Work Package 2: Novel Detectors and Components

Carsten Kramer (IRAM)

WP2: Novel detectors and components

- Key Objectives: Components for future receivers of ALMA, NOEMA, IRAM-30m, and others. **Analog parts** of the signal chain: Optical elements, detectors, low noise amplifiers, enhancing their **performance** with support by **industrial partners**. Develop and test prototypes. Create **toolbox for future receivers**.

- 17 European Partner Institutes: IRAM, Fraunhofer-IAF, MPG, GARD/ Chalmers, UOXF/Oxford, RUG/Groningen, UKRI, TUD/Delft, UNIMAN/ Manchester, CNIG, UCO/Köln, INAF, OBSPARIS, ESO, HES-SO, Lytid, TTI Norte

- Budget: 1.8 MEuro

- Timeframe: 4 years (3/2023 - 3/2027)

WP2 Partners

WP2:
17 Partner Institutes
6 Main Tasks:

WP2.1: Optical Elements:
TUD, RUG, OBSPARIS, UNIMAN, INAF

WP2.2: SIS-Mixers:
GARD, RUG, UCO, UOXF

WP2.3: LNAs:
UNIMAN, CNIG, UKRI, MPG, IAF, GARD, UOXF, TTI Norte

WP2.4: LOs:
OBSPARIS, UCO, Lytid

WP2.5: W-band module:
IAF, MPG, IRAM

WP2.6: Filters for LNAs:
HES-SO, IRAM

WP2 at the core of RADIOBLOCKS

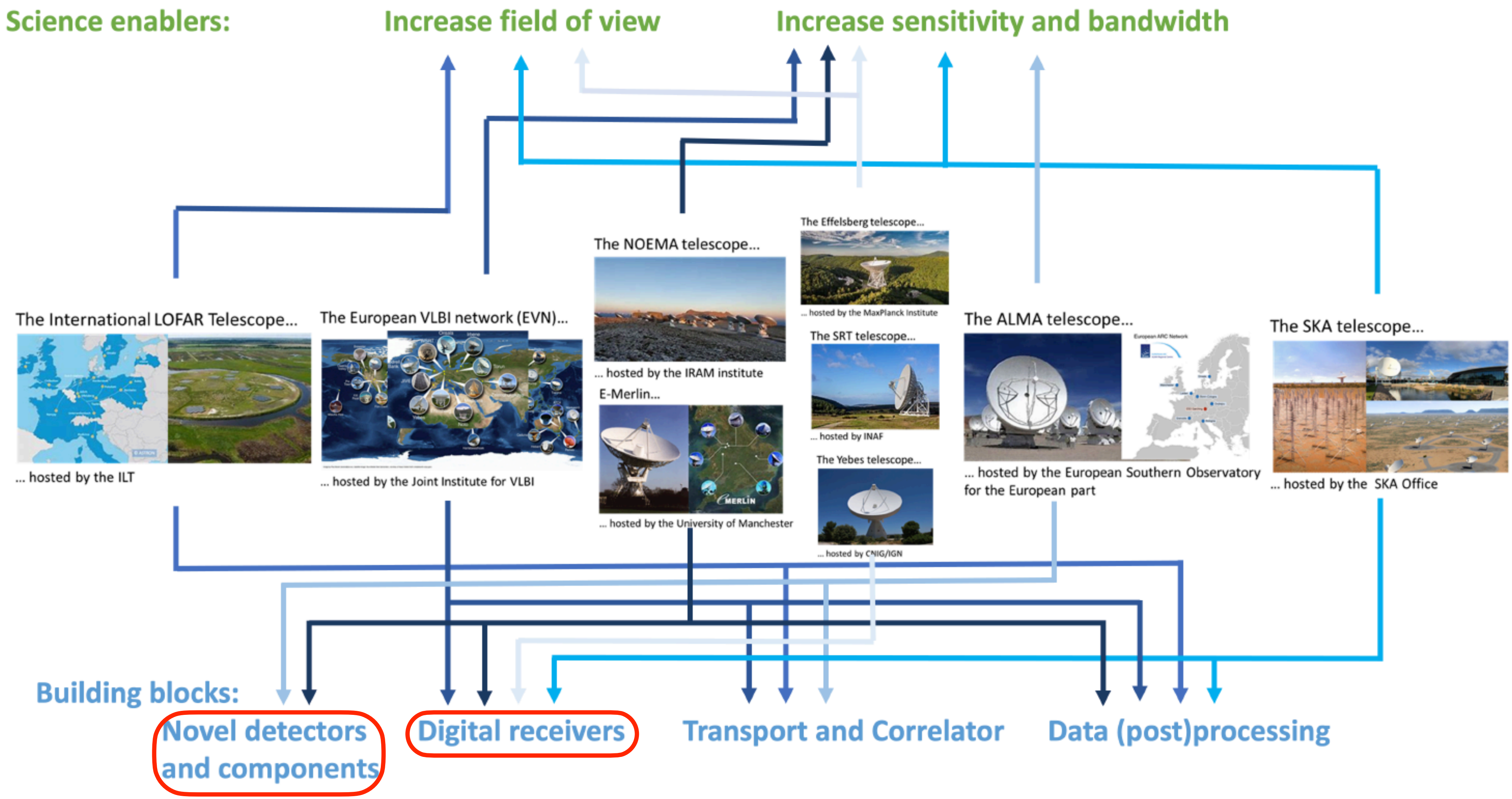
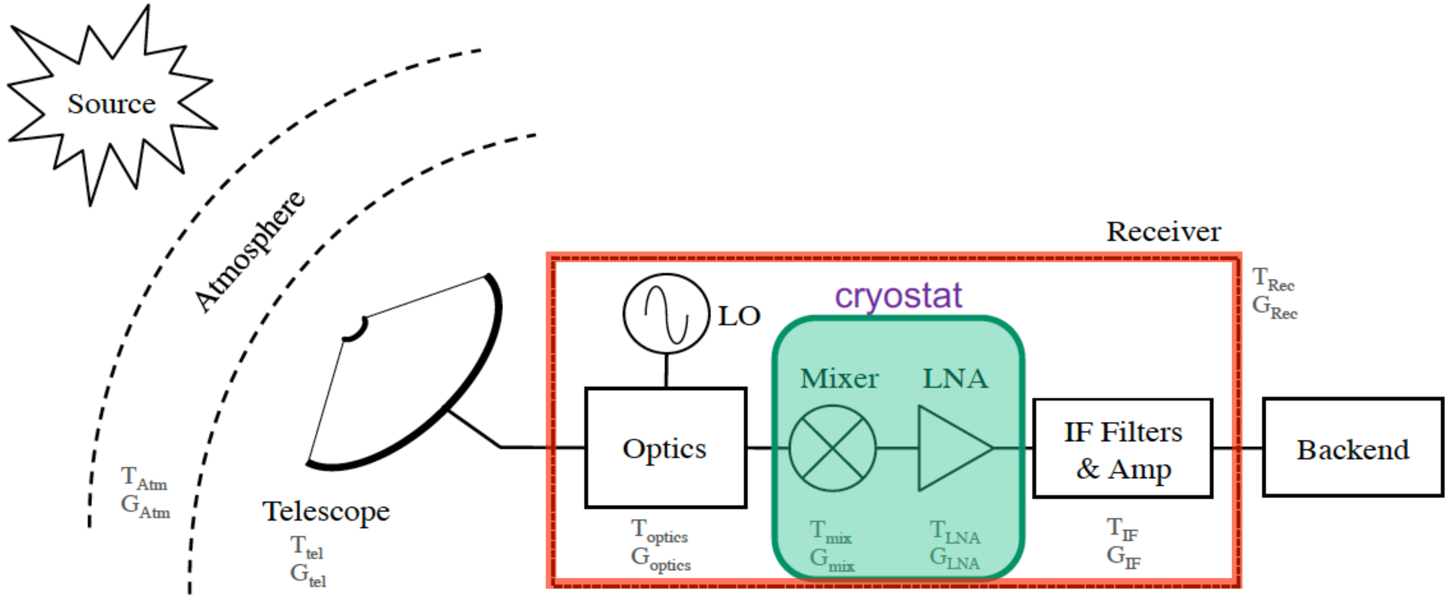


