STEAMR Receiver Chain

Peter Sobis, Anders Emrich and Magnus Hjorth

Abstract— **We report on the development of the STEAMR radiometer system, including the front-end receivers, LO multipliers and the back-end spectrometer system. STEAMR constitutes the submillimeter wave limbsounder on board PREMIER, one of three ESA Earth Explorer Core missions that have entered a feasibility study phase. The STEAMR instrument is based on a linear array of 14 heterodyne receivers operating in the 320 GHz to 360 GHz band processing over 260 GHz of instantaneous IF bandwidth. Thereto, eight of the fourteen receivers are to be sideband separating (2SB) and a novel waveguide based topology with integrated LNA's has been developed.**

An overview of the receiver system is presented together with a conceptual design optimized to meet the scientific goals of the instrument. Preliminary results on critical receiver components such as front-end mixers, LO chains and the back end spectrometer are presented and different alternatives for realization are discussed.

Index Terms—**Radiometer Systems, Submillimeter wave circuits, Submillimeter wave mixers, Submillimeter wave receivers, Submillimeter wave waveguides**

I. INTRODUCTION

The STEAMR (Stratosphere Troposphere Exchange And Climate Monitor Radiometer) instrument is a part of the ESA PREMIER mission [1] with the overall goal to observe atmospheric composition for a better understanding of the chemical and climate interaction. The mission has its provenance from earlier IR emission sounders (MIPAS Envisat, 2002, HiRDLS and TES Aura, 2004) and millimetre wave limb emission sounders (SMR Odin, 2001 and MLS Aura, 2004), with the main objective to provide vertically (1-2 km) and horizontally (30-50 km) well resolved information on the distribution of UT-LS constituents such as water vapor, ozone and carbon monoxide on the global scale by using the 320-360 GHz range.

PREMIER was recently selected as one of three Earth Explorer Core missions that now have entered a feasibility study phase with the goal to be launched in 2016. Omnisys Instruments AB is currently under contract for the development of the STEAMR receiver electronics including front-ends, back-ends, control and power interface electronics. The Swedish Space Corporation (www.ssc.se) is the prime contractor and is responsible for the instrument design concept and final integration of the subsystems.

Limb sounding provides vertical resolution and allows for the detection of key trace gases which are too tenuous to be detectable thru the shorter path lengths of nadir observations. The limb sounding geometry also has a better contrast (S/N ratio) as the cold space rather than the warm earth is used as a background. The STEAMR millimeter wave limb sounder will together with two infrared instruments, an InfraRed Limb Sounder and an Infrared Cloud Imager, fly in the MetOp satellite sun-synchronous orbit (with a reference altitude of 817 km) in a rearward limb-viewing configuration of the UT-LS range, see figure 1. This will make it possible for co-registration of the MetOp nadir observations and PREMIER limb soundings and will produce unique data on the atmospheric chemistry and climate processes.

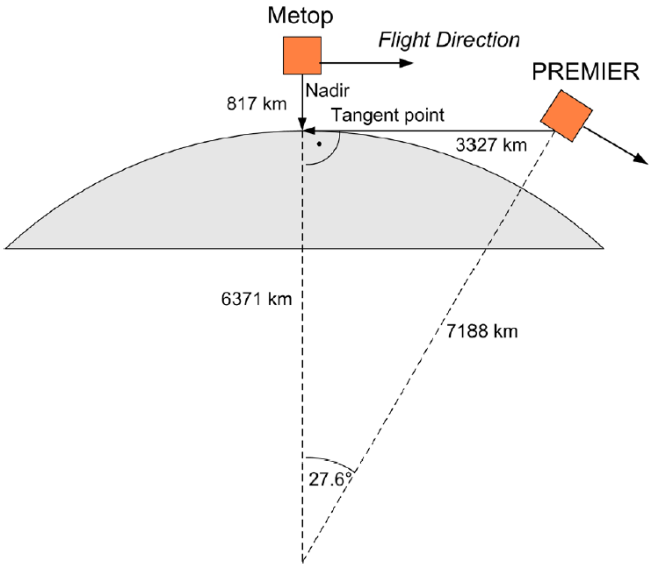


Figure 1. Observation geometry of the Metop and PREMIER satellites [1].

