# Low noise GaAs Schottky TMIC and InP Hemt MMIC based receivers for the ISMAR and SWI instruments

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## Introduction

The operational frequency bands for science missions carrying planetary atmosphere characterisation instruments are moving towards higher frequencies (1 – few THz) [1, 2], for which the technology is not currently available within Europe. As such this work addresses this technology gap through the refinement of existing technology [3, 4] and development of new enabling technology [5, 6] for future science missions. In particular the development of dedicated MMIC chip-sets for low noise and broadband front-end receivers for the SWI instrument on JUICE operating at 600/1200 GHz, and for the ISMAR 874 GHz V/H channels, are discussed.

The ISMAR (International SubMillimetre Airborne Radiometer) instrument [7] currently under development by the Met Office in UK, is an airborne platform dedicated for the demonstration and validation of microwave atmospheric sounding instruments in the 200 GHz to 1000 GHz range. Omnisys is currently responsible for the development of the two 874 GHz channels under ESA contract. From a science perspective, the addition of the 874 GHz channels will primarily enhance the ice mass detection limit and improve the accuracy of the particle size estimate.


Figure 1. SEM of a 1.2 THz antiparallel Schottky diode structure and cryogenic InP HEMT transistor from CHALMERS. The anode size and gate length of the devices are ~0.1 μm$^2$ and ~50 nm respectively.

The Submillimetre Wave Instrument (SWI) is part of the JUpiter ICy moons Explorer (JUICE) mission [8, 9], which is the next large European science mission planned for launch in 2022 and arrival at Jupiter in 2030. The spacecraft will spend at least three years studying Jupiter as well as the three largest moons, Ganymede, Callisto and Europa, mapping their surfaces, sounding their interiors and assessing their potential for hosting life, as the moons are thought to harbor vast amounts of water. Omnisys is responsible for the development of the front-end receiver modules for the broadband 530 GHz to 625 GHz spectrometer, as well as for the development of the 1200 GHz channel.

Driven by the requirements of astronomy and aeronomy instruments (e.g. SWI, METOP-SG, EOS MLS, STEAM-R and other), sub-millimetre heterodyne radiometer technology has markedly improved in the last few years. In particular, heterodyne mixers based on planar Schottky diode technology have been demonstrated at all frequencies up to at least 2,500 GHz in a laboratory environment. There are many advantages of GaAs Schottky diode technology; ability to operate at room temperature, versatility of working as detector and multiplier, and inherent tolerance to radiation. Together with the maturity of III/V device technology and long track record in space, planar Schottky diode based sub-systems are of strategic importance for sub-millimeter wave instruments dedicated to the study of the Earth's atmosphere, the study of planets and astrophysics.

However, a drawback of Schottky based sub-systems is that they traditionally require relatively high local oscillator (LO) powers, in the order of ~mW, compared to SIS and HEB technologies, which operate at ~uW levels. This becomes increasingly challenging when moving to higher frequencies ~1 THz and in particular for space born systems like SWI, with very limited mass and power budgets and with relative broad spectral coverage (17% relative LO bandwidth). The way to overcome this challenge is to apply mixer biasing schemes and by cooling the system, which can reduce the LO power requirement by up to an order in magnitude. Another aspect of THz receiver systems is of course that losses in waveguides and flange interfaces start to be significant and close integration of the mixer, horn antenna, IF low noise amplifier, and last stage multiplier becomes highly beneficial.

In this paper the current status of Omnisys 600/874/1200 GHz receiver development for the SWI and ISMAR instruments is presented, including a technology and system design overview. The receiver technology we are developing is entirely based on Terahertz Monolithically Integrated Circuits (TMIC's) [10] and cryogenic InP HEMT LNA MMIC's [11] from Chalmers University of Technology.

## Receiver System Design

From a receiver design perspective the main difference between the SWI and ISMAR instruments is the LO frequency requirement of ~17% bandwidth for SWI and fixed LO frequency for ISMAR. In addition the power constraints and operational temperatures differ as SWI will be operating in space using passive cooling of the receiver front-ends (~150K), while ISMAR is an airborne system heated to 40 degrees Celcius with over 8 Watts of available power per V/H channel excluding the back-end. The targeted cooled receiver DSB noise temperatures for the SWI 600 and 1200 channels are 1500 K and 3500 K respectively, for ISMAR this number is 4000 K DSB. In summary the sensitivity requirements for all three channels and combination of bandwidth and power limitations for SWI in particular, impose a technological challenge to the current state-of-the-art for Schottky diode technology.

