Work package number [9]	WP5	Lead beneficiary [10]	3 - IRAM
Work package title	AETHRA		
Start month	1	End month	36

Objectives

AETHRA (Advanced European Technologies for Heterodyne Receivers for Astronomy) aims at exploiting new technologies, such as highly integrated microelectronic semi- or superconducting circuits, to significantly improve the next generation receivers of mm and sub-mm wavelength telescopes, reinforcing European technological and scientific leadership by considerably improving the receiver performance and observing speed of the European-owned world-leading facilities ALMA, APEX, NOEMA and PV. The most effective means to boost the observing speed of those instruments at a reasonable cost consist of:

a) widening the Intermediate/Radio frequency (IR/FR) receiver bandwidths and
b) implementing large focal plane arrays (FPAs) of heterodyne receivers.

Both paths should be followed without degrading and as much as possible even improving the receiver. Precursor-developments have started via the JRA AETHER and have clearly demonstrated the potential available for facility upgrades. AETHER developed a range of high performance components for mm/sub-mm heterodyne receivers, mostly mixers and amplifiers. The receiver modules were fit to be assembled together in FPAs. However, their architecture of lumped mechanical elements meant poor homogeneity, reduced performance and high fabrication costs. Moreover, their footprint area (typically few cm^2 at 1 mm) limited the number of potential sky pixels to a few tens. Only a novel architecture, implying micro-devices, as much as possible integrated on planar substrates and fabricated in large quantities per foundry run, will open the way to spectral line imaging arrays with hundreds of sky-pixels. This will only be possible through a core understanding of the complete receiver system, in particular device physics, and through the application of industrial-type methods. AETHRA will make decisive steps along aforementioned paths and develop complete receiver prototypes, from RF antenna to IF signal digitization, that will provide ultra-high sensitivities across the entire mm/sub-mm wavelength spectrum readily observable from the ground, i.e. 70 GHz to 1 THz.

- The receivers will be physically compact enough to be integrated into large FPAs.
- Reduced size array demonstrators will be built and tested on the sky using e.g. the IRAM 30m and APEX telescopes.

The four-octave RF band under consideration makes it necessary to choose, depending on wavelength, different technological solutions for detectors, Local Oscillator (LO) and optics. Solutions for the most critical of those components, the detectors, are: hybrid or monolithic microwave integrated circuit (MMIC) low-noise cryogenic amplifiers (down to 3 mm), highly integrated 2SB or balanced SIS mixers (around 1 mm), and Silicon Integrated Systems (SIS) and Hot Electron Bolometer (HEB) mixers around 1 THz.

Description of work and role of partners

WP5 - AETHRA [Months: 1-36]
IRAM, MPG, INAF, OSO, STFC, SRON, OBSPARIS, UOXF, UAH, ESO, Fraunhofer, RUG, UCO, TUD
WP5.1: Semiconductor LNAs and MMIC receivers [MPG, IRAM, INAF, Fraunhofer]

5.1.1 Investigate the new 35 nm gate length mHEMT technology available at IAF to improve noise performance of cryogenic MMIC LNAs at W-band (72-116 GHz) – Previous cryogenic GaAs mHEMT MMIC Low-Noise-Amplifiers (LNA) developments at W-band have relied on the well-established 100 nm and 50 nm gate length processes. Theory and experimental results on InP HEMT-based LNAs indicate the benefit of exploiting 35 nm mHEMT devices to obtain superior noise performance. Utilizing the latest transistor models, a 35-nm MMIC LNA for the W-band will be designed and fabricated at IAF.

5.1.2 Develop and build a W-band MMIC array demonstrator – Cryogenic part of the demonstrator will include a corrugated horn, an OMT and 2 W-band MMIC LNAs per pixel. A down conversion module will be designed which integrates full down conversion from RF to 4-12 GHz IF: a post-LNA at RF, a mixer, a LO-multiplier and an IF-LNA, possibly all on a single IAF GaAs MMIC. The module will be developed by MPG and IRAM. IRAM will make the receiver system design and assemble several of the cryogenic pixel modules into a test cryostat, which will allow for a demonstration of a small W-band FPA at the telescope. As a compact and cost-effective alternative to the waveguide OMT based on the existing turnstile approach, a planar version of the OMT will be tested possibly integrating OMT and LNAs in a single mechanical block with small footprint.

WP5.2: Very large Focal Plan Array of SIS mixer receivers [IRAM, OSO, UOXF, UAH]

5.2.1 Increase RF/IF bandwidths of SIS mixer receivers – Work on solutions, and develop prototypes, to allow broadening RF band of 2SB SIS mixers beyond single-mode waveguide band: this includes OMT, substrate-to-waveguide transitions, RF 3dB wideband hybrids and power division circuits. The work will result in a prototype 2SB SIS mixer operating close to APEX Band 2. The mixer will be tested on APEX and used as part of the APEX SEPIA receiver and, possibly, on the LLAMA antenna.