The STEAMR measurement concept is based on tomographic multibeam limb sounding using heterodyne Schottky diode detectors, where 14 predefined tangent heights will be observed simultaneously utilizing a staring view configuration with 7 beams for each polarization, see figure 2. A linear fixed array of 14 heterodyne receivers is used instead of 1-2 single channels being scanned in altitude, thus providing an order of magnitude improvement in sensitivity and simplification in parts of the optics. The instrument integration time will be around 2.5 s per measurement producing highly resolved spectral data with a spatial vertical resolution of about 1.5 km.

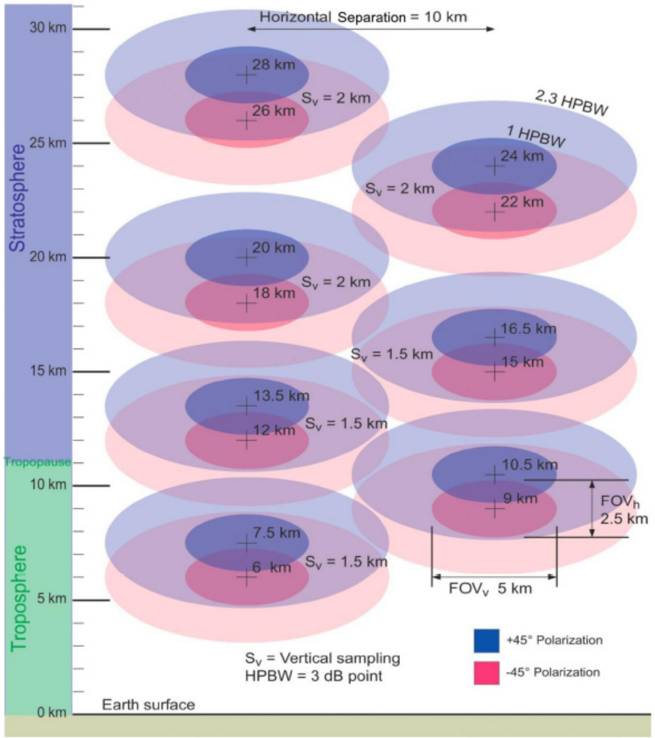


Figure 2. Staring view concept of the STEAMR satellite [1].

II. RECEIVER SYSTEM

STEAMR will use receivers operating at a fixed LO frequency of about 170 GHz covering the 320-360 GHz range with a T_{rec} of less than 2000 K DSB. The receivers will be divided into blocks of 3-4 elements employing DSB or sideband separating (2SB) functionality depending on the specific altitude coverage. The effect of line broadening at lower altitudes is the driving factor that motivates the use of sideband separating (2SB) receivers, see figure 3 for a schematic overview of the system.

The focal plane unit beam array concept will be adopted from the Compact Heterodyne Array Receiver Module (CHARM), developed at the KOSMA observatory in Köln, Germany, employing a 9 pixel array of 345 GHz SIS mixers. The horns within each receiver block are tightly spaced, about 20-25 mm distance from each other, and a six-mirror antenna system will be used with a main reflector measuring 1.6m by 0.8m adopting a Ritchey-Chretien telescope (RCT) design.

Back-end units consisting of a autocorrelator spectrometer with a total of 12 GHz of bandwidth and 20 MHz resolution will be used. This is achieved using wideband IQ mixers dividing the IF into four 3 GHz wide channels processed by state of the art single autocorrelator ASIC chips from Omnisys Instruments, with more than 6 GHz of bandwidth.

A. Front-End Subsystem

The front-end subsystem will use a subharmonic (x2) Schottky diode mixer [2], where the current baseline is to use a design employing an inverted suspended hybrid topology [3]. The mixer consists of a 75um thick fuzed quartz circuit, on which an anti-parallel diode chip is mounted in a flip-chip fashion. The mixer circuit is then mounted using silver epoxy in a micromachined E-plane splitblock containing an IF LNA chip. Waveguide flange interfaces are used for the LO and RF signal interconnects and a coaxial interface is used for the IF output, see figure 4.

