2/1998

1 Capabilities in mm- and submm-wave receiver technology

This document describes the technological capabilities of the member institutes of the LSA Receiver Working Group, compiled from input of these members. The list is not (yet) exhaustive.

MRAO Cambridge
MRAO has many years of experience developing and building low-noise submillimetre-wave instrumentation. Current emphasis includes SIS mixer modelling, including device physics and the electromagnetic behaviour of superconducting planar RF circuits. Mixer-block design and manufacture, including high-performance submillimetre-wave horn-reflector antennas. Submillimetre-wave optical design including aberrations in off-axis optics.

IRAM
1 -Fabrication of Superconductive Devices and Circuits

The IRAM Superconductor Device Laboratory routinely fabricates high quality SIS junctions with integrated tuning circuits in Nb technology for the IRAM telescopes and a large number of external users. The junction surfaces can be as small as 0.5 square micrometers and the current densities can be as high as $15kA/cm^2$ for high quality IV characteristics. The frequency range covered with this devices is 80 to 900 GHz. IRAM has also experience in producing high quality stacked Nb junctions.

Aside from Nb SIS junctions the lab has successfully produced devices in various other technologies: Submicron high current density NbN junctions with Nb or Al tuning structures, Large surface Nb photoncounters, submicron NbN phonon, cooled bolometric mixer elements.

Current and near-future development efforts will include: establishing a new high yield and high reproducability standard process for production of high quality Nb submicron junctions and integrated circuits. Development of new process and film characterization standards. Development of passive planar lumped elements and transmission lines for mm/submm MMIC's. Incorporation of micromechanical technologies for new integrated mm/submm device types with improved electrical properties and high reliability.

2 - Mixer development and fabrication.

IRAM has developed, for the equipment of its telescopes, receivers at frequencies up to 370GHz, with receiver noise as low as $3h\nu/k$ SSB. Ongoing development focuses on achieving wideband (typ. a waveguide band), low noise, stability, reliability, ease of tuning, and relaxing the demands on mechanical fabrication (full-height waveguide).

Possible developments for the LSA project could be : - exploring SSB mixers with inherently reliable mechanical tuning. - integrating first stage(s) of IF amplifier for wider IF bw; - exploring quadrature mixers; Such developments need additional manpower.

3 - Characterization of mm-wave devices and materials.

IRAM has developed for its own needs a mm-wave VNA, allowing S-parameter measurements up to 370GHz (fully calibrated up to 270GHz) , with a dynamic range between 20 and 50dB (depending on frequency). This equipment has proven very valuable for testing prototype and production components (couplers, horns) before integration into systems. Quasi-optical components (windows, quarter-wave plates) can also be cheracterized. Measurement of components could be offered to other groups during the development/prototyping phase; testing of series production components would require to duplicate the equipment on the basis of the acquired experience. A confocal cavity under development will allow accurate measurements of the real and imaginary part of dielectrics.

4 - Fully electronic LO's

As a first step, IRAM has started a design study for a fully electronic LO system for the 85-115GHz band, based on YIG oscillator, active and passive multipliers. This development could be extended to higher frequency bands, building upon the experience with multipliers and ongoing developments around planar varactors.

5 - Antenna range.

IRAM operates an anechoic chamber that permits the measurement of the amplitude and phase of radiation patterns of optical components and subsystems in either angular or X-Y scanning modes. This equipment currently operates up to 270GHz, but could be upgraded to higher frequencies with suitable harmonic generators and downconverters.

6 - Water vapour radiometer.

IRAM has started the design of a 22GHz radiometer system for the PdB interferometer. Although the 183GHz water line may be a better choice for the LSA/MMA site, the experience gained in the design and operation of a 22GHz radiometer will certainly be useful for the LSA.

7 - Cryogenics.

The LSA project might benefit from the experience IRAM has accumulated with various types of cryostats : wet, hybrid, and closed-cycle JT (no 4K GM, however).

Onsala Space Observatory

Onsala has long time experience in SIS mixer design including submm and array applications. We are acquiring new dedicated sputter machine for Nb/NbN tri-layer processing which is due to installation early Autumn 1998. We have extensive experience in satellite integration. The Swedish satellite ODIN radiometer platform is being assembled at at Chalmers University. For this satellite we have developed grid technology up to 1 THz (insertion loss of the grid less than 2%). For SRON we have made some further developments for a grid up to 1.8 THz. Also, all mirrors and lenses for ODIN optics were designed and fabricated at Chalmers (118, 570 GHz).

We have experience in 3-D Gaussian beam optics tracing and quasioptical design. We are going to build a new facility for near-field Gaussian optics testing for 400-1100 GHz frequency band dedicated for final testing and integration of the mixer assemblies for HIFI FIRST including cryogenic stand, subject to funding of our participation in FIRST by the Swedish Space Board.

