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Square Kilometer Array Swiss project (SKACH)
Winter meeting 2024
MID band 6 instrument EBB Status and current issues

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Neuchâtel, HES-SO/HE-Arc
23.1.2024 – D. Bovey

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Mid-band 6: presentation outline

- Brief reminder of receiver structure
- Status of EBB work packages
  - Project management and documentation (WP2404)
  - System design and requirements (WP2410)
  - Front-end (WP2400)
  - Digitizer (WP2300)
- Next and concurrent actions
  - PDR Preliminary design review
  - Innosuisse project for digizer EM
  - RadioBlocks
- Miscellaneous subjects
  - Quantum limit and 15-50GHz Mid-band 6+
  - Evaluation of noise figure of a future EM
  - Surface quality in cavity filters
- Credits

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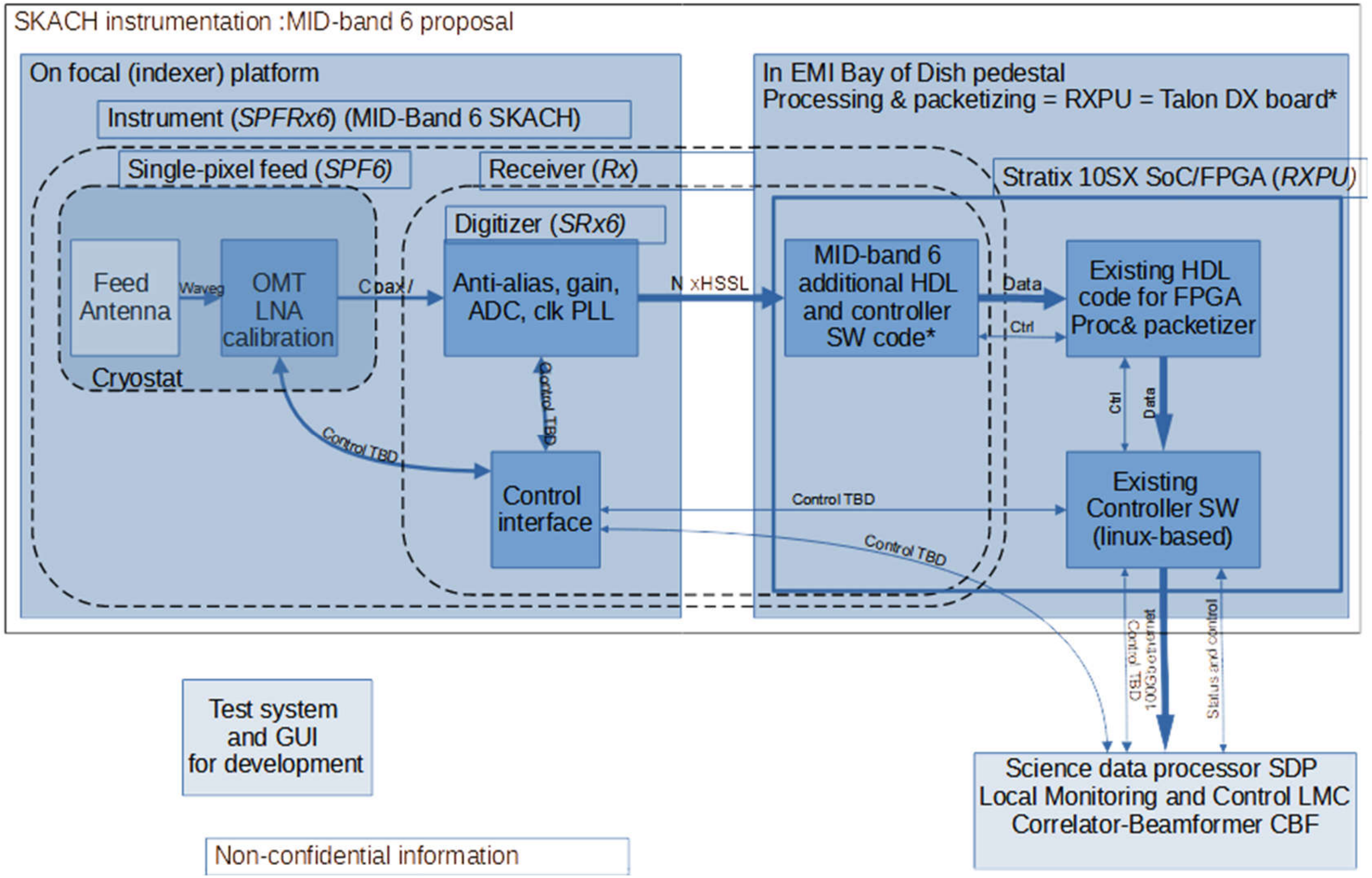
Block diagram of MID-band 6 receiver