Figure 2: Building blocks for the science enablers

WP2: Six main tasks along the signal chain



- WP2 develops all key components along the receiver signal chain: **Lenses, horns, SIS mixers, RF and IF amplifiers, W-Band downconverter, local oscillators, filters**.
- Parameter space for improved performance: **bandwidth, sensitivity**, **power consumption**, **compactness**, **inter-operability**, **resilience against RFI**, … .
- Development timeline (similar for each component): **Simulate, Test setup, Design**, **Fabricate**, **Test**, **Analyze**, **Report and Publish**
- **Links to next-generation ALMA and NOEMA receivers**, **AMT**, **Focal Plane Arrays**, …

WP2: Six tasks along the signal chain

- **(Task 2.1.1) RF windows, lenses, filters**
  - Development of nearly reflection less flat meta-lenses over large bandwidths
  - Two approaches. Promising simulations. Preparation of test setups and first tests.
- **(Task 2.1.2) Orthomode-Transducers**
  - Planar technology from 100 GHz to 650 GHz, separate polarizations, optimum pointing
  - Two approaches, simulations, interfaces to 2SB mixers, LNAs, and feedhorns, test setup in preparation
- **(Task 2.1.3) Horns**
  - High performance corrugated horns, silicon micromachining: new technology for easier manufacturing.
  - Design study, establish manufacturing process, different approaches, aim at integrated, compact horn-OMT structure for Focal Plane Arrays.
- **(Task 2.2) SIS mixers**
  - Development Expanding RF and IF bandwidths. exploring new materials
  - see below
- **(Task 2.3) LNAs**
  - RF LNAs up to 150 GHz. IF LNAs: expanding bandwidth, exploring new technologies
  - see below

WP2: Six tasks along the signal chain

- **(Task 2.4) Local Oscillators**
  - Increasing power and efficiency
  - Developing source at 346 GHz with doubler, design model, optimizations underway

- **(Task 2.5) W-Band downconverter module**
  - Block conversion of 67-116 GHz RF band with fixed LO.
  - see below

- **(Task 2.6) Tunable filters**
  - band reject filters to suppress radio frequency interferences (RFI). Integration in the front-ends before the LNAs. Micro-actuators.
  - Same technology as passband filters developed in WP3
  - Planned application: NOEMA water vapour sensors
  - Investigation on exploiting cavity modes above the fundamental with promising results.

Highlights of 1st year

focussing on three major areas of work:

+ SIS mixers

+ IF Low Noise Amplifiers

+ W-Band down-converter

Highlights of 1st year: SIS junctions

Superconducting tunnel junction (SIS) mixers: workhorse for mm/submm astronomy.
Aims: wider RF and IF bandwidths, improving noise performance

In the 1st year of work, GARD work has focussed on arbitrary shaping of substrates for SIS mixers, ortho-mode transducers at frequencies of ~210 to 380 GHz by micromachining (see examples below).