Equipment at Onsala includes various microwave measurement equipment for DC-20 GHz band including HP scalar 4-channel network analyzers and synthesized sources; 40 GHz, 85-119 GHz BWO sweep generator, tunable Gunn oscillators for 3 mm wavelength; Waveguide and quasioptical components for mm-wave measurements (attenuators, wave-length meters, etc.); Cryo-amplifier measuring setup based on close cycle 15 K machine with precision temperature variable load; home-developed software for data acquisition and radiometer study and measurements; precision 3D scalar beam measurement computerized system (used for ODIN); Access to vector network analyzer equipment within DC-115 GHz band; Access to HP MDS and Compact microwave design software; Access to PCB/microwave board fabrication Precision mechanical equipment with highly qualified personnel.

Arcetri Observatory

Different institutions, together with Arcetri Observatory, are working in Italy on the design and construction of receivers and components for millimetre and submillimetre bands. On behalf of these institutions, namely IRA-CNR of Bologna, and Radio Group at Physics Dept-University of Milano, we describe the available technological capabilities in the field.

- Arcetri Observatory, also in collaboration with Electronic Engineering Faculties of Firenze and Pisa Universities, has a large experience in designing and construction of wide-band corrugated feed horns and microwave components such as polarizers and orthomode transducers for frequencies up to 50 GHz. All horns for the Medicina radiotelescope receivers have been designed and built in Firenze.

We are involved in the design of the new 64 meter antenna (and receivers) for the band 2 - 90 GHz to be built in the next years in Sardinia. The task of our institution will be the analysis of the optical coupling, using also quasioptical methods, of millimetric receivers to the antenna.

The Milano group has experience in assembling and using absolute radiometers up to 33 GHz, is currently preparing an experiment for measurements of the CBR polarization up to 90 GHz and, in collaboration with CAISMI in Arcetri, IEN in Torino and Electronic Dept. of the Polytechnics in Torino and Milano, is developing SIS junctions and SIS based mixers for frequencies up to 350 GHz.
A 2.5x2x2.5 meter anechoic chamber is available in Firenze for horn testing.
Industries: SILO, a small firm (SILO) here in Florence, working in optics that could produce large quantity of high quality glass or metallic mirrors at reasonable cost.
CSELT, design and construction of high quality microwave components.
MEDIALARIO, design and construction of high precision mechanical and optical components (mechanics for LBT and optics for XMM).

SRON Groningen, Space Research Organization Netherlands
The research group Physics of Thin Films at the Materials Science Center, Applied Physics Laboratory of the University of Groningen (RuG) and the Low Energy Astrophysics (LEA) division of the Space Research Organisation (SRON) are collaborating on research and development of sensitive mixers and receivers for (sub-)millimeter waves using superconducting technology. The core of these mixers is the superconductor-insulator-superconductor junction. The SIS junctions are made at the RuG, the SIS mixers are made at SRON.

Both institutes have been pioneers in this field, and, thanks to a well coordinated and integrated approach, both are respected world-wide. SIS-products from RuG/SRON are used at institute and research groups all over the world, including the JCMT. SRON is the leader/principle investigator on a big proposal to ESA to build the heterodyne spectroscopy instrument for the FIRST satellite, which involves collaboration between 12 nations, including the US. Thus, close contacts between the various receiver groups in Europe and the US already exist.

Centro Astronomico de Yebes
The Yebes Observatory can make contributions in the development and fabrication of HEMT amplifiers. During the last 10 years there has been uninterrupted activity in the design and fabrication of amplifiers to be used as IF stages of mm-wave radio-astronomy receivers equipped with Schottky or SIS mixers. The institute has built amplifiers from 0.9 GHz to 8.8 GHz with stae-of-the-art performance. The Observatory is now actively involved in the

development of a prototype X-band amplifier for project FIRST. During 1998 third party InP devices will be tested. Plans for the next 5 years include the design and fabrication of mm-wave amplifiers at frequencies around 22 GHz, 45 GHz and 100 GHz.

Rutherford Appleton Laboratories (RAL)

The Rutherford Laboratory has vast expertise and heritage in the development of heterodyne components (e.g. semi- or superconducting mixers, LO sources) and complete receiver systems for ground, air and spaceborne use.

Typical frequency range covered is 100 GHz to 2.5 THz Mixers and multipliers use waveguide technology. Systems have been used in atmospheric and astronomical remote sounding experiments. Available facilities and expertise include:

Precision machining of mm and sub-millimetre waveguide cavities. Novel device fabrication techniques e.g., planar whiskers, micro-machining.