15-25GHz in 4x2.5GHz sub-bands

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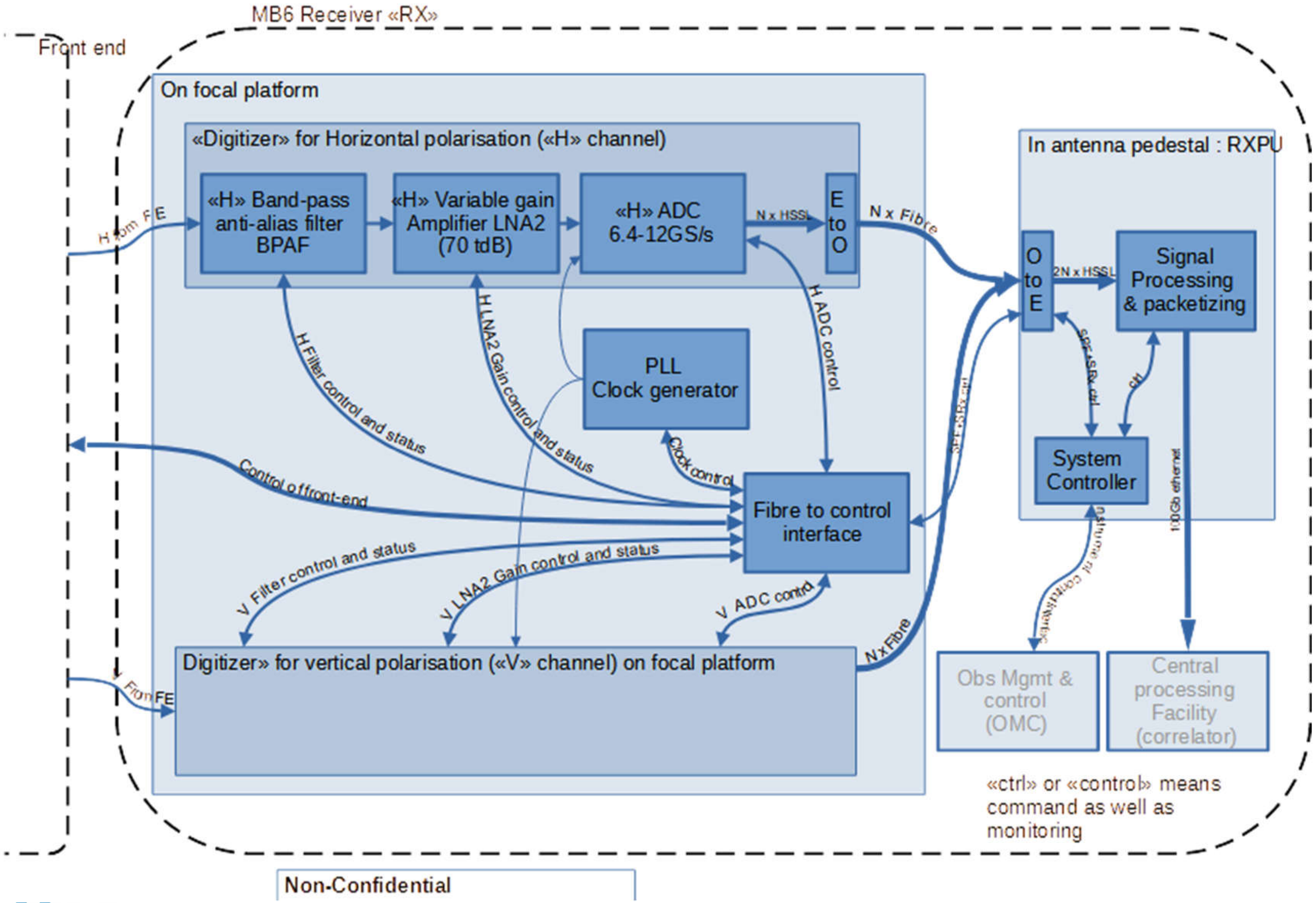
Block diagram: receiver