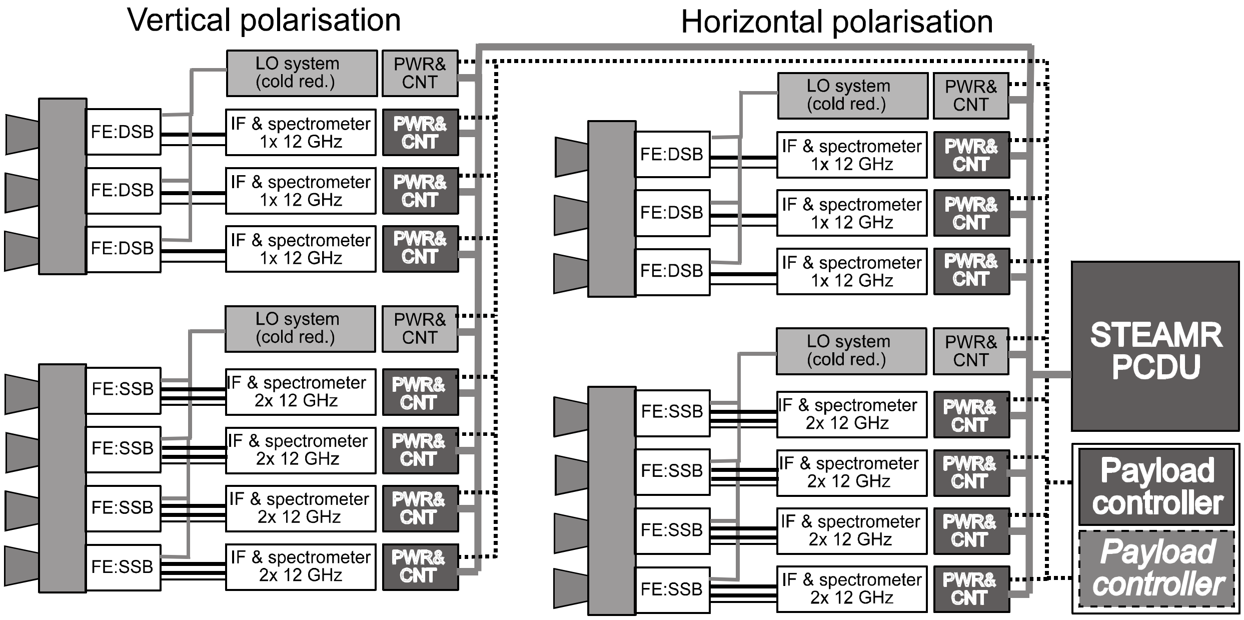


Figure 3. Schematic overview of the STEAMR receiver system.

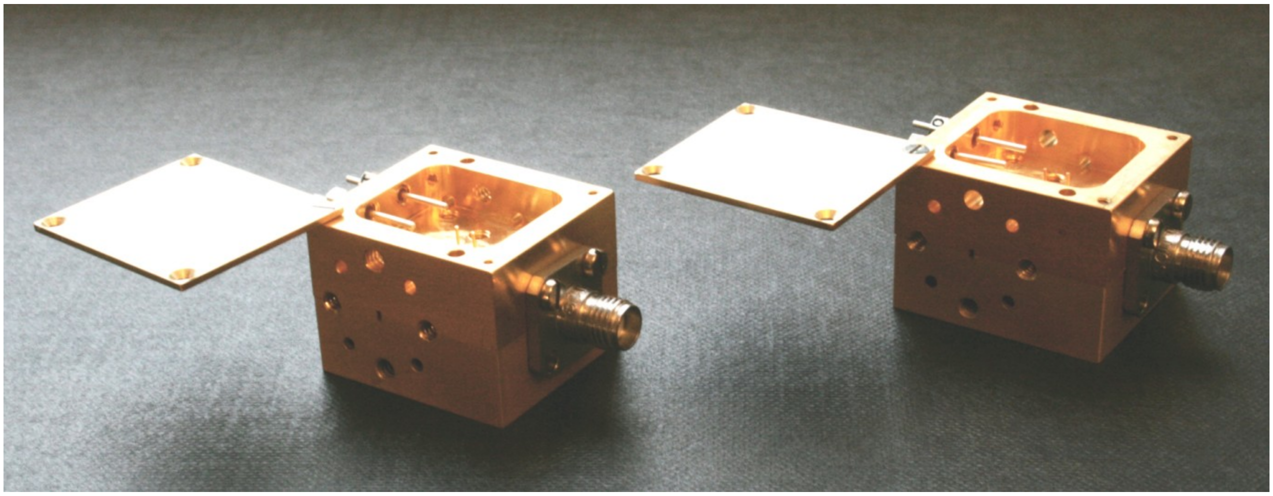


Figure 4. Photo of the mixer with integrated LNA assembly.