5.2.2 Develop and build a 1mm FPA receiver demonstrator using highly integrated 2SB SIS mixer with large IF/RF bands – Development of miniaturized single-chip 2SB SIS mixers, as much as possible integrated with RF/IF hybrids and first stage amplifiers, will be made by IRAM and UAH. The chip design and fabrication process will target top performance, reasonable cost and good reproducibility. Novel solutions for the optics, LO injection and IF transport (e.g. minimalizing the use of coaxial cables) will be explored. Full receiver modules will be fabricated and integrated into an FPA demonstrator that will be tested on the sky on the IRAM 30-m telescope. The possibility to build FPAs for use on the NOEMA antenna will be explored.

WP5.3: FPA of receivers operating around 1 THz [UOXF, SRON, OBSPARIS, RUG, UAH, UCO, TUD]

5.3.1 Development of SIS mixers for 1 THz receivers – In this task we will develop SIS tunnel junctions with a superconducting gap high enough to give good mixer noise temperature in a frequency range 780-950 GHz, which is suitable for ALMA band 10. The consortium will aim to improve on existing mixer performances by employing high gap superconductors such as NbN and AlN barrier. Mixer chips will then be fabricated using recent technologies such as SOI and beam-lead technology. Single pixel mixer tests will be performed to verify and compare the performances.

5.3.2 Development of highly integrated 2SB balanced SIS mixer array at around 1 THz – An up to 7-pixels receiver array module will be designed, fabricated and tested with a foot-print that can easily be integrated into telescope receivers. It will use highly integrated side-band separation mixers operating in the ALMA Band 10 frequency range. A smooth-walled horn array will be used to feed the mixers with integrated circular-to-rectangular transitions. Cryogenic amplifiers will be integrated to the mixer array as much as possible to reduce the IF noise contribution. We will also use efficient LO power injection in order to reduce the RF power required to pump the mixer array.

5.3.3 Explore new paths for enlarging the IF bandwidth of HEB devices – While HEB mixers have shown excellent noise performance, their IF bandwidth has been limited to ~3.5 GHz. Increasing the IF bandwidth has become the outstanding issue in the HEB community, and is also known to be extremely challenging. In this subtask, new paths will be explored to double this bandwidth, while maintaining the lowest possible noise. One way is to make use the existing NbN thin film technology, but by introducing additional phonon cooling channels around the HEB.

5.3.4 Develop and build a HEB mixer FPA demonstrator – NbN HEB mixers have great advantages of low LO power requirement, no magnetic fields, and no upper frequency limit. Therefore they are good candidates for a large array around 1 THz. We propose to build a HEB demonstrator array with a quasi-optical coupling scheme. We are going to explore an optical method to split a single LO for multi-pixels using a phase grating. In this task we will build a small array to prove the principle that could later be upscaled to larger arrays. The Observatory of Paris will develop, build and test the FPA demonstrator at LERMA. SRON and TUD will develop the final test setup, including preparing a cryostat with a large window, and will also be a backup supplier for the HEB devices.

WP5.4: Subtasks common to Tasks 5.1-5.3 [IRAM, OSO, STFC, OBSPARIS, UOXF, UAH, RUG, UCO, TUD]

5.4.1 Develop and build LO chains able to drive mixer arrays – Develop new local oscillator generation schemes involving frequency harmonic up-conversion of baseband frequencies. Particular focus will be placed upon Schottky multiplier diode high power and high frequency operation enhancement, device integration, and structural compactness. Additionally, the impact of the LO concept on 4K cooling requirements will be considered and device topology will be developed to mitigate adverse effects.

5.4.2 Develop and build large-bandwidth cryogenic IF amplifiers – Work on increasing the bandwidth of cryogenic IF amplifiers, using MMIC or discrete HEMT design, and employing balanced layout. Work towards a prototype covering up to 16 GHz.

5.4.3 Establish networking on fabrication of superconducting circuits and micromachining facilities – Share information on the technologies available in the AETHRA partner institutes, in order to foster through mutual agreement further collaborations, including with external SMEs. A data basis consisting in a description of the in-house equipment and technologies will be set up and circulated without commitment to all AETHRA partners. At the end of the JRA, the progress reports and publications dealing with these technologies will be disseminated to interested third parties whenever possible.

IRAM will perform the overall management of the WP5 AETHRA and will be the main contact point for the project management bodies. Additionally, each of the subtasks have appointed leader, who will be responsible for the daily implementation of the task's work plan, the preparation and communication of the deliverables, publications and progress reports to the AETHRA leader, as well as their presentation at the AETHRA meetings. The AETHRA partners will meet twice a year, at least once face-to-face. The progress reports, presentations at the face-to-face meetings, reports on the deliverables and publications will be made accessible at AETHRA wiki pages. The results and publications will be presented in international conferences such as SPIE and ICMTT as well as in specialized journals.