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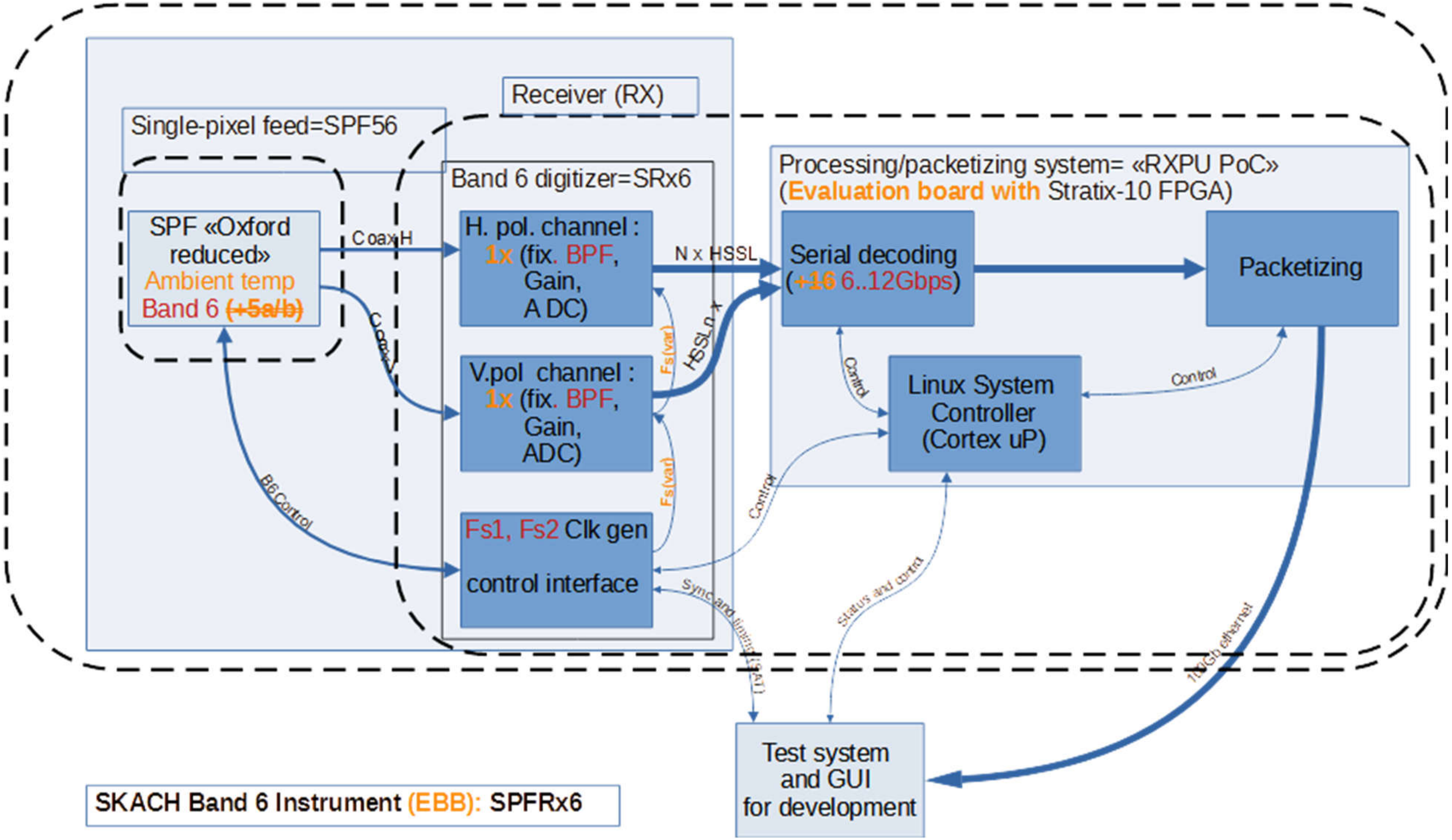