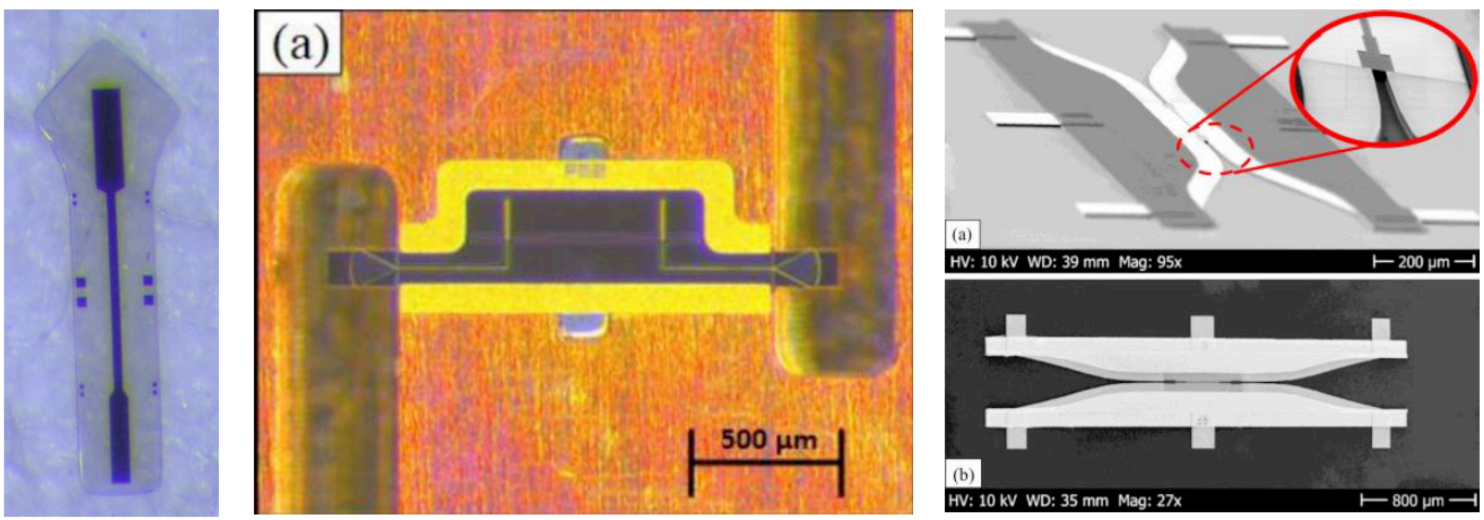
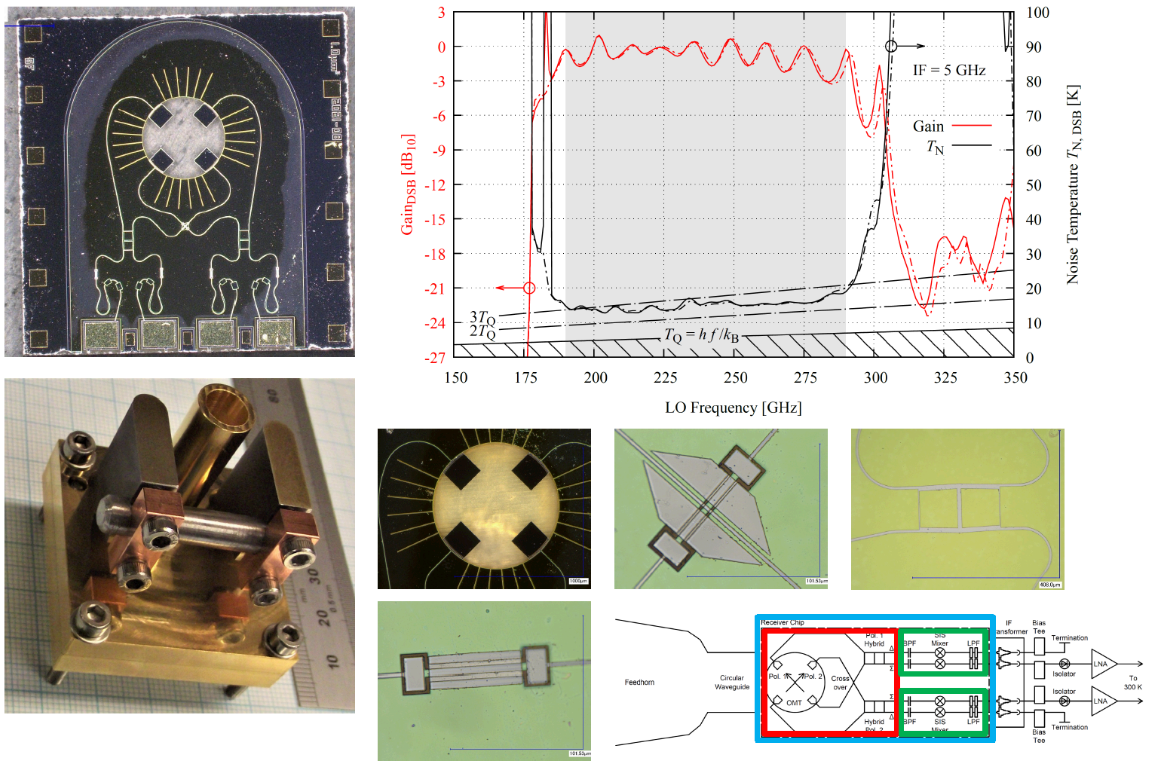


