Integrated submillimeter system

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ABSTRACT

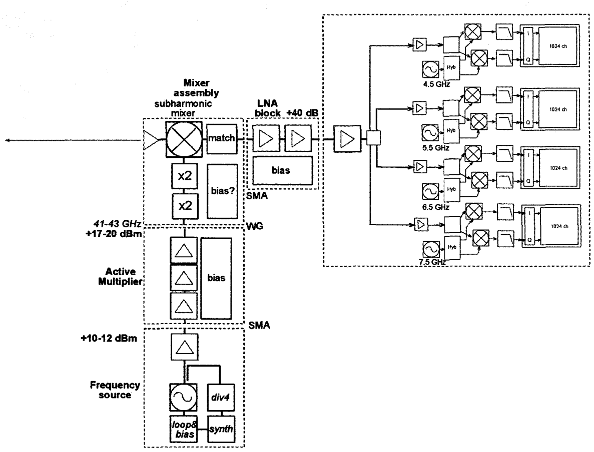
Traditionally, many radiometer systems have been designed and developed in collaboration between several groups, often residing in different countries. The reasons are obvious, but there are disadvantages, the major one is perhaps to achieve a high level of system integration and optimization.

Omnisys has started a project, funded by the Swedish National Space Board, with the goal to demonstrate the performance of a complete sub-millimeter radiometer, designed as an integrated instrument. It will be demonstrated in lab environment, but capable of operation in balloon, or low cost satellite environment. The radiometer will cover 320-360 GHz and incorporate high resolution as well as broadband spectroscopy capability. This scientific requirement specification is very similar to Mambo (radiometer for Mars), VEMEX (radiometer for Venus) and STEAM (multibeam radiometer for aeronomy).

To our knowledge, the ODIN payload is the only frequency agile submillimeter radiometer in space, but this system will show much improved bandwidth coverage, while providing state of the art performance (for non cryogenic systems). The spectrometer will be able to cover both the Herschel/HIFI high resolution and wide bandwidth specifications, with a power budget of less than 10 W and mass of 600 grams.

SYSTEM

The radiometer consists of three sections; the front-end block, the local oscillator subsystem and the spectrometer back-end. The front-end is based on a VDI mixer block and passive doublers, together with a LNA (Gain 50 dB and NF 2 dB). The local oscillator chain is based on a synthesized YIG source, followed by active multipliers and amplifiers. The spectrometer back-end consists of four spectrometer blocks, covering a bandwidth of 4 GHz with 4096 channels.



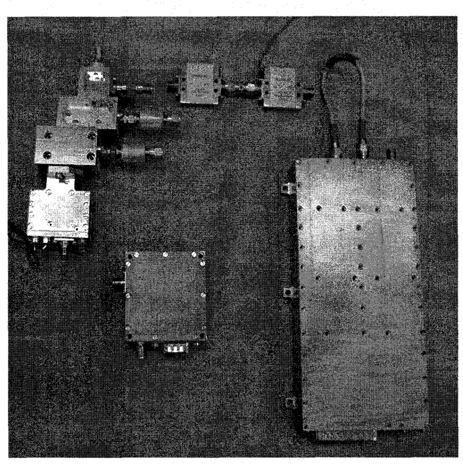
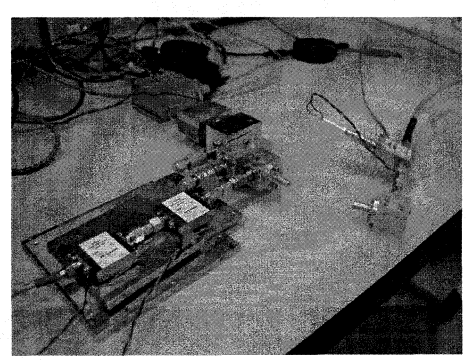


Fig 1a an 1b. The radiometer block diagram on the left, with physical blocks on the right.