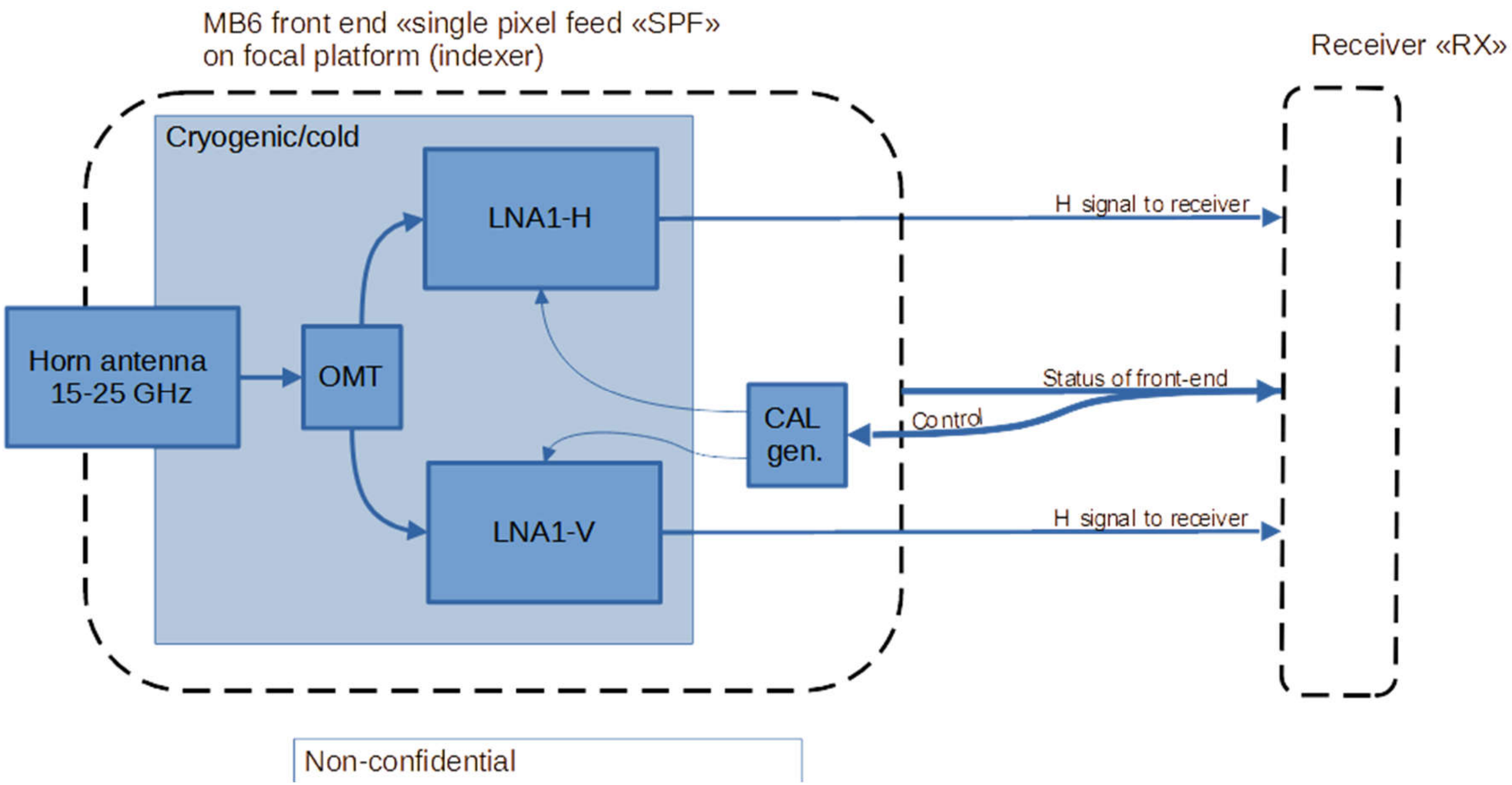
Block diagram: Mid-band 6 receiver EBB

