Compact 340 GHz Receiver Front-Ends

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Abstract— **A compact 340 GHz room temperature receiver front-end has been developed consisting of a subharmonic Schottky diode mixer module with an integrated LNA. A novel sideband separation topology has been evaluated by using a pair of the developed mixers interconnected by external waveguide branch guide coupler hybrids for the LO and RF feedings and coaxial IF hybrids, measuring sideband suppression levels of 5 dB to 15 dB over the 315-365 GHz band.**

For efficient LO pumping of the sideband separating mixer, a novel high power LO chain based on a 5 x 34 GHz HBV quintupler (170 GHz LO source) has been developed with an ultra compact mechanical block housing, not much larger then a waveguide flange. We have also looked into a broadband medium LO power source consisting of a W-band active multiplier module, based on commercial MMIC chips from Hittite, followed by a medium power Schottky doubler from VDI.

The demonstrated compact receiver front end has a considerably reduced size and weight owing to the high multiplication factor of the compact LO chain and mixer with integrated LNA. The novel sideband separating topology that uses 90 degree hybrids for both LO and RF resolves the standing wave issue of a previously proposed topology, in which a matched Y-junction was used as an RF hybrid and a branch guide coupler with a 45 degree differential line phase shifter at the output, was used for the LO feeding. The proposed topology improves both the sideband suppression and reduces the standing waves at the LO and RF ports.

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

I. INTRODUCTION

There is a need for compact heterodyne receivers operating in the sub-millimeter wave band (above 300 GHz) for earth observation instruments and space science missions. The sub-millimeter wave or terahertz domain allows studying several meteorological phenomena such as water vapour, cloud ice water content, ice particle sizes and distribution, which are important parameters for the hydrological cycle of the climate system and the energy budget of the atmosphere.

In this paper an ultra-compact 340 GHz receiver front-end module is presented suitable for earth missions as well as future planetary missions. The receiver has specifically been designed to meet the specification of the STEAMR instrument, promoted by the Swedish Space Corporation (www.ssc.se), which constitutes the millimeter wave limb sounder in PREMIER [1], one of three ESA Earth Explorer Core missions that now have entered a feasibility study phase.

The STEAMR submm-wave front-end consists of 14 RT SSB or DSB receivers divided equally over two polarizations in a focal plane array configuration operating in the 310-360 GHz band. The broadening of spectral lines in the earth lower sphere layers motivates the use of SSB receivers while in the upper layers the narrow lines can be resolved using DSB configurations. In this work we propose a novel subharmonic sideband separating mixer topology that better can withstand LO port mismatches and variations in between the mixer pair.

The subharmonic sideband separation mixer topology that was suggested in [2] was employing a matched Y-junction to split the RF signal and a 45/135 degree phase shifter hybrid for the LO feeding. This topology is sensitive to standing waves at the mixer RF inputs, due to the poor isolation in between the mixers, leading to considerable ripple in the image rejection response. The proposed novel image rejection mixer topology circumvents this problem by using 90 degree hybrids for both the RF and LO, moreover it improves the LO and RF SWR as the reflected power is terminated. The quadrature feeding of the LO and RF port is possible, as the effective "fundamental" LO phase shift is translated to 180 degrees by the subharmonic x2 mixers.

II. FRONT-END RECEIVER MODULE

The STEAMR submm-wave front end consists of a total of 14 receiver modules divided into sub-arrays of 3-4 DSB or SSB mixers. In such a configuration there is room for optimization and partial integration of the front-end receiver modules and LO system. The system LO signal will be fixed to about 170 GHz with an IF band of 6-18 GHz SSB covering an RF band of 320-360 GHz instantaneously, where the goal is to reach a DSB noise temperature better than 2000 K for each individual receiver. In this context, a compact front-end receiver module architecture consisting of a subharmonic Schottky mixer and LNA integrated into one block has been developed, see figure 1.