Function and performance:

Input frequency:	300-380 GHz
T_{sys}:	2000 K
IF bandwidth:	2-18 GHz
Processed bandwidth:	4 GHz
Resolution:	1 MHz - 10 MHz
#channels:	4096
Mass:	1.2 kg
Power consumption:	5-13 W



ACTIVE MULTIPLIER

The active multiplier block is based on one multiplier MMIC and one power amplifier, covering the frequency band of 33-45 GHz. The integrated bias supply allows for simple system integration, as well as providing local protection as filtering functions.

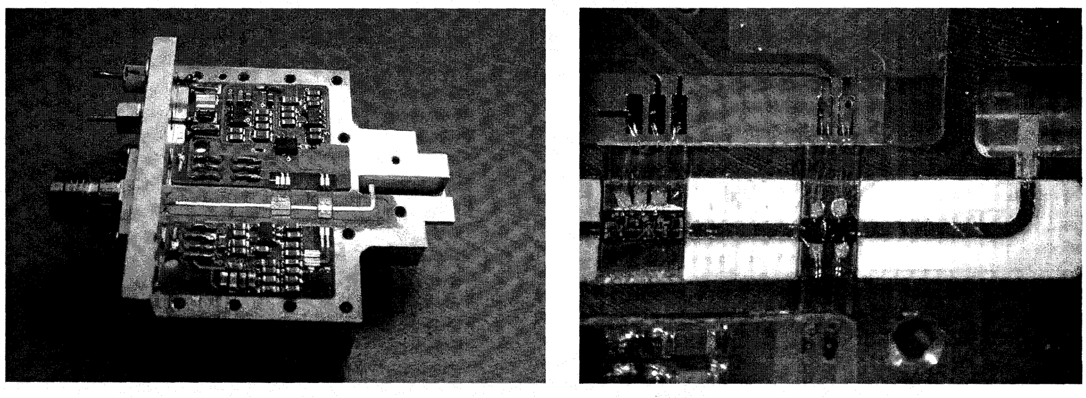


Fig 2a and 2b. Active multiplier block with the cover of to the left, and close up of the MMIC's on the right.

Input frequency:	8-11 GHz tested
Output frequency:	32-44 GHz tested
Output power level:	22 dBm (max)
Power supply:	1600 mW
Mechanical:	40x38x18 mm

FREQUENCY SOURCE

The frequency synthesizer/source design can be configured for output frequencies between 2-16 GHz, with resolutions of 0.1-1 MHz, and is based on a phase locked custom YIG oscillator. The IntRad configuration covers 10-11 GHz with 1 MHz resolution.

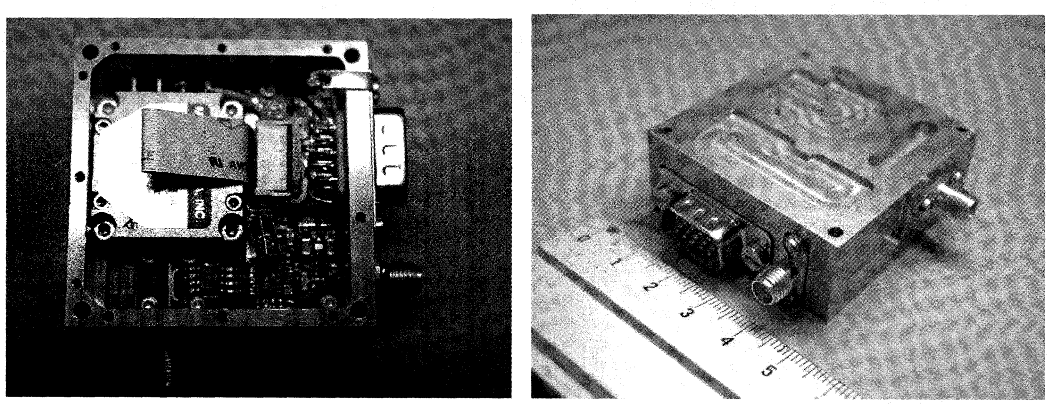


Fig 3a and 3b. The frequency source.