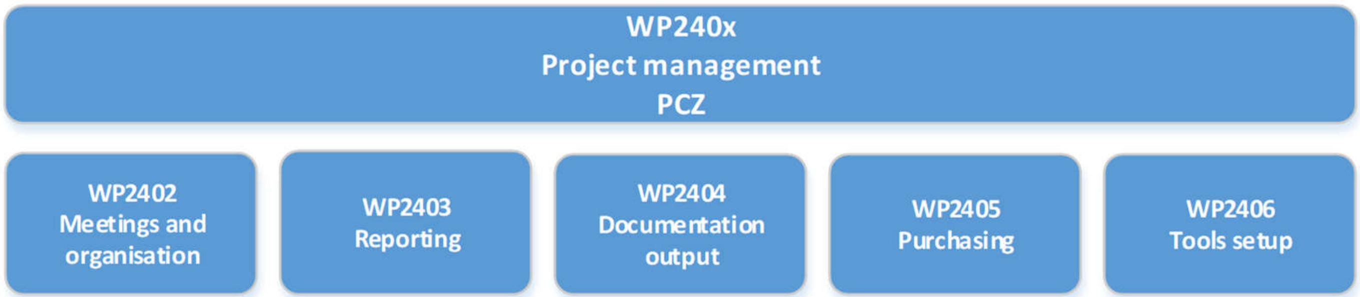


Front end block diagram



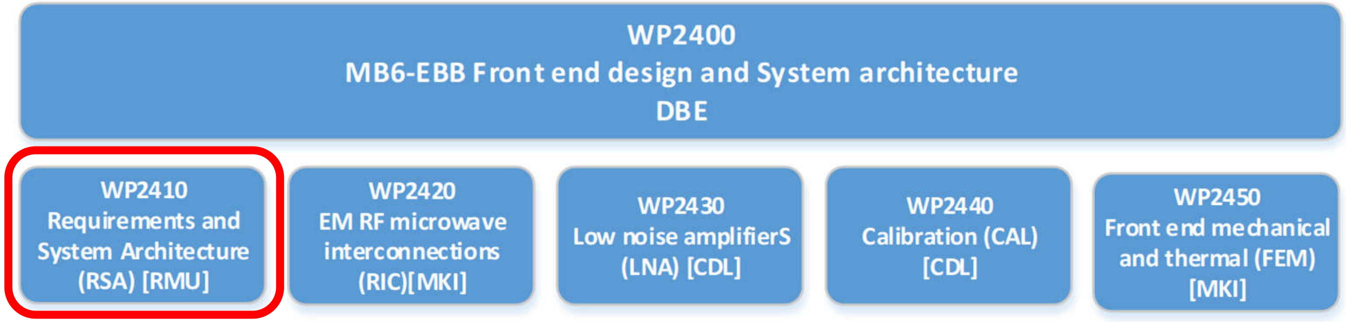
EBB is ambient/connectorised, EM will be cryo (20K) and wave-guide based

EBB Work breakdown: WP240x PM



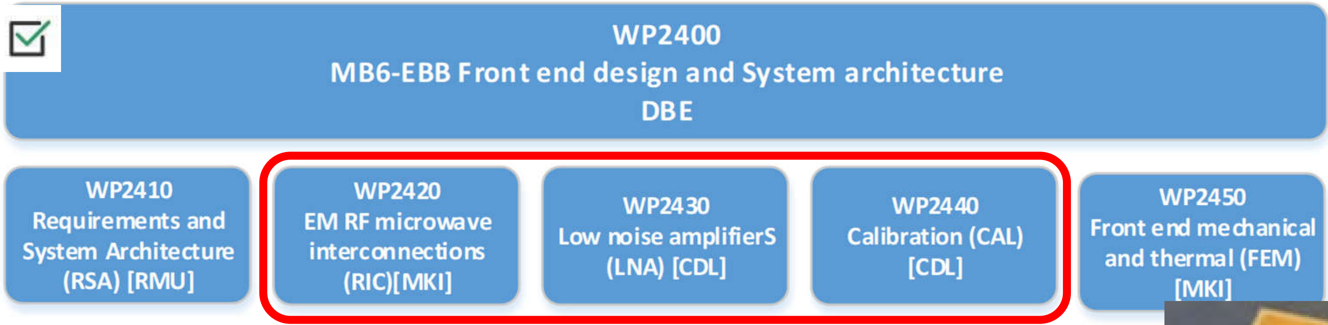
- **WP2404:** Documentation:
  - ☑ **Project Management Plan (PMP)**
  - ☑ **Design & Development Plan (DDP)**
  - ⚠ **Risk analysis**, in updating after SRR (will be including FPGA)
  - ☑ **Template for the “Stories” for the “agile” Sprints**
  - 🕓 EMC control plan for EM
  - ⚠ Master test plan (MTP) 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: Preliminary Design Review, March 2024

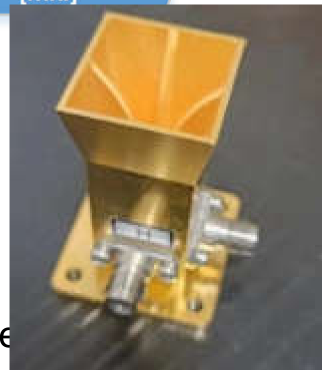
EBB Work breakdown: WP2410 Req+Sysarch

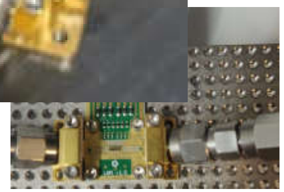


- **WP2410:**
  - **System requirements review SRR**
  - **Noise model and analysis**
    - **Electronics (Horn output to ADC)**
      - **Rough model (excel file) for ambient temp EBB**
      - **Fine model with frequency caracteristics of subsystems**
    - **Antenna noise**
      - **Sky and earth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