Figure 4 Micromachined GaN substrate, silicon membrane device, ultra-wideband waveguide-to-slotline transition.

Highlights of 1st year: SIS junctions

Planar On-Chip Dual-Polarisation SIS Mixer: Design & Simulation



Oxford in collaboration with Paris Observatory:

Focus on integrating **OMTs** and dual-polarisation 220 GHz **SIS junctions on-chip** and improving **RF bandwidths** and **noise** performance. Go for a cryogen-free cryostat.

Simplifying design of SIS mixers for ALMA Band 5+6, especially for broad RF and IF bandwidths.

Highlights of 1st year: IF Low Noise Amplifiers (LNAs)

Goals: cryogenic LNAs

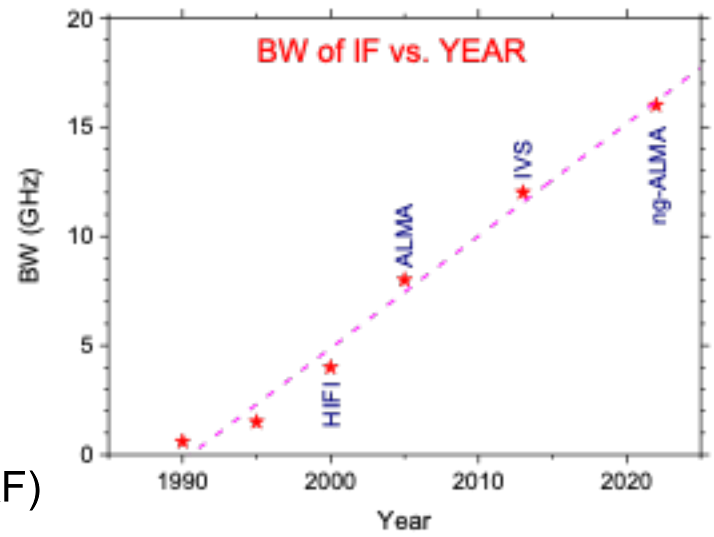
- Bandwidths: tentative goal of ~30 GHz
  - Depending on technologies
  - Coordination with SIS development for bandwidths and seamless interface

- Technologies:
  - mGaAs HEMT MMIC with superconductive input-matching network (MPG+IAF)
  - InP HEMT (Yebes)
  - Superconducting Parametric Amplifiers (SPAs) (UOXF)
  - Balanced LNAs using superconductive 90º hybrids (GARD + Yebes)

- Possible front-ends of cm-wave telescopes (WP3)

- Address compactness through:
  - LNA footprint reduction
  - LNA bias simplification
  - LNA bias connector placement at RF output side

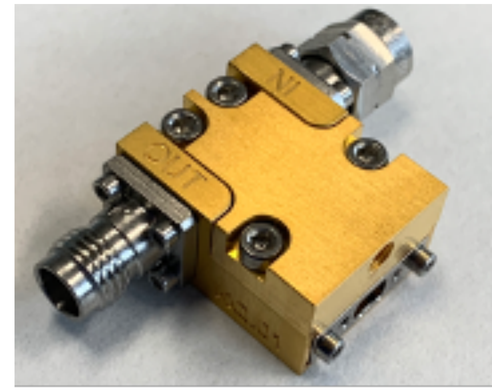
IF bandwidth Evolution of Yebes amplifiers
(in projects that set a new standard for radio astronomy)