1) *Subharmonic Sideband Separating Mixers*

Based on the subharmonic mixer architecture with an integrated LNA, two sideband separating (2SB) mixer topologies have been considered. A series of different waveguide hybrid designs have been manufactured in order to evaluate the two concepts. Preliminary results are showing an advantage of using 90 degree hybrids for the LO and RF to a matched Y-junction for the RF and 45/135 degree hybrid for the LO feeding [3]. The reason is that branch guide couplers (90 degree hybrids) have isolated ports resulting in less ripple in the image rejection response and a lower SWR at the inputs as a larger amount of the reflected power is terminated in the isolated port.

The downside of using hybrids with isolated outputs is that the RF termination will radiate noise into the system increasing the receiver noise temperature. In figure 5 the modular 2SB receiver prototype can be seen and a drawing of a proposed integrated prototype sideband separating mixer module is presented in figure 6.

2) *Mixer with Integrated LNA*

An estimate based on obtained results from the mixer configured with a custom 1-12 GHz LNA (50 K noise temp.) developed at Chalmers University of Technology, and on the results of the newly developed mixer modules containing an integrated AMMC-6220 LNA (175 K noise temp.) from Agilent, is showing that a receiver noise temperature of less

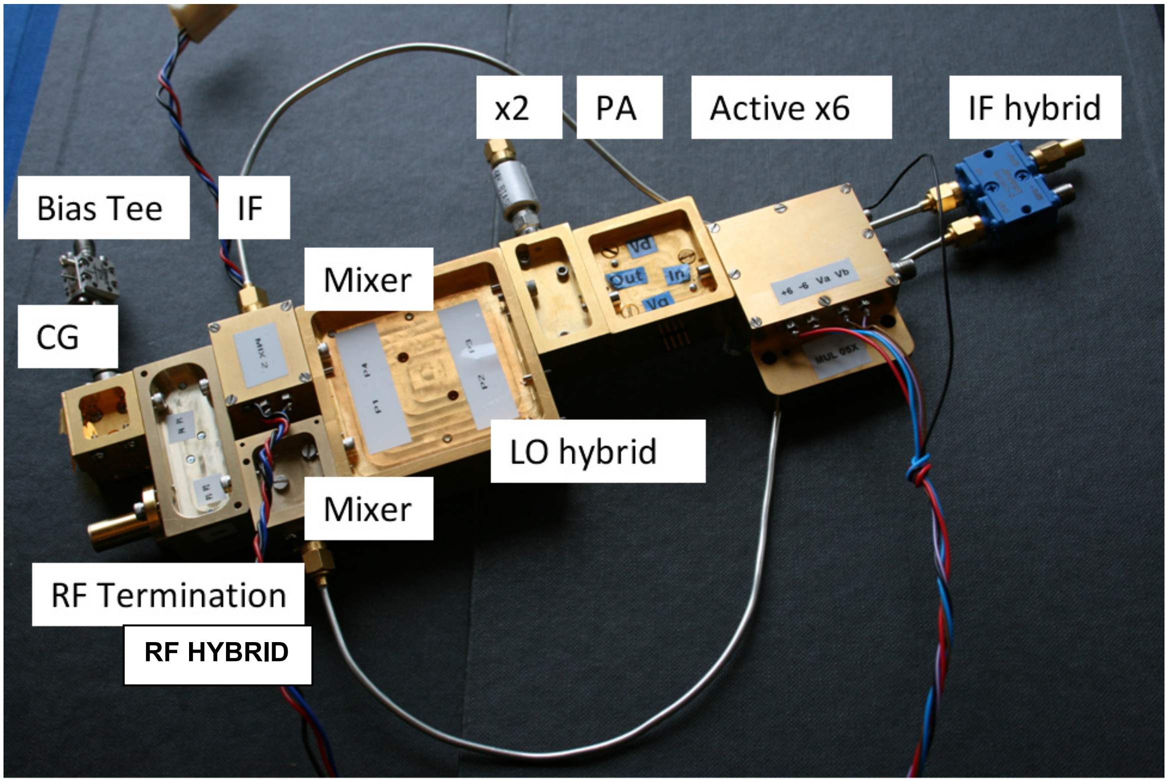


Figure 5. Modular prototype sideband separating (2SB) receiver.

then 1800 K (DSB) covering 20 GHz of IF bandwidth is realistic, see figure 7. In the estimate calculation a total mixer conversion loss of 8 dB and average difference in LNA noise of 120 K has been assumed.