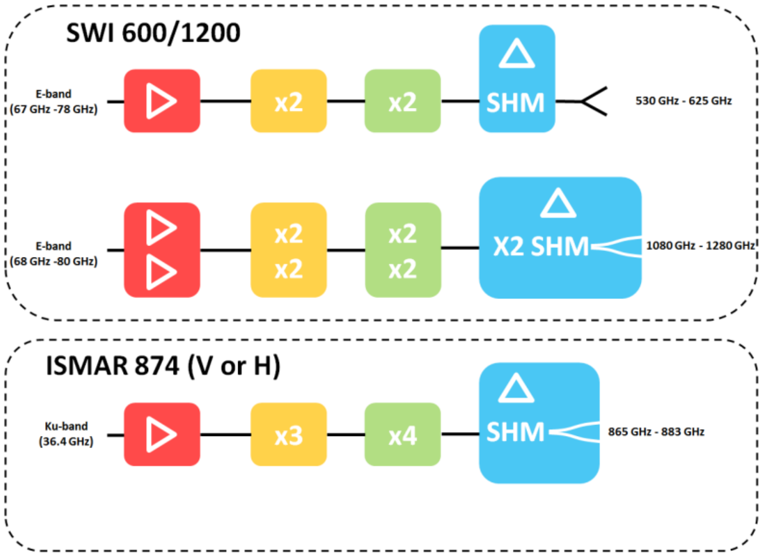


Figure 2. Schematic of the SWI 600 GHz and 1200 GHz receiver channels and ISMAR 874 GHz V/H channels.

Looking at the multiplier chain designs for the SWI 600/1200 channels, the main challenge is to reduce the LO ripple coming from standing waves in between the LO subsystem components and interaction with mixer. The current baseline is to use E-band PA units from RPG based on commercially available MMIC chips, delivering about 100 mW and 350 mW respectively. These are followed by a chain of 2-3 varactor diode multipliers; 150 GHz (RPG), 300 GHz (LERMA) and 600 GHz (Omnisys), with an estimated combined efficiency of about 6% (x2x2) and 0.5% (x2x2x2) respectively. The main difference on system block level is that for the 1200 channel, the baseline is to have the last stage 600 GHz doubler integrated with the mixer/lna FE module, as well as the RF feed horn. This not only reduces the associated losses from interconnects, but also eases the design of the LO and optical subsystems owing to the increased flexibility of the FE receiver design. On a component level the main difference is that power combining techniques with 2 or 4 devices working in parallel are used. The main motivation for keeping the similarities between the two channels is that much of the design and qualification work can be re-used for the 1200 GHz band.

Based on the SWI 600 GHz mixer design, two scaled mixer circuit designs have been developed; one for the ISMAR 874 GHz channel and one for the SWI 1200 GHz channel. The scaling of the designs included compensation for the dielectric loading of the membrane substrate, as the thickness of the membrane was not changed.