Participation per Partner

Partner number and short name	WP5 effort
1 - MPG	9.00
3 - IRAM	50.00
4 - INAF	4.00
7 - OSO	11.00
8 - STFC	9.00
9 - SRON	7.00
10 - OBSPARIS	16.00
11 - UOXF	15.00
12 - UAH	31.00
13 - ESO	0.01
14 - Fraunhofer	18.00
15 - RUG	15.00
19 - UCO	8.00
26 - TUD	10.00
Total	203.01

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D5.1	SIS junction mixer operating around 1 THz	11 - UOXF	Report	Public	30
D5.2	Low noise, cryogenic 35 nm mHEMT MMIC amplifiers	14 - Fraunhofer	Demonstrator	Confidential, only for members of the consortium (including the Commission Services)	36
D5.3	Multipixel W-band FPA demonstrator composed	3 - IRAM	Demonstrator	Public	36

List of deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
	of cryogenic module and down conversion module				
D5.4	Very wideband RF/IF SIS receiver Design and test report on prototype wideband mixer built on 2SB technology and operating around 1-mm	7 - OSO	Report	Public	36
D5.5	Multipixel FPA demonstrator composed of miniaturized 2SB receivers operating near 1 mm	3 - IRAM	Demonstrator	Public	36
D5.6	Multipixel FPA demonstrator composed of 2SB SIS mixer receivers operating around 1 THz	15 - RUG	Demonstrator	Public	36
D5.7	Multipixel demonstrator of FPA of HEB mixer receivers	10 - OBSPARIS	Demonstrator	Public	36

Description of deliverables

A mixer operating around 1 THz and equipped with SIS tunnel junctions with high gap material will be developped, built and tested.
A W-band mHEMT MMIC low noise amplifier demonstrator with a 35-nm gate length operating at cryogenic temperature will be developed, built and tested.
A dual-polarization W-band focal plane array receiver, consisting of cryogenically cooled MMIC LNAs, integrated with horns and OMTs in a cryostat, and of down conversion modules, will be built and tested on a telescope.
A prototype 2SB SIS junction mixer operating around 1-mm and with very wide IF band built and tested on a telescope. Design report of an RF wideband 2SB mixer, if possible exceeding a single-mode waveguide band.
A focal plane array receiver demonstrator, operating near 1 mm wavelength, with several tightly packed sky pixels and composed of wide-band, low-noise 2SB SIS junction receiver modules will be developed, built and tested.
A focal plane array receiver demonstrator, operating near 1 THz, with up to 7 sky pixels and composed of 2SB SIS junction receiver modules will be developed, built and tested.
A small focal plane array receiver demonstrator, operating around and above 1 THz, composed of HEB receiver modules will be developed, built and tested.

D5.1 : SIS junction mixer operating around 1 THz [30]

SIS junction mixer operating around 1 THz

D5.2 : Low noise, cryogenic 35 nm mHEMT MMIC amplifiers [36]

Low noise, cryogenic 35 nm mHEMT MMIC amplifiers

D5.3 : Multipixel W-band FPA demonstrator composed of cryogenic module and down conversion module [36]

Multipixel W-band FPA demonstrator composed of cryogenic module and down conversion module

D5.4 : Very wideband RF/IF SIS receiver Design and test report on prototype wideband mixer built on 2SB technology and operating around 1-mm [36]

Very wideband RF/IF SIS receiver Design and test report on prototype wideband mixer built on 2SB technology and operating around 1-mm

D5.5 : Multipixel FPA demonstrator composed of miniaturized 2SB receivers operating near 1 mm [36]
Multipixel FPA demonstrator composed of miniaturized 2SB receivers operating near 1 mm

D5.6 : Multipixel FPA demonstrator composed of 2SB SIS mixer receivers operating around 1 THz [36]
Multipixel FPA demonstrator composed of 2SB SIS mixer receivers operating around 1 THz

D5.7 : Multipixel demonstrator of FPA of HEB mixer receivers [36]
Multipixel demonstrator of FPA of HEB mixer receivers

Schedule of relevant Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS24	Low-noise cryogenic MMIC amplifiers operating in W-band	14 - Fraunhofer	29	Test report
MS25	W-band down-conversion module based on a semiconductor MMIC	1 - MPG	32	Test report
MS26	Multipixel demonstrator of FPA of MMIC receivers	3 - IRAM	36	Report on test on telescope
MS27	Single-chip 2SB SIS mixer operating around 1 mm wavelength	3 - IRAM	29	Test report
MS28	Multipixel demonstrator of FPA of miniaturized 2SB SIS mixer receivers operating around 1 mm	3 - IRAM	36	Report on test on telescope
MS29	Fabrication of SIS junction with very high current density for operation around 1 THz	11 - UOXF	29	Test report.
MS30	Demonstrator of FPA of 2SB SIS mixer receivers operating around 1 THz	15 - RUG	36	Test report
MS31	Multipixel demonstrator of FPA of HEB SIS mixer receivers operating around 1 THz	10 - OBSPARIS	36	Operating
MS32	LO chain with high output power around 1 THz	8 - STFC	30	Operating