Excellent mm/submm wavelength circuit design expertise applicable to SIS and Schottky mixer and frequency multiplier technology.

Substantial quasi-optical design, construction and test expertise.

Substantial system integration and test expertise.

State-of-the-art performance (devices and systems). Space qualified structures.

Current Programme of Work

Support SIS receiver development work at the James Clerk Maxwell Telescope - 800 - 900 GHz receiver (Rx E) currently under construction.

Development of 820 GHz SIS Rx for the TIRGO telescope.

Development of SIS and Schottky mixers and receivers for atmospheric remote sensing instruments.

Instrument studies and development for ESA and the EU.

Variety of contracts with UK, European world-wide institutes and industry For example:

Development of spaceborne mixers for Matra Marconi Space Systems, UK, Manufacture of feedhorns (to 700 GHz) for the Smithsonian Astrophysical Observatory. Design, manufacture and test of multiplier sources for the Smithsonian Astrophysical Observatory. Manufacture of large scale free-standing wire grids for IRAM. Design, manufacture and test of 2.5 THz Schottky mixers for ESA and JPL. Design and manufacture of receiver cryogenics systems e.g., for TIRGO and EU. Manufacture of SIS mixer block for ASIAA, Taiwan. Upgrade of MARSS aircraft radiometer for the UK Met. Office.

KOSMA, I. Physikalisches Institut der Universität zu Köln

KOSMA is the Kölner Observatorium fuer SubMillimeter-Astronomie operating a 3m diameter submillimeter telescope on Gornergrat, Zermatt, Switzerland. The telescope allows observations up to 900GHz, taking advantage of the excellent atmospheric conditions of Gornergrat (3100m elevation) during the winter months. All instrumentation for the telescope, including acousto-optical spectrometers as backends, has been built in house. SIS receivers for the 230, 345, 490, 660, and 820 GHz atmospheric windows are in operation at the telescope. Since 1990, KOSMA has a facility to fabricate Niobium-based SIS-junctions. KOSMA has played a pioneering role in extending the SIS technology to the submillimeter range, developing novel integrated tuning circuits as well as broadband fixed-tuned waveguide mixers. The lab is now also working on the design and fabrication of superconducting hot-electron bolometers for Terahertz frequencies.

For all receivers, the waveguide mixers, SIS junctions and HEMT amplifiers were developed and manufactured at KOSMA. A closed cycle 4K J-T cooler was developed and built at KOSMA and is in routine operation at the telescope. There is also experience with commercial 4K GM coolers.

Current projects of the KOSMA group are a dual frequency array receiver for the 490 and 800 GHz bands, a 1.4-1.9 THz receiver system for SOFIA (in collaboration with MPIfR Bonn) using diffusion cooled superconducting hot electron bolometers, and the development of a mixer from 640-800 GHz for the ESA satellite FIRST. We collaborate with MRAO, Cambridge, in developing a series of finline mixers operating in the 230 and 345 GHz bands. These mixers have prospects to be scalable to submillimeter wavelengths and are very well suited to be extended to integrated single-sideband and/or balanced mixers.

Max-Planck-Institut für Radioastronomie (MPIfR)

The Max-Planck-Institut für Radioastronomie (MPIfR) in Bonn, Germany, has long-lasting experience in the design and development of new telescope facilities based on novel technologies. Since 1977, the institute operates the world's largest fully-movable radio telescope near Effelsberg. The institute initiated and supervised the construction of the 30m mm-telescope on Pico Veleta (since 1985 operated by IRAM). In a joint collaboration with Steward Observatory, University of Arizona, construction of a 10m submm-telescope on Mt. Graham, the Heinrich-Hertz-Telescope (HHT), has been completed recently.

The MPIfR operates well-equipped laboratories in support of its scientific missions. A mechanical workshop, capable of high precision mechanics, is available. The MPIfR Submillimeter Technology Division includes ~25 scientists, engineers, and technicians. Next to providing the HHT with submm heterodyne and bolometer detectors and AOS backends, the group's activity has focused on the development of large detector arrays – both for continuum (e.g., a 37-element bolometer array, working at 1.3mm wavelength at the IRAM 30m-telescope) and for heterodyne work. Later this year, first light is expected for a unique 16-element SIS heterodyne-array to better exploit the 625 μm atmospheric window. The instrument comes with a new flexible autocorrelator, built in the MPIfR Digital Electronics Laboratory, offering up to 2 GHz of bandwidth for each of the 16 pixels. In addition, waveguide and quasi-optical SIS receivers for operation in all ground-based atmospheric windows up to 800–900 GHz are built in the division. Recently, a project group has been established for the development of a dedicated 2.6 THz 2×2 pixel receiver for SOFIA (in collaboration with KOSMA, Köln), based on NbN HEB mixers (with IRAM).