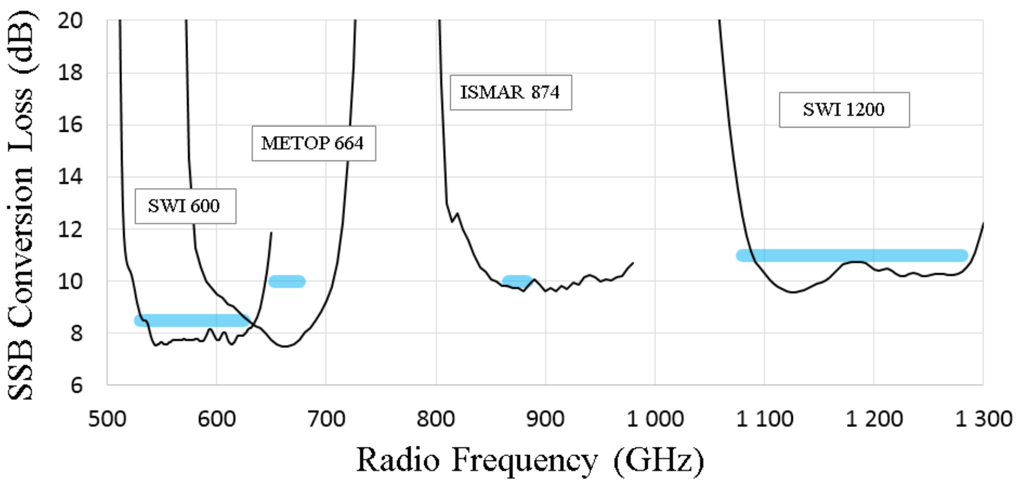


Figure 3. Simulated mixer performance based on full 3D-EM models for four different Omnisys TMIC designs. The simulations were performed at fixed LO powers ranging from 1.2 mW to 1.8 mW.

For the ISMAR 874 GHz receivers we have developed a custom MMIC chip set including the mixer, two multiplier stages, and a room-temperature gain drift compensated LNA from Low Noise Factory that can be integrated to the mixer package. Thereto a high performance spline horn with integrated lens cover has been designed, that also can be integrated to the FE split-block. A SPACEK K-band amplifier with close to 1 Watt of output power, and a X3 HBV multiplier MMIC [12, 13] from Wasa Millimeter Wave is used as a W-band driver for the LO Schottky multipliers. For initial tests a diagonal lab test horn from VDI will be used.

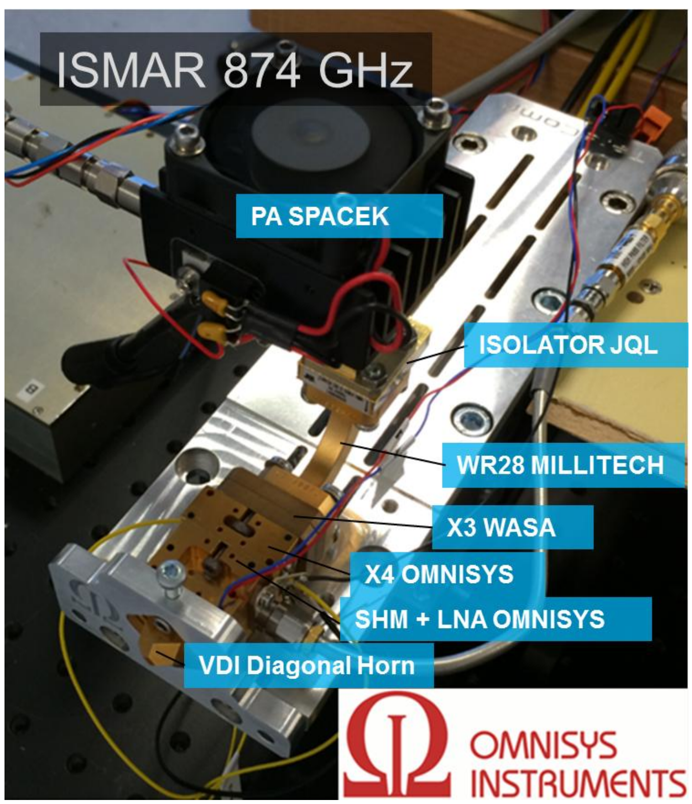


Figure 4. Prototype setup for the ISMAR 874 GHz front-end receiver MMIC system.

**Results**

A broadband 530-625 GHz GaAs membrane TMIC mixer and a cryogenic InP Hemt MMIC LNA design from Low Noise Factory have been integrated to a single receiver module including bias circuitry for the LNA. As part of the SWI development the integrated mixer module has been tested at IAP in Bern at room temperature over the full LO bandwidth, showing a DSB receiver noise temperature of 1800 K – 3000 K (including optical losses and measured as average IF response over the full LNA bandwidth), with only 1 mW of typical required LO power. The results are in good agreement with simulations and the receiver noise response is expected to improve considerably when cooling the system down to 150 K in temperature.