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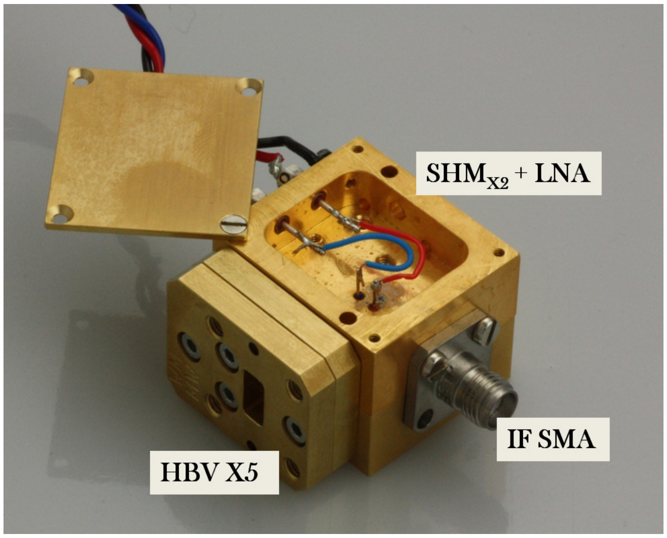


Figure 1. Photo of the novel compact 340 GHz front end receiver consisting of a mixer module with an integrated LNA and an ultra compact HBV x5 multiplier.

Furthermore, two LO source alternatives capable of pumping two or more mixers have been evaluated. The first LO chain is based on a high power x5 multiplier using HBV-technology [3] driven by a 0.5 W amplifier at 35 GHz while the other LO chain is using a medium power Schottky based x2 multiplier driven by an active W-band x6 module. See figure 2, for a schematic overview of the receiver front-end system showing the two LO chain alternatives.

III. SUBHARMONIC MIXER

The receiver mixer module design, presented in [4], is based on a subharmonic inverted suspended mixer circuit topology [6], and uses a 75 um thick fuzed quartz substrate and a commercial SC1T2-D20 antiparallel Schottky diode chip from Virginia Diodes Inc., that is soldered to the thin film circuit in a flip chip fashion. The mixer has been design for a LO bandwidth of about 5% and a RF bandwidth of more then 20%. The relatively long distance (5mm) in between the IF port and mixer diodes, limits the bandwidth of the IF response

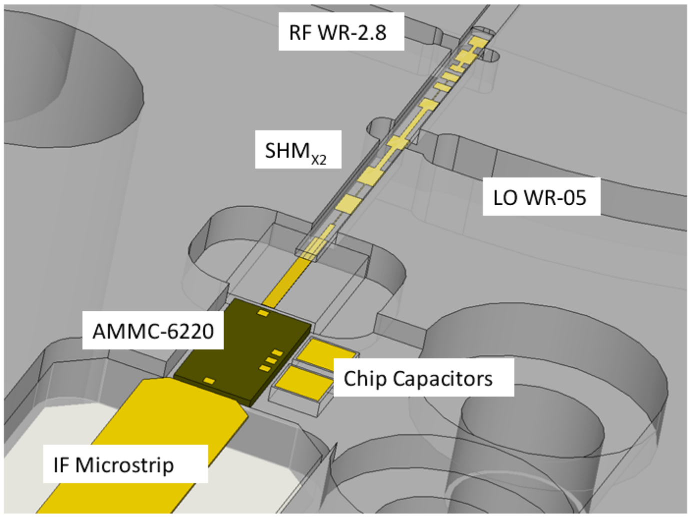


Figure 3. 3D-model of the developed 340 GHz mixer module with an integrated LNA (AMMC-6220).