Output frequency:	2-16 GHz (10-11 GHz tested)
Output power level:	10 dBm
Power supply:	800 mW
Mechanical:	49x48x21 mm
Mass:	116 gram
Phase noise:	-113 dBc/Hz @ 100 kHz

SPECTROMETER

The spectrometers have been through a tremendous development over the last decade. The correlator chip set power consumption has been reduced by a factor of 3600 in one decade by Omnisys, and it is a factor of 25 better than current US and French designs. On system level, the bandwidth per chip set has been increased with a factor of 100. However, the spectrometer does not only rely on the correlator core, the complete spectrometer must be designed and developed to fulfill the end user requirements, and the complete spectrometer must be optimized together.

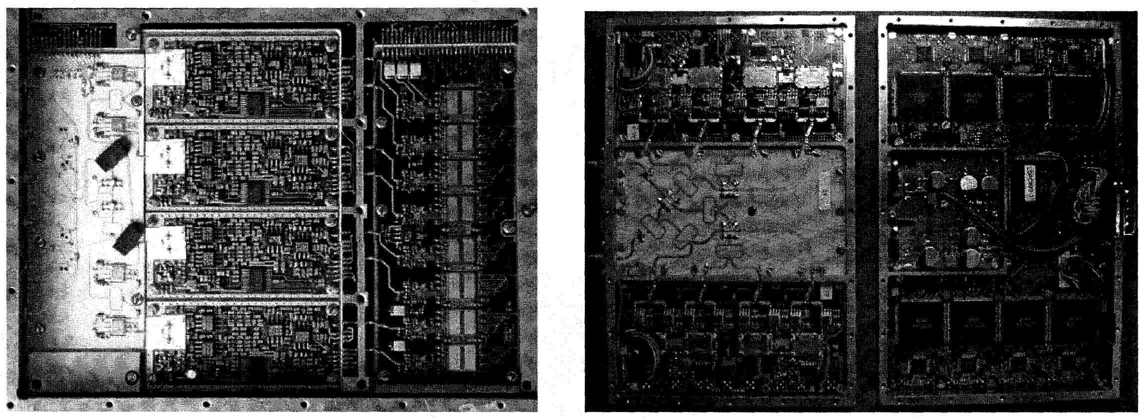


Fig 3a and 3b. The ODIN spectrometer on the left and the TELIS spectrometer to the right.

	ODIN (SATELLITE):	**TELIS (BALLOON)**	**IntRad (demo):**
Bandwidth:	100-800 MHz	2x 2 GHz	0.1-6 GHz
resolution:	0.13-1.1 MHz	2 MHz	0.01-1 MHz
mass:	1050 grams	950 grams	700 grams
size (mm):	220x180x30 mm	170x210x35 mm	152x77x24 mm
power:	18 W	20 W	10.2 W
basic technology	two full custom ASIC's	two full custom ASIC's	two full custom ASIC's
packaging:	Chip on board and parylene	Plastic QFP	MCM
use:	aeronomy & astronomy	aeronomy	demonstration
note	2 in orbit since february 2001	2 will fly in 2005	demonstration

The new spectrometer is based on four spectrometer modules, each covering bandwidths between 10 MHz-1.5 GHz, with center frequencies between 1-12 GHz. For the resolution, each module is software controlled to use between 128-1024 channels. For the IntRad project, the spectrometer covers the 4-8 GHz band. There are several configurations that will reduce the power consumption from the nominal 10 W, even down to less than 5 W.