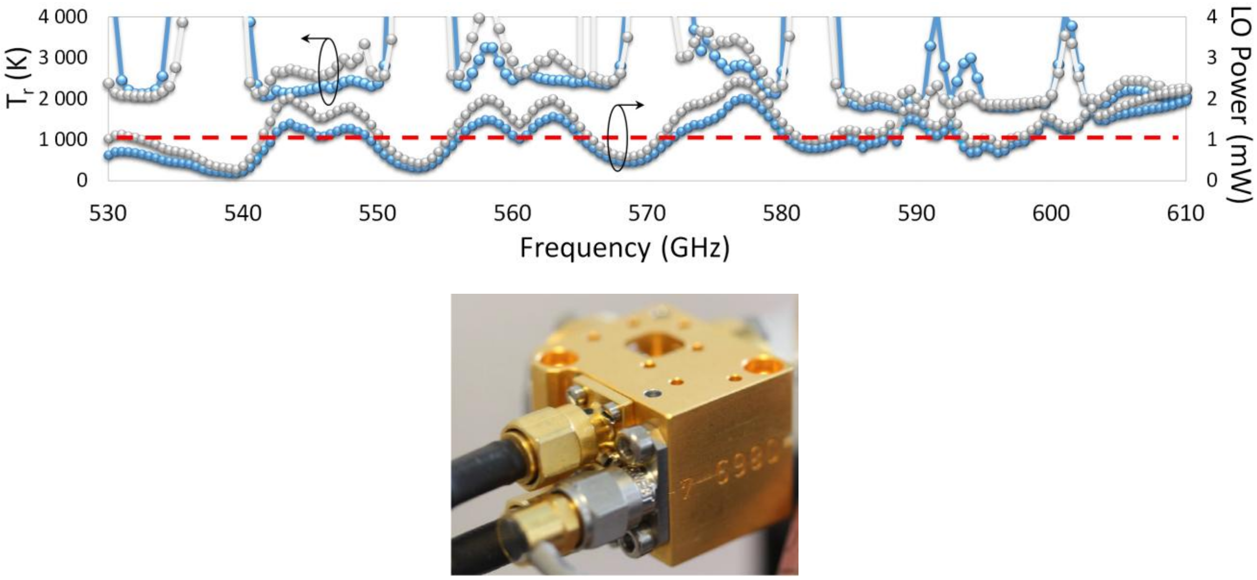


Figure 5. Measured performance (top) and photograph (bot), of the SWI 530-625 GHz receiver front-end prototype.

A new narrowband (10%) X4 440 GHz diode multiplier module for the LO subsystem in ISMAR has been developed, see figure 4. It was based on a previous 332 GHz quadrupler x2x2 module design consisting of two cascaded MIC doublers with a measured peak flange to flange efficiency of 8% (including waveguide taper and WR-10 saver). The new 440 GHz varactor diode quadrupler consists of two cascaded doubler TMIC's integrated to the same waveguide package only 10 mm in length. At only 60 mW drive level, a peak efficiency of 5% corresponding to an output power of 3 mW was measured, including losses of a waveguide taper and a WR-10 saver. The measurements are in good agreement with simulations, reaching efficiencies of about 30% and 20% for the 1:st and 2:nd stage doubler TMIC's respectively.

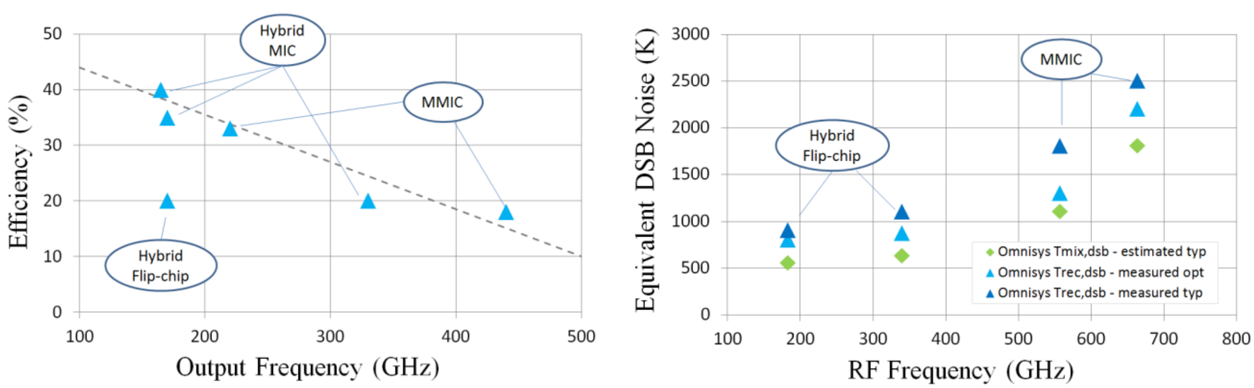


Figure 6. Short summary of Omnisys receiver systems showing measured receiver noise temperature (right) and x2 multiplier efficiency (left).