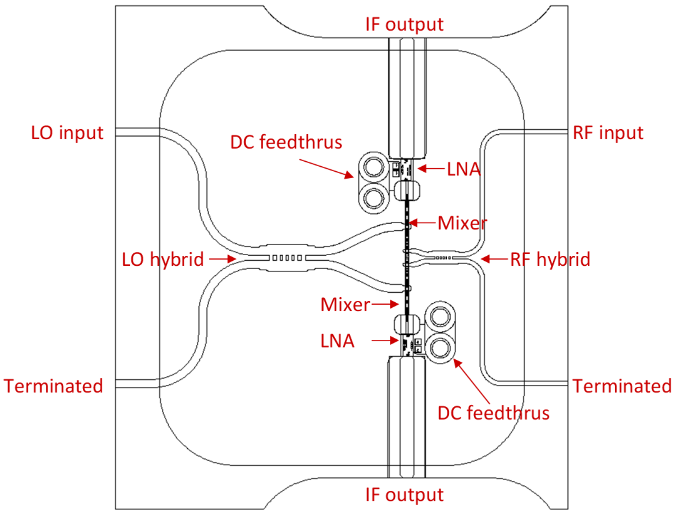


Figure 6. 2D-drawing of the proposed integrated prototype sideband separating (2SB) mixer module.

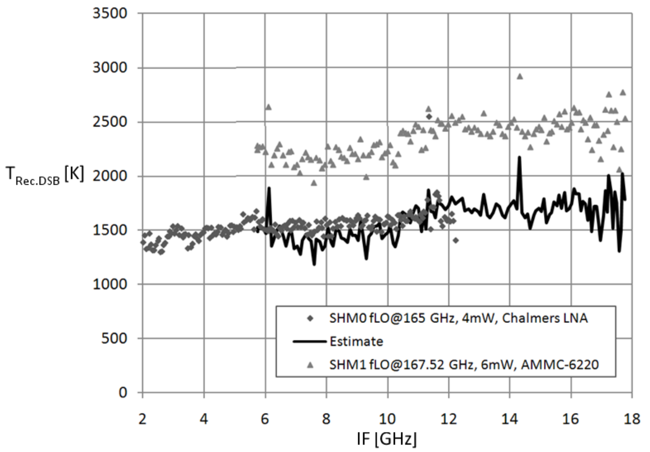


Figure 7. Measured receiver noise temperature and noise estimate based on simulated performance of a custom 6-18 GHz LNA design.

III. LOCAL OSCILLATOR SYSTEM

Three different LO solutions are being considered in this project, two high power alternatives able to pump 2-4 mixers and one low power alternative able to pump only one mixer. Even though it today is possible to produce output power levels that could cover the LO need of 10 mixers or more, this is not wanted from a reliability perspective.

The first high power alternative consists of a Schottky doubler D166 from VDI, driven by an active W-band multiplier module that was developed for the ALMA WVR. This LO chain can, in its current state deliver up to 12 mW of output power consuming less then 2 W of DC power. The other alternative is a high power module based on a HBV quintupler developed by Wasa Millimeter Wave [4]. The quintupler module is not much larger then a waveguide flange and the first prototype module is capable of producing output powers of around 16 mW with a 3 dB bandwidth of about 4%. The third low power alternative is a single MMIC chip solution from Fraunhofer IAF using GaAs Metamorphic HEMT technology. The design has been developed in cooperation with Herbert Zirath's group at Chalmers University of Technology, see figure 8. The power amplifier is showing a measured output power of 6 dBm in compression broadband and consumes about 0.5 W of DC power. An extra stage would probably increase its' power handling capabilities.