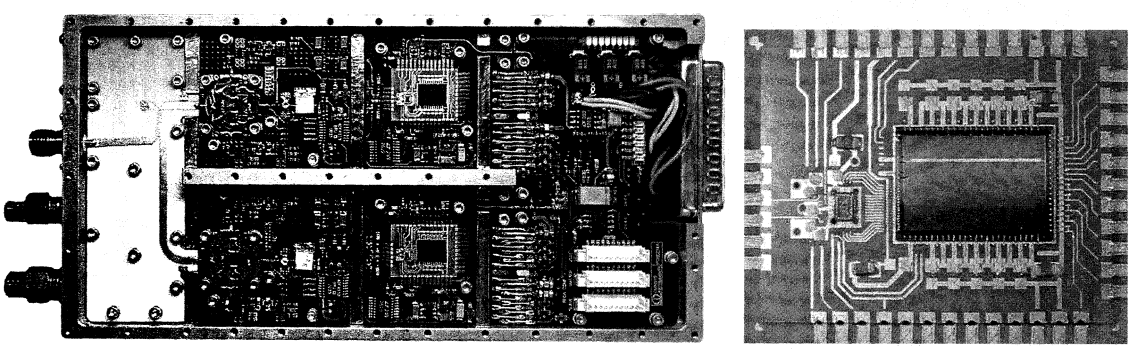


Fig 4. IntRad spectrometer with one lid removed on the left and a close up of the correlator MCM on the right.

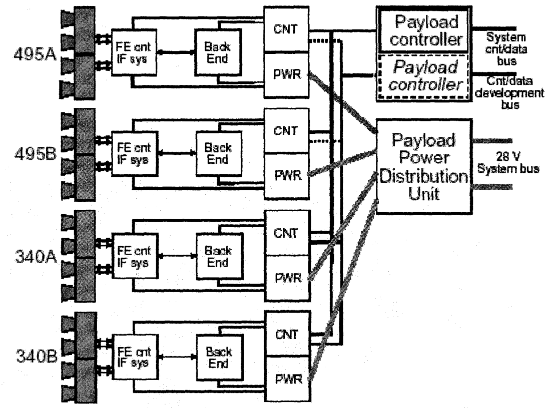
STEAM

STEAM is a concept that is studied by a team from Sweden, France, Canada and the UK. It is a 8-16 beam, 320-360 GHz limb scanning mission with 8 GHz / 512 channel spectrometers for each beam.

For the STEAM project, it is has been found that it is possible to provide a 16 beam receiver system instead of a single receiver, by removing the cryostat and operate in ambient temperature, with improvements in mass, size and power budgets. This further shortens development time as well as system integration efforts by a large factor, and for space projects: **Time = cost.** This makes the 8-16 beam system lower cost than the single beam cryostat system.

Major features

- Multi-beam (simplified optics)
- Developed as an integrated instrument
- 8-16 front-ends at 320-360 GHz, DSB
- 8 front-ends at 490-505 GHz, DSB ?
- 8x8 GHz + 8x4 GHz = 96 GHz of spectrometers
- (HIFI/Herschel = 8 GHz)
- ambient temperature instrument
- 2000 K Tsys
- less than 10 kg, 60-70 W
- on-board, near real-time signal processing (Linux)



INTERSTELLAR PROBE RADIOMETERS

There has been several submillimeter radiometers proposed for interstellar probes, Mambo, Vemex and others. If we look at possible realization for the Mambo (Mars) radiometer, a fully redundant system is shown below. The major lines that will be covered are: CO at 345.796 GHz, 13CO at 330.588 GHz, H2O at 325.153 GHz, HDO at 335.395 GHz, O3 at 326.901 GHz and H2O2 at 326.981 GHz.