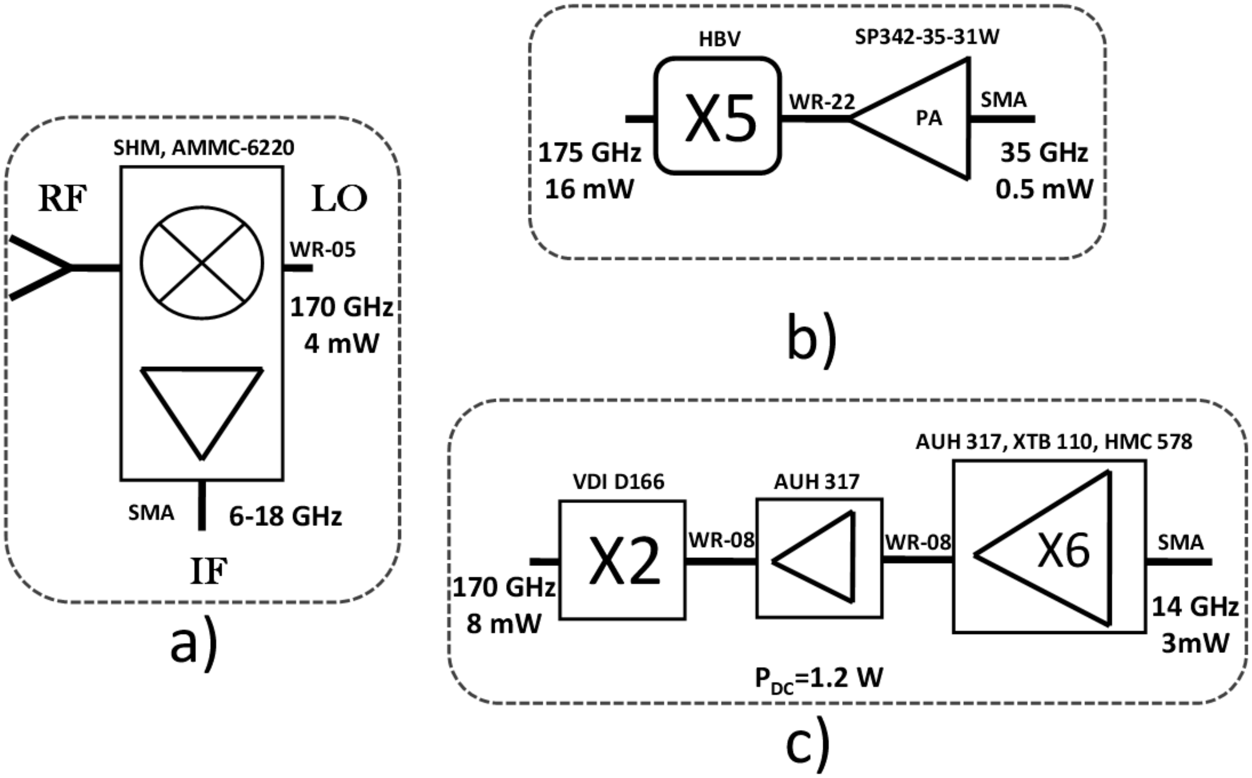


Figure 2. Schematic of the front-end receiver module a) the HBV quintupler LO chain b) and the Schottky doubler based LO chain c).

to about 30 GHz. The AMMC-6220 MMIC LNA with a typical noise temperature of 165 K has been integrated to the E-plane mixer splitblock using vertical DC feedthrus, see figure 3. A lid covers the outer side of the splitblock half which houses a small mounting cavity in which a simple DC bias circuit could be placed.

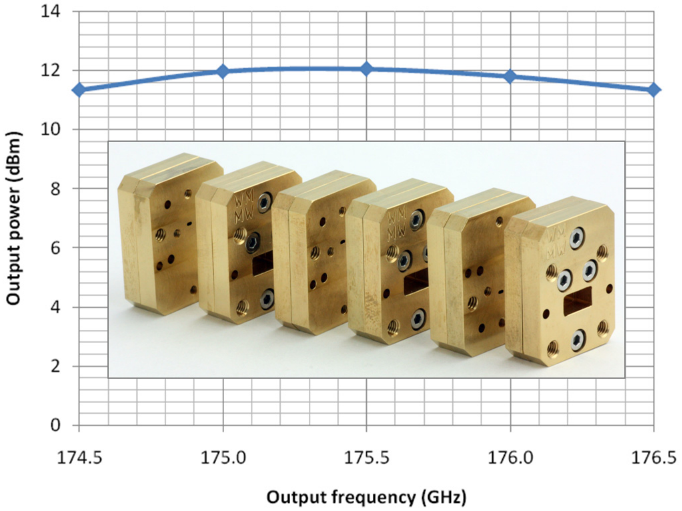


Figure 3. Measured output power for the HBV quintupler LO module.