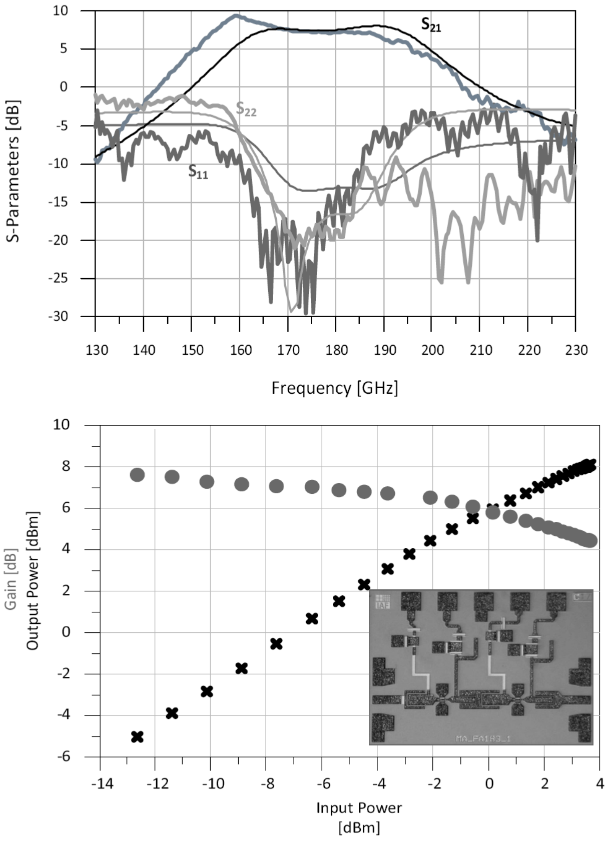


Figure 8. Measured performance of the Chalmers developed power amplifier MMIC chip using the Fraunhofer IAF mhemt process.

IV. BACK-END SUBSYSTEM

The back-end subsystem will encompass a chain of intermediate broadband amplifiers and a duplex filter stage leading to the IQ-mixers modules. The IQ-outputs with around 3 GHz of bandwidth are processed by ASIC custom designed correlator chips, see figure 9 for a block diagram.

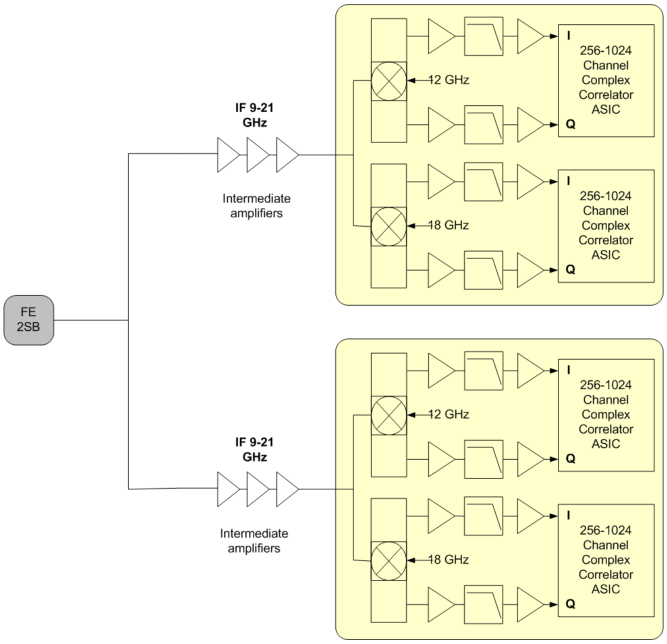


Figure 9. Back-End spectrometer block diagram.