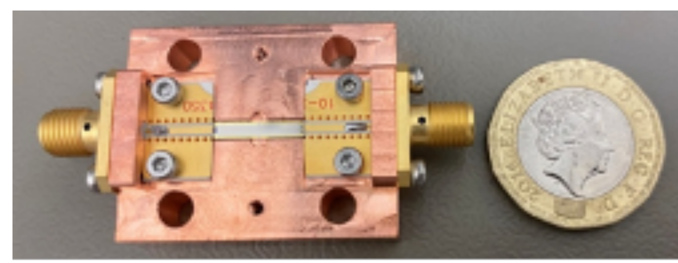
Highlights of 1st year: IF Low Noise Amplifiers

Work within WP2 is progressing on several fronts:

- IAF & MPG:
  - Development and fabrication of 18-50 GHz mHEMT MMIC LNAs
    Room temperature evaluation completed;
    noise measurements started
- Yebes (& Diramics):
  - 4-20 GHz InP LNA MIC prototypes tested at NOVA, GARD, IRAM and NAOJ.
  - Production of a Product Development Kit for MMIC LNA design
    4-20 GHz LNA to be ported to MMIC technology
  - *Working on further band expansion, compactness, and SIS integration.*
- UOXF & IRAM:
  - 4-12 GHz Josephson junction Traveling Wave Parametric Amplifier prototype developed
  - Quantum noise promised, but still experimental technology.



IAF & MPG 18-50 GHz mHEMT MMIC LNAs



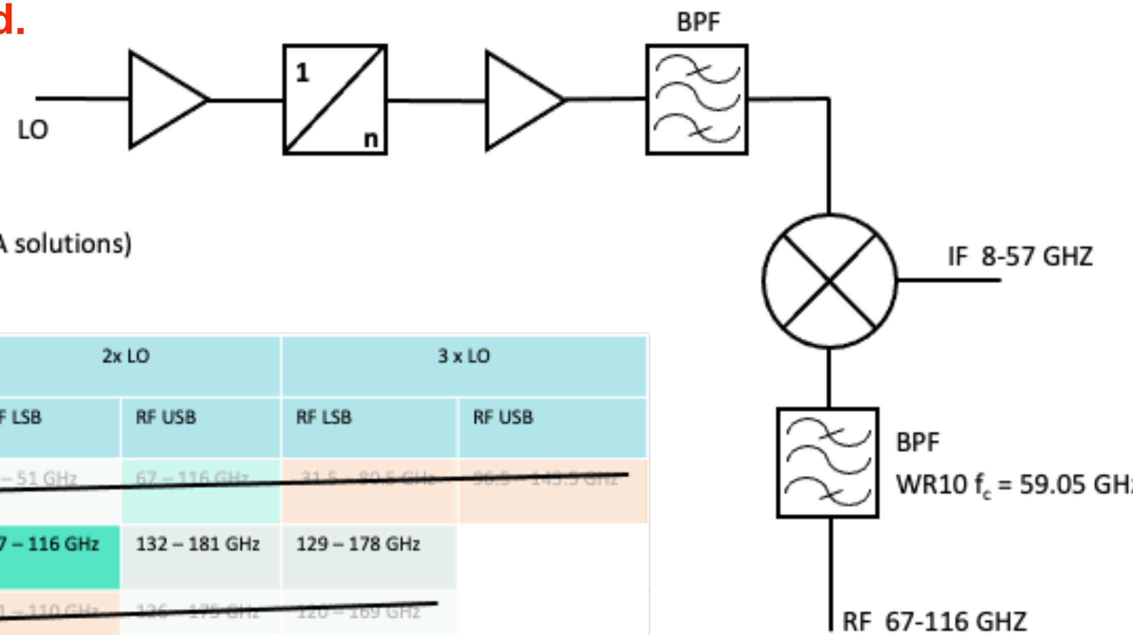
UOXF 4-12 GHz Traveling Wave Parametric Amplifiers

Highlights of 1st year: W-Band downconverter

Goals: block conversion of 67-116 GHz RF band.
Several different designs discussed.