## Conclusions and Acknowledgments

We have presented the progress and status of THz room temperature and cooled heterodyne receiver technology based on the CHALMERS Schottky diode membrane TMIC's and InP HEMT MMIC's. As a main result a broadband low noise response of the 530-625 GHz receiver front-end for the SWI band1 spectrometer has been measured, with a typical receiver noise of 2400 K DSB (at room temperature) with around 1 mW of LO input power. Thereto a TMIC based x2x2 quadrupler module to 440 GHz with peak 5% efficiency has been developed. Performance of scaled mixer designs to 874 GHz and 1200 GHz have also been presented, currently under development by Omnisys in collaboration with Chalmers University of Technology.

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## References

[1] E. Schlecht, J.V. Siles, C, Lee, R. Lin, B. Thomas, G. Chattopadhyay, I. Mehdi, "Schottky Diode Based 1.2 THz Receivers Operating at Room-Temperature and Below for Planetary Atmospheric Sounding," *Terahertz Science and Technology, IEEE Transactions on* , vol.PP, no.99, pp.661,669.

[2] S.A. Retzloff, A. Young, J. Hesler, "A 1.46 THz Schottky receiver at cryogenic temperatures," 39:th Int. Conf. on *Infrared, Millimetre, and THz waves, IRMMW 2014*.

[3] P.J. Sobis, N. Wadefalk, A. Emrich, J. Stake, "A Broadband, Low Noise, Integrated 340 GHz Schottky Diode Receiver," *Microwave and Wireless Components Letters, IEEE* , vol.22, no.7, pp.366,368, July 2012

[4] P.J. Sobis, A. Emrich, J. Stake, "A Low VSWR 2SB Schottky Receiver," *Terahertz Science and Technology, IEEE Transactions on* , vol.1, no.2, pp.403,411, Nov. 2011.

[5] P.J. Sobis, V. Drakinskiy, A. Emrich, H. Zhao, T. Bryllert, A-Y. Tang, J. Hanning, J. Stake, "300 GHz to 1.2 THz GaAs Schottky membrane TMIC's for next generation space missions," *24$^{th}$ International Symposium on SpaceTerahertz Techniques, ISSTT 2013*.

[6] P. Neumaier, H. Richter, J. Stake, H. Zhao, A.-Y. Tang, V. Drakinskiy, P. Sobis, A. Emrich, A. Hülsmann, T. Johansen, T. Bryllert, J. Hanning, V. Krozer, and H.-W. Hübers, "Molecular Spectroscopy With a Compact 557-GHz Heterodyne Receiver," *IEEE Transactions on Terahertz Science and Technology*, vol. 4, 2014.

[7] http://www.metoffice.gov.uk/research/foundation/observational-studies/microwave

[8] http://sci.esa.int/juice/

[9] P. Harthog, Max-Planck-Institut fur Sonnensystemforschung, Germany, "JUICE – Jupiter Icy Moons Explorer, SWI – Sub-Millimeter Wave Instrument, PART II - Experimental Interface Document – Part B (EID-B)"

[10] Terahertz heterodyne receiver components for future European space missions (242424) - www.fp7-teracomp.eu.

[11] J. Schleeh, G. Alestig, J. Halonen, A. Malmros, B. Nilsson, P.-A Nilsson, J. P. Starski, N. Wadefalk, H. Zirath and J. Grahn, "Ultralow-power cryogenic InP HEMT with minimum noise temperature of 1 K at 6 GHz," *IEEE Electron Device Lett*,. vol. 33, no. 5, pp.664-666 2012.

[12] A. Malko, T. Bryllert, J. Vukusic, J. Stake, "Silicon Integrated InGaAs/InAlAs/AlAs HBV Frequency Tripler," *Electron Device Letters, IEEE* , vol.34, no.7, pp.843,845, July 2013

[13] A. Malko, T. Bryllert, M. Sadeghi, J. Vukusic, and J. Stake, "High efficiency and broad-band operation of monolithically integrated W-Band HBV frequency tripler," *Indium Phosphide and Related Materials (IPRM), 2012 International Conference on* , vol., no., pp.92,94, 27-30 Aug. 2012.