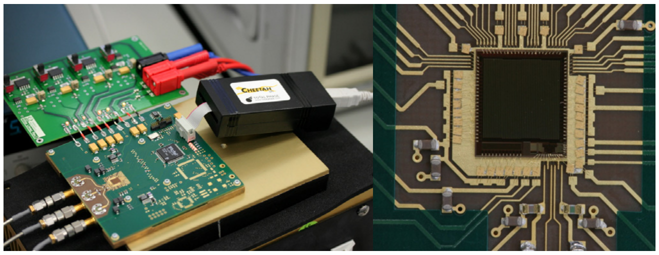


Figure 10. Test board for correlator ASIC(left). Close-up on ASIC (right)

A. Autocorrelator unit

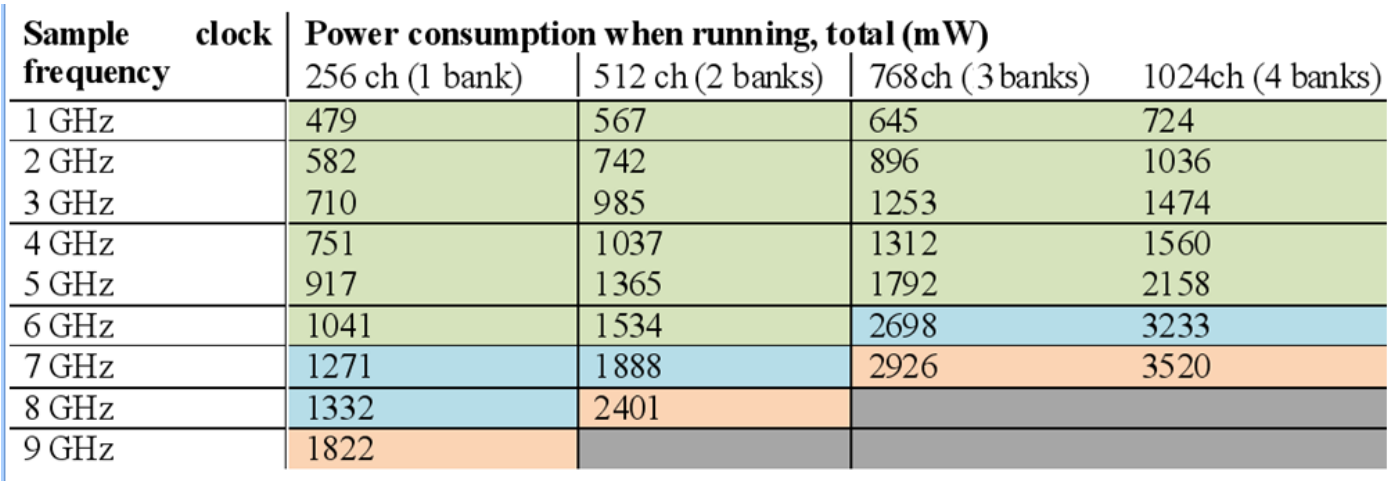
A full-custom ASIC using the IBM 7WL process (0.18 um BiCMOS technology) has been developed, featuring both 3-level digitiser and a digital autocorrelator, see figure 10. One single chip is capable of processing more than 6 GHz of RF bandwidth with 250 channel resolution, while dissipating slightly over one Watt of power, see figure 11 for test results of power consumption for different modes of operation.

B. Initial test

An initial test of the front-end prototype and back-end breadboard combined has been made, and a test signal in the 320-360 GHz range (generated by a comb generator) was successfully captured by the spectrometer. See figure 12 for test setup and results.

V. CONCLUSIONS

A concept for realizing the instrument has been developed. Initial breadboarding results of critical receiver components such as mixers, LNA's and backend processing are pointing to that fundamental instrumental specifications can be met. The project has moved from a concept study phase to a prototype phase and the work will now be intensified to further develop and integrate the subsystems and to narrow down the number of options for realization.



Sample clock frequency	**Power consumption when running, total (mW)**			
	256 ch (1 bank)	512 ch (2 banks)	768ch (3 banks)	1024ch (4 banks)
1 GHz	479	567	645	724
2 GHz	582	742	896	1036
3 GHz	710	985	1253	1474
4 GHz	751	1037	1312	1560
5 GHz	917	1365	1792	2158
6 GHz	1041	1534	2698	3233
7 GHz	1271	1888	2926	3520
8 GHz	1332	2401		
9 GHz	1822			

Figure 11. Total correlator power consumption in different operating modes.