Goals/decisions from meeting on 23 Mai 2023:

- Use LSB (Image Mixer)
- IF port 1.85mm coax
- RF port WR10 (f_c = 59GHz)
- CG (< 10 000 K; including reasonable T_e of possible IF LNA solutions)



		1x LO		2x LO		3 x LO	
Version	f_{LO}	RF LSB	RF USB	RF LSB	RF USB	RF LSB	RF USB
~~Subharmonic low side~~	~~59/2 GHz = 29.5 GHz~~		~~37.5 – 86.5 GHz~~	~~2 – 51 GHz~~	~~67 – 116 GHz~~	~~31.5 – 80.5 GHz~~	~~96.5 – 145.5 GHz~~
Subharmonic high side	124/2 GHz = 62 GHz	5 – 54 GHz	70 – 119 GHz	67 – 116 GHz	132 – 181 GHz	129 – 178 GHz	
~~Fundamental low side~~	~~59 GHz~~	~~2 – 51 GHz~~	~~67 – 116 GHz~~	~~61 – 110 GHz~~	~~126 – 175 GHz~~	~~120 – 169 GHz~~	
Fundamental high side	124 GHz	67 – 116 GHz	132 – 181 GHz				

Decisions of 27-March-2024:
+ the most promising design is the block-conversion of RF bandwidth 67-116 GHz observed in the LSB to IF 8-57 GHz (49 GHz width) using fixed Local Oscillator at 124 GHz.
+ Downconverter includes a fundamental mixer MMIC.
+ IAF has designed MMIC based on 50nm mHEMT technology. Wafers are currently fabricated.

Highlights of 1st year: W-Band downconverter

Work Plan (IAF, MPG, IRAM)

03/2023: Project Start
03/2023 – ~~09/2023~~ 03/2024: Concept Phase (slightly extended, no affect on overall project schedule)
- Evaluation of promising downconverter topologies and technology

03/2024: (Design) Review (in-person meeting)
- Down-selection on mixer

10/2023 – 03/2026: Development Phase
- MMIC final design, fabrication, and test (IAF)
- Packaging (MPIfR, IRAM)
- MS0.1 (IAF): end 08/2024 – test mixer MMICs measured
- MS0.2a (IAF): end 09/2024 – redesign/optimization/streamlining fundamental mixer MMICs
- MS0.2b (IAF): MMIC interface definition ready
- MS0.3 (IAF): end 04/2025 – measurements of “final” MMICs ready
- MS0.4 (MPIfR): end 09/2024 – evaluation LO waveguide transition (WR10 antenna in a WR6.5 waveguide vs. dedicated WR6.5 transition)
- MS0.5 (MPIfR/IRAM): test module fabricated and assembled

04/2026 – 03/2027: Breadboard Down-Converter Evaluation
- Measurement setup configuration
- RF characterization @ RT
- Reporting

General comments reflecting the work of WP2

+ Some of the challenges, but no show-stoppers:
  + Lack of <u>manpower</u> in the field (design, test, fabrication) affects most institutes, in particular also Oxford, GARD, Yebes.
  + Delays due to difficulties with <u>equipment</u>, e.g. breakdown of helium liquefier at Oxford or move to new clean room at Yebes.
+ Growing connectivity between partner institutes and beyond. Examples are
  + RUG establishing collaboration with GARD on SIS junctions in synergy with a dedicated ESO study
  + Oxford is collaborating with wider European Consortium, led by Paris Observatories and RUG, to develop heterodyne instrument for one of the proposed NASA probe mission, FIRSST, including horn array and SIS mixers.
  + HES-SO and IRAM establishing collaboration and links on tunable filters and NOEMA water vapour monitors
+ A lot of activity, progress, training, dissemination. During 1st year, some focus on design and simulations, preparing test setups.