Azadifar









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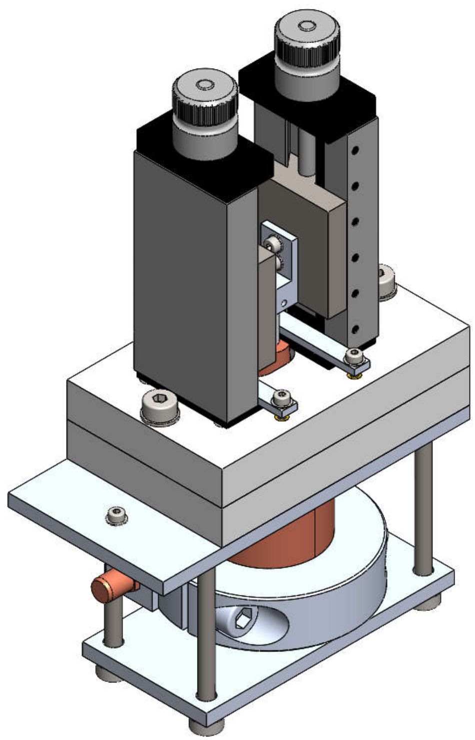
WP2360 1 cell PoC



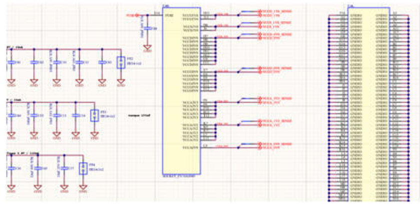
- **Single cavity PoC as preparatory work for future full filter (Proof of Concept)**
- **PoC scaled down 8:1 in frequency**
  - 1.9-3.1GHz
  - Single cell resonator
  - Single coaxial interface (SMA)
  - Actuators for frequency and coupling factor are commercial micrometric screws
  - Will enable studying ambient temperature variations etc.
  - Mechanical design is buildable
  - 2 units to be ordered

EBB Work breakdown: receiver 3/3

WP2300
MB6-EBB Receiver: digitizer, processing and system controller
DBE

WP2310 High-gain LNA2 [YDO]	WP2320 Band-pas antialias filter, fixed (BPAF-F) [YDO]	WP2330 Digitizer (ADC) [CDL]	WP2340 Internal optical interface (IOI) [EPO]	WP2350 FPGA processing [EPO]	WP2360 BPAF-V pre-study (BPS) [MKI]	WP2370 System controller (SYC) [RMU]	WP2380 digitizer mechanics (DIM) [APT]	WP2390 MB6-EBB Full system test platform (FTP) [RMU]

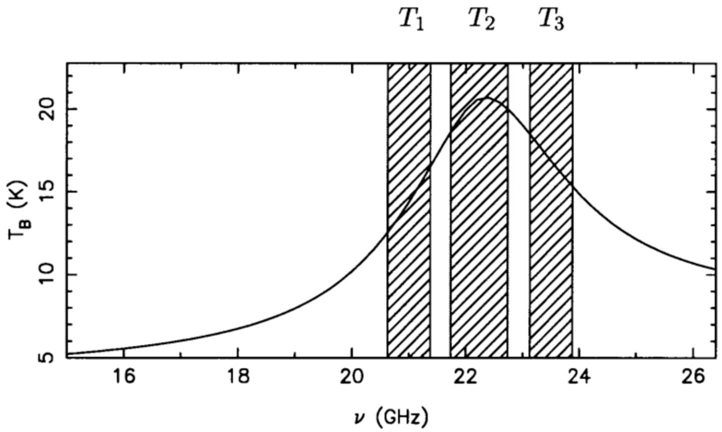
- **WP2330 ADC**:
  - ☑ “All” requirements clear, User Story defined (FMC+ format + PLL board)
  - ☑ Block diagram re-done ➔ DDP
  - ⚠ Schematic work (PLL)
  - ⚠ Schematic work (ADC)
  - ⚠ 40GHz PCB line simulation (in-house)
  - 🕓 PCB design/routing

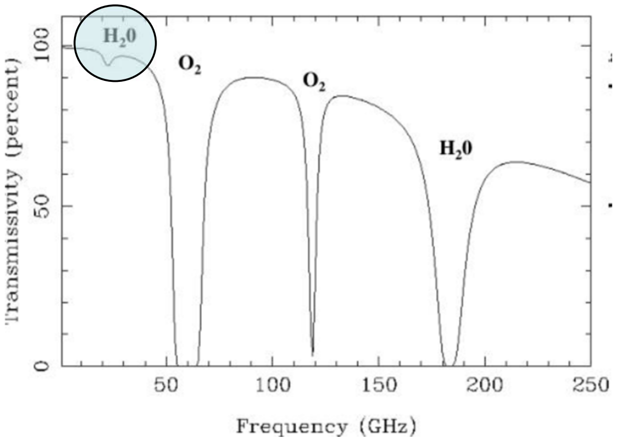


- **WP2340**: **optical Links:**
  - ☑ tech pre-study: some resources identified ➔ DDP*
  - ☑ Block diagram defined ➔ DDP
  - ⚠ Electronic design

- **WP2350 FPGA packetizer**:
  - ☑ FPGA eval board (Stratix 10 SX) **and exploitable** (linux installed)
  - ☑ HDL code for Data ztansfer from ADC out to 100GB ethernet at up to 12.5GSamples/s (need 12.8GS/s)
- **WP 2370 SYC system controller:**
  - ☑ architectural study ➔ cortex quad A53 core on Stratix FPGA
  - 🕓 SW drivers for ADC, PLL
- **WP2380-90:** on hold (HW platform =eval board is available, see above)

Test case: MB6 EBB as radiometer?





- **Dual-band Integrated Water Vapour radio-meter (IWV)**
- H_2O absorption max ~22.2GHz
- E.g. 23.5-24.5 GHz + 20-21GHz
- Or variable bands, agile switching using on-chip ADC DDC
- FPGA signal processing
- Ambient temperature front-end
- Ambient temperature COTS horn
  - Single-polarisation or circular
  - Aperture angle TBD
- «Easier» than installing a receiver on an RA dish
- Possible use case:
  - IWV measurements from ground
- Future uses:
  - space IWV (from LEO)
  - on SKA-MID site as real-time measurement for IWV
- Little modification needed from RA functionality (only reconfig and SW)
- Measurement disturbed by liquid water (droplets=clouds)

- **«EBB+» Use case: test receiver for evaluating SKA1 dish performance > 20GHz (e.g bank of 8 fixed filters ➔ 20-40GHz)**

Mid-band 6: Next actions

- Finalise technical requirements
  - With SKAO engineering
  - Discuss and close open points
- RA-derived system requirements
  - For EBB, if applicable for RA
  - For EM (15 up to 30/40/50GHz? Sensitivity? etc)
- Continue development of EBB
  - Goal: EBB operational 2024-04
  - Find where EBB used as H_2O radiometer could be useful
- Parallel/beyond project: Horizon Europe Radioblocks
  - Development of 7-cavity mechanically tuned bandpass filter
  - Bandstop/notch filters for RFI rejection/attenuation
  - Development of cryo LNA
- Next milestone: PDR dec 2023 (Preliminary design review)
  - EBB design: 80% of functions available
  - Documentation notably:
    - Design
    - Test
    - Risk
    - Quality