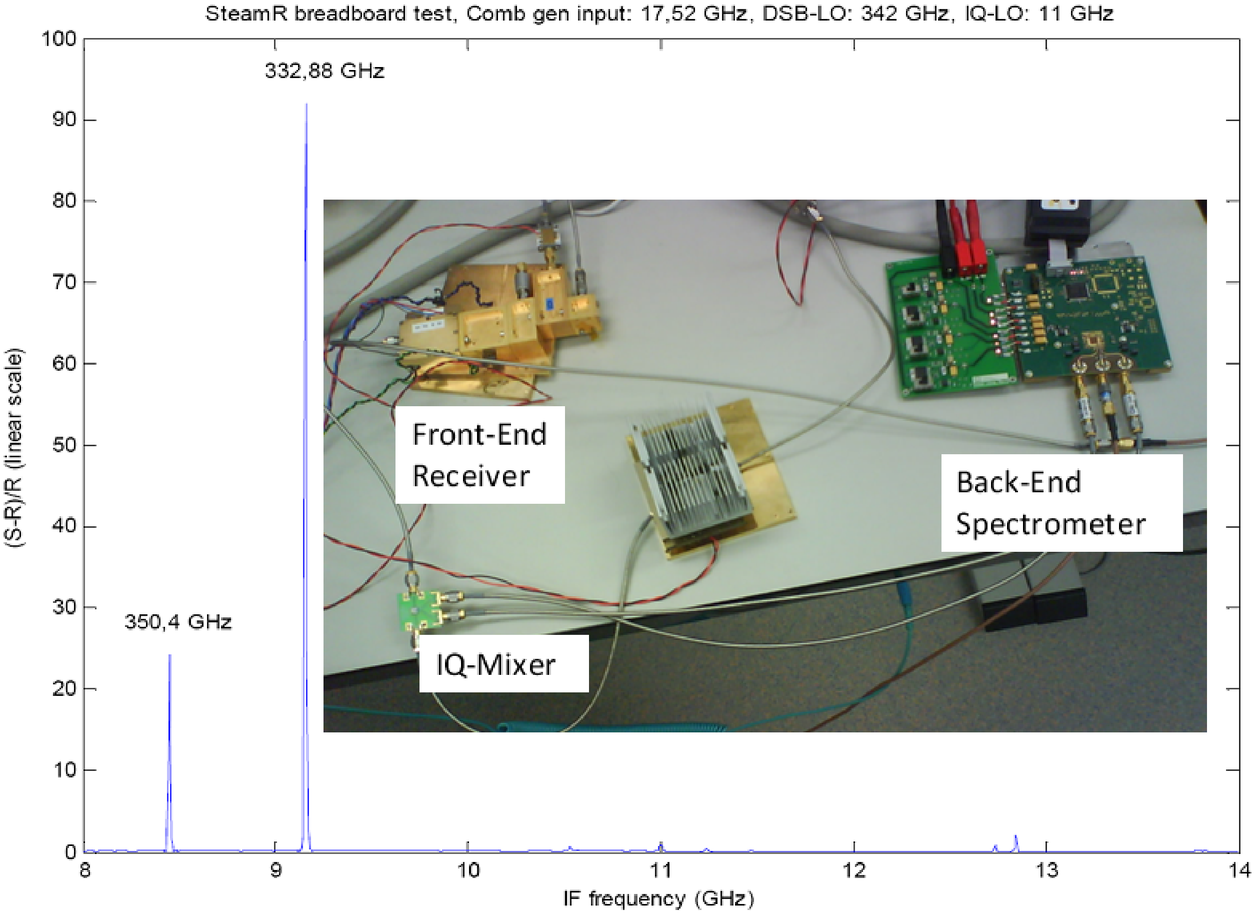


Figure 12. Test results from a prototype receiver setup consisting of the front-end and spectrometer back-end units, successfully transmitting and capturing the spectrum of a RF CW signal running the correlator chip with 6 GHz of bandwidth.

VI. ACKNOWLEDGMENTS

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VII. REFERENCES

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