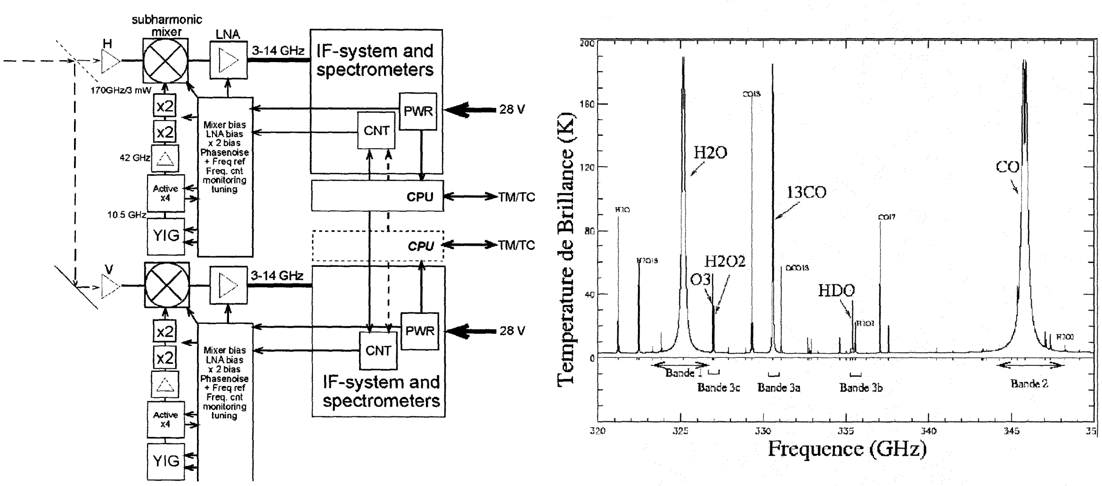


Fig 7. A possible Mambo realization is shown to the left, and the frequency coverage to the right.

DEMONSTRATOR SYSTEM CONSIDERATIONS

The radiometer system requirements enclose several aspects apart from the obvious ones like frequency coverage etc. Other important aspects are performance issues like stability and calibration, with solutions including thermal stabilisation and hot&cold load implementations. Several solutions have been investigated, but the selection will have to wait until the platform and the application have been decided.

The design has targeted on a radiation total dose tolerance of 30 kRAD+ with latch-up free operation. The system allows for graceful degradation, following the ODIN radiometer design philosophy. As for vibration, chock and thermal cycling tolerance, the requirements for the ODIN project has been used as a baseline for the design.

The power and control system for the radiometer is developed in a parallel project at Omnisys. The power system is more advanced than a collection of simple DC/DC converters, including protection mechanism as well as monitoring and control functions. The control system is based on a 32-bit CPU, running Linux, with several design features used to make the design compatible with the space environment. The mass of the power and control systems should be much less than 800 grams, the power system would operate with 75-80% efficiency and the CPU should end up in the 2-4 W class, depending on configuration, type of system interface etc.

The 32-bit CPU with the correct software promise to provide between 10-50 data compression compared with standard compression techniques, i.e. potentially providing an order of magnitude science output improvement, if the instrument is data link limited. The idea is to let the scientist and instrument providers provide an instrument specific data compression algorithm. This will of course be flexible, on and board software update capability will be one of the main features in the design.

The radiometer can also be operated as a stupid subsystem without the control cpu, as all blocks use simple serial interfaces for control and readout.

In addition, the radiometer will also need some optical interface to the observed object. This could be based on a lens or horn, or more advanced antenna solutions. This will also be determined on a platform&application basis.

CONCLUSION

We have demonstrated a complete, frequency agile submillimeter radiometer, including a wide bandwidth spectrometer in the 1 kg / 10 W class. This is an improvement in mass and power consumption with an order of magnitude, extremely important for space projects. Omnisys view is that it is vital that the SpaceTHz community looks at the cost and complications of using THz technology in Space.

The 4-8 GHz/4096 channels spectrometer specification can easily be modified for other requirements, i.e. using several different sub-bands with different resolutions, implementing flexible bandwidth/resolution combinations etc.

The front-end shows a bandwidth of 300-380 GHz, without any bias or mechanical tuning operation, just utilizing a simple digital command.

The LO source shows extremely good phase noise in combination with low mass and power consumption. The design covers any frequency between 2-16 GHz. The combination of the source and active multiplier block produce a 33-45 GHz, 20 dBm synthesizer function with a power budget of 2.5 W and a mass budget of 250 grams.

All parts have been designed with space requirements being considered. This includes environmental aspects, i.e. radiation, vibration etc. as well as performance aspects such as stability. One of the major design parameters has been to allow for simple and fast system integration and validation testing on the spacecraft.

The 1 kg class radiometer also makes the instrument compliant with interstellar probes. We have then the tradeoff between an ambient temperature radiometer in orbit around Mars or Venus, and a cryogenic radiometer in our lab.