EBB Work breakdown: WP2400 front-end







- **WP2420**: microwave **front end components**
  - ☑ prelim work on OMT v1, 1st PoC on OxU mockup ➔ not used
  - ☑ COTS Horn with Built-in OMT **selected**
- **WP2430**: LNA1 v1..1 in delivery and validated at ambient
  - ☑ Gain 27-28dB, Noise figure 1.8dB, X-microwave format, encase
  - ☑ Miniature polarisation ("power supply") circuit **validated**
- **WP2440**: A **calibration** source
  - ☑ is **selected** (calibrated COTS white noise diode)
  - ⚠ Coupling mechanism **in design**
- 🕓 **WP2450**: **thermo-mechanical** issues which also have an impact on the noise performance are handled in this WP ➔ this is more for the EM. For the EBB, **mechanical design** of the front end (fitting of the various connectorized elements) once we have all the elements

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Front end components

- ☑ 10-40GHz QRFH Feed antenna (Acura Microwave)
- ☑ 2-40GHz splitter (Mini-Circuits or HEIG-VD design)
- ☑ 2-40GHz high ENR noise source (Noisecom)

- ⚠ Noise source: **selected**
- ⚠ Circulators: **Custom** 15-25GHz are possible

- ⚠ Coaxial cables, adapters etc (Mini-Circuits et al.)

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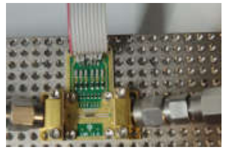
EBB Work breakdown: receiver 1/3

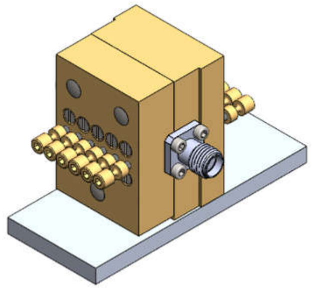
WP2300
MB6-EBB Receiver: digitizer, processing and system controller
DBE

WP2310	WP2320	WP2330	WP2340	WP2350	WP2360	WP2370	WP2380	WP2390
High-gain LNA2 [YDO]	Band-pas antialias filter, fixed (BPAF-F) [YDO]	Digitizer (ADC) [CDL]	Internal optical interface (IOI) [EPO]	FPGA processing [EPO]	BPAF-V pre-study (BPS) [MKI]	System controller (SYC) [RMU]	digitizer mechanics (DIM) [APT]	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, although searching some means of decreasing the cost
  - ◷ X-MW based build



- **WP2320**: fixed band-pass **anti-alias** filter for selecting the 2.5GHz sub-bands (1 in 4)
  - ☑ HEIG-VD design for 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 **completed**
  - ◷ To be manufactured
  - ☑ 4:1 sub-band switches defined and ordered ➔ delivered



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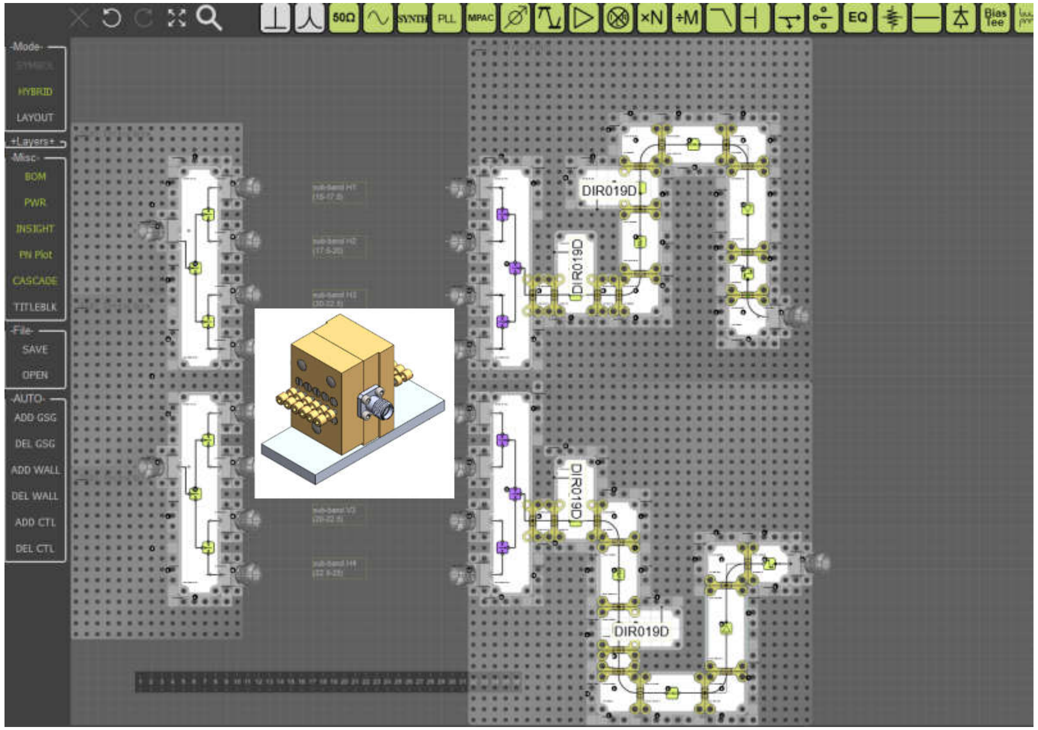
Digitizer analog design (WP2310 and 2320)