Other technical groups within the MPIfR are developing state-of-the-art, low-noise HFET amplifiers covering the whole radio frequency range up to the 3-mm band and advanced digital correlator technology.

In summary, the MPIfR has a wide range of technological capabilities that are of interest for the LSA project. In addition, the institute's scientific support for the project is extremely strong. Therefore, there is great motivation to participate in LSA technical developments, but it seems premature to discuss details of this involvement now.

Hertzberg Institute for Astrophysics, Canada

We design and build complete SIS receivers at 200 und 300 GHz for the JCMT. The SIS devices currently come from U Va and SRON, Groningen but we can also make them in Canada ath the AMC. We design the SIS device tuning structures and draw up the multilevel masks. We do all the mixer machining in house using a super-precision CNC mill and CNC lathes. We design and build all the off-axis mirrors, interferometers and other optical components. We have software design tools such as Touchstone and Microsim. We have a a well equipped lab and clean room. We have various solid state LO sources including one at 700 GHz. In addition we have a group supporting a centimetre wavelength aperture synthesis telescope who have a great deal of experience in correlator design and all aspects of interferometry.

ETH Zurich

At the Laboratory for Electromagnetic Fields and Microwave Electronics we are working since about 4 years on the development of integrated mm-wave

(MMIC) circuits based on Indium Phosphide High Electron Mobility Transistors (InP-HEMT).

2 1999 Development Plans

This section describes proposals to spend possibly available development money in 1999 with the goal of developing a practical European design concept for the LSA receivers. The issues to be addressed are a pre-development of SIS mixers to find out feasible ways of achieving the LSA goals, HEMT amplifier development and a development study for the front-end optics. It would be highly desirable to address the local oscillator questions in this study as well. It is not yet clear which of the members could do work in that area. The study could possibly be outsourced to industry. Below, some of the institutes involved explain their possible area of interest in the study. It should be made clear that some of the institutions cannot yet make a firm commitment towards participation in a 1999 predevelopment programme.

MRAO
As part of a development effort, MRAO would like to be involved in the electromagnetic design of mixers and mixer testing. The finline mixers would be a good candidate for sideband-separating mixers; although the radial probes have advantages too. Our split-block horn technology is interesting, and the automation of block manufacture should receive some attention. MRAO would also be interested in looking at the design of easy-to-manufacture, high-efficiency optics for small multifrequency arrays. MRAO could make a particularly good contribution to a development study in the area of front-end optics.

SRON, Groningen
We propose to use development funds to set up an additional group at SRON/RuG to carry out design and development of the SIS mixers for the LSA/MMA at the higher frequencies, i.e., > 345 GHz. Specifically, they need to be tunerless, and integrated circuit mixers must be developed to achieve the necessary frequency coverage (>30 percent bandwidth) and a large IF bandwidth (> 4 GHz). A close interaction between device people and receiver designers is needed. Some aspects of this research (in particular, tunerless and the broad IF bandwidth) will also be of benefit to the parallel design and development of receivers for FIRST at SRON/RuG.

KOSMA
We would like to work on the design of integrated single-sideband mixers. We would strongly be interested in collaborating further with MRAO to extend the work on finline mixers in that direction. As in the current collaboration with MRAO, KOSMA would take responsibility fabrication of the devices, but also would like to be involved in the design work and could especially make contributions toward integrating a first HEMT amplifier stage for 8-12GHz.

Yebes, Spain
The Centro Astronomico de Yebes is interested in participating in the development of HEMT amplifiers for the LSA, both at the RF and IF levels. In view of the current status of the definition of the receivers for the project and of the availability of instrumentation at Yebes, the development of a prototype amplifier in the 30-48 GHz band seems a very reasonable and feasible action for the year 1999. Yebes proposes to carry out this task.

OSO, Sweden
Our ambition for 1999 is to have a Postdoc/Engineer position funded and 100 percent working to the Project.

Arcetri Observatory
For the development of SIS mixer for frequencies up to 350 GHz, we already have a post-doc full time fellowship, but additional funds would be needed for our interest in the development of quasioptical techniques for analysis of optical coupling of receivers to the telescope.

For all proposed studies, the institutes would need funds for manpower of the order of a postdoc position including some overhead for travel and an amount for materials and equipment. There cannot be a decision yet how to distribute the funds among the interested groups and some discussion is still needed as there are overlapping interests.

Funding of the studies would have to be as following:
Postdoc position: DM 100.000
Overhead DM 20.000
Materials, equipment DM 80.000
Total per study area: DM 200.000

We would foresee studies in the above mentioned four areas which would amount to a total of DM 800.000.