A. HBV Quintupler

The quintupler source module features an ultra-compact block design, and a microstrip matching circuit on high-thermal-conductivity AlN to improve the power handling capability [3]. The HBV diode is flip-chip soldered onto a microstrip circuit that contains the impedance matching elements and waveguide probes [5]. The AlN circuit is then mounted in a waveguide block with waveguide input/output interfaces (WR-22 / WR-5). One of the ambitions of the work was to make a design that was reliable and reproducible – therefore care was taken to minimize the number of manual steps in the fabrication and mounting. No DC electrical connection between the microstrip circuit and the waveguide block was therefore used. The epimaterial is a generic HBV design with three barriers. High power HBV diodes are fabricated using standard III-V processing techniques and utilizes four-mesas in series (4 x 3 = 12 barriers) in order to increase the power handling capability.

The output power from multiplier module was evaluated using an Erickson power meter PM2 and a frequency synthesizer followed by a Spacek power amplifier providing the input signal. A waveguide isolator was also used between the power amplifier and the HBV multiplier. In figure 3 the output power is plotted as a function of frequency for a constant pump power.

B. The Schottky Doubler based x12 Module

A W-band active x6 multiplier module developed for the LO chain of the ALMA water vapour radiometer (www.almaobservatory.org), was used together with an additional packaged W-band amplifier chip AUH-317, to pump a low power Schottky x2 multiplier (D166) from Virginia Diodes Inc.. This configuration was able to produce sufficient output power to pump two mixers and had a relative broadband response, see figure 4. The output power was measured using an Erickson power meter (PM2).

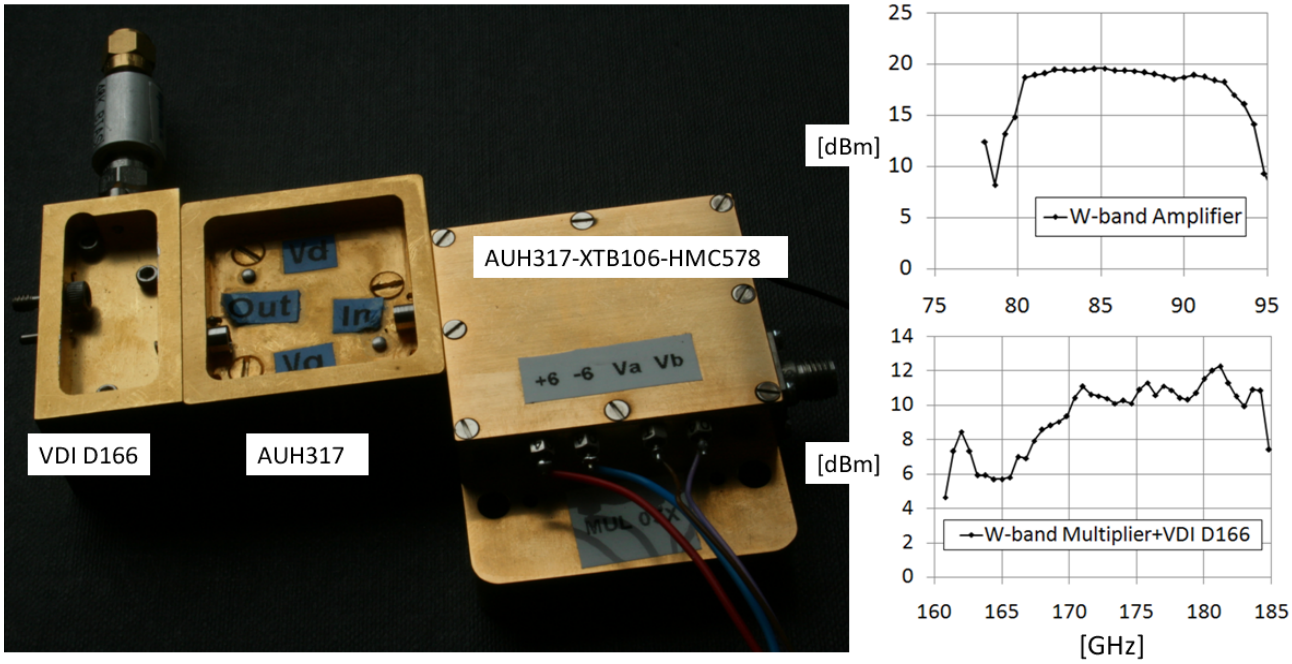