X-Microwave prototyping

Switching of BP filters

large variable gain

Diramics amplifiers

8x BPAF-V needed (single design)
(Bandpass anti-alias filters – fixed)

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**:
  - Approach changed
    - Instead of 1x dual ADC board developed for mfr, use 2x single ADC boards designed by ADC mfr
    - Decouples one project from the other (de-risking)
  - HEIG-VD need to fabricate single-ADC board (long delays too..)
- **WP2340**: **optical Links:**
  - tech pre-study: some resources identified ➔ DDP*
  - Block diagram re-defined ➔ DDP
  - Electronic design ongoing
- **WP2350 FPGA packetizer**:
  - FPGA eval board (Stratix 10 SX) operational
  - HDL code validated - data from ADC out to 100GB ethernet at up to 11.5GSamples/s (margin, 92gb/s out)
  - Design of control system through the fiber
- **WP 2370 SYC system controller:**
  - architectural decision ➔ NOT USING processor core on FPGA
  - PC GUI will control FPGA
- **WP2380-90 testing:** on hold (HW platform =eval board is available, see above)
  - Test architecture design started

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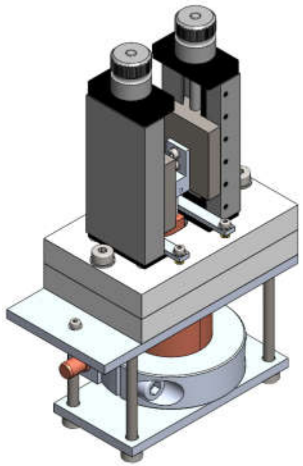
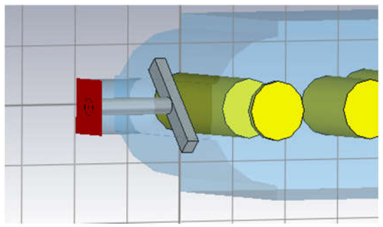
EBB Work breakdown: receiver 2/3 (WP2360)

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]





- **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
  - Lots of back-and forth on the mechanical plans

Mid-band 6: Next actions

- Continue development of EBB
  - Goal: EBB operational 2024-06
  - Find where EBB used as H_2O radiometer could be useful
    - ➔IRAM collaboration (Radioblocks)
- Next EBB milestone: PDR 2024-04 (Preliminary design review)
  - Designs of all subsystems
  - Documentation notably:
    - Design, Test, Risk, Quality (“SKAO-compatible”)
- Parallel/beyond project: Horizon Europe Radioblocks
  - Bandstop/notch filters for RFI rejection/attenuation “notch”
    - Collaboration with IRAM started,
    - specs confirmed: ambient temp, 17-24GHz, radiometer
  - Development of 7-cavity mechanically tuned bandpass filter
  - Development of cryo LNA? If there is interest
- Innosuisse project:
  - MB6+ digitizer EM for SKA with swiss SME
  - Proposal kick-off 02/2024
  - Project start 2024-08 (TBC)

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The quantum limit

- Is thermal noise energy >> photon energy? If not, impossible to **sum thermal noise over a signal chain**
- Boltzmann vs Planck
- Mainly about cold front-ends

- Simple “engineering-wise” calculation Boltzmann kTB >> Planck hf
- Ratio kTB/hf >9 (8dB)
- For various frequencies of interest and 20K temperature
- 1yJ=1yoctoJoule=10^{-24} J

RJ coefficient in dB (limit: 8dB)

		1.4	**4.6**	**8.5**	**15**	**25**	**50**	**230**	**850**	**f [GHz]**
T [K]		0.92764	3.04796	5.6321	9.939	16.565	33.13	152.398	563.21	hf [yJ]
300	4.1E+03	36.5	31.3	28.7	26.2	24.0	21.0	14.3	8.7	
77	1.1E+03	30.6	25.4	22.8	20.3	18.1	15.1	8.4	2.8	
20	2.8E+02	24.7	19.6	16.9	14.4	12.2	9.2	2.6	-3.1	
4	5.5E+01	17.7	12.6	9.9	7.4	5.2	2.2	-4.4	-10.1	
0.01	1.4E-01	-8.3	-13.4	-16.1	-18.6	-20.8	-23.8	-30.4	-36.1	
	kT [yJ]									

➔ 50GHz is just at the defined limit for 20K operation

Ref: “Receiver Noise Temperature, the Quantum Noise Limit, and the Role of the Zero-Point Fluctuations* A. R. Kerr', M. J. Feldman 2 and S.-K. Pan, 1997

Noise temperature evaluation

- Mainly about front-end: noise contribution of digitizer is negligible
- Based on “above Rayleigh-Jeans” criteria: allows summation of noise temperatures in the signal chain
- EBB Elegant breadboard (project SKACH instrumentation)
  - 15-25GHz covered in 4 fixed sub-bands of 2.5GHz (15-17.5, 17.5-20GHz,…)
  - Coaxial cable ➔ high loss
  - Ambient temperature front-end, with 100K LNA noise temperature
  - Use as vH_20 radiometer

➔ Preliminary result: 160K noise temperature

- EM Engineering model and beyond (further project TBC)
  - 2x 2.5GHz simultaneous bands (but same as 1 band)
  - Waveguide-based ➔ low loss
  - Several options:
    - non-simultaneous Band 6 (15 to 28GHz) and Band 7 (27 up to 50GHz, 40GHz at least)
    - Band 6+: 15 up to 50GHz (40GHz at least)

➔ Preliminary result: 40K noise temperature appears to be reachable with 10K LNA noise temperature (operating at 20K)

Surface quality in cavity filters: state of the art

- Where we start from:
  - Cavity filters (and many RF microwave devices) rely on surface currents in metal
  - The current is confined in a very shallow zone: depth of penetration (DoP) e.g. 0.45um @ 20GHz
  - Usual roughness of machined or plated surfaces is in the 10s of um, or worse
  - Base metal machined is brass, copper, aluminium, which oxidizes readily
    - ➔ it is a “very hilly terrain”
    - ➔ increases length of current path therefore resistance AND inductance
  - Oxidation “digs” into conductive metal, replacing metal with troughs of insulating metal oxide
  - even **Silver Oxide is insulating** as a semiconductor, 10^4 to 10^5 times less conductive than Ag metal
- Usual measures are:
  - Plate with inert metal (gold…) (Ag, Cu, Al adequate only when protected from oxidation)
  - Polish surfaces (not done very often as it is time-expensive and requires savoir-faire)

Surface quality in cavity filters: evolution

- What we are looking for:
  - Roughness << DoP
  - Fortunately: “Mirror polish” (roughness below lambda/5 of visible light, i.e. 0.1um or less)
  - Result easy to see “by eye”
  - Polishing to be done by hand (for the moment) by specialised workers in watch-making industry
  - Methods on how to polish small cavities and parts
- Open questions
  - Impact of various machining technologies on surface roughness
  - Metal lay-up and electroplating process
  - Polishing process (hand process) and when to stop
  - Ensure preliminary choices allow future cost optimization

Note: Superconducting parts are a whole different story

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All this wouldn't happen without:

- Mohammad Khalvati: EM simulations, crazy/creative ideas
- Mohammad Azadifar: EM Simulations
- Martin Loos: micromechanical design
- Pascal Coeudevez: Strategy, group leader, purchasing, micromechanical guru
- Gilbert Menth: Quality, documentation, planning/scheduling… and electronics
- Rostand Mitouassiwou: system thinking, test systems
- Christophe Donzelot: Microwave wizard, system thinking
- Yann Dolivo: Microwave wizard #2

And…

- Stefan Koegl: Deadline enforcement

And…

- The REDS team (Alberto Dassatti and team):

High speed electronics and FPGA (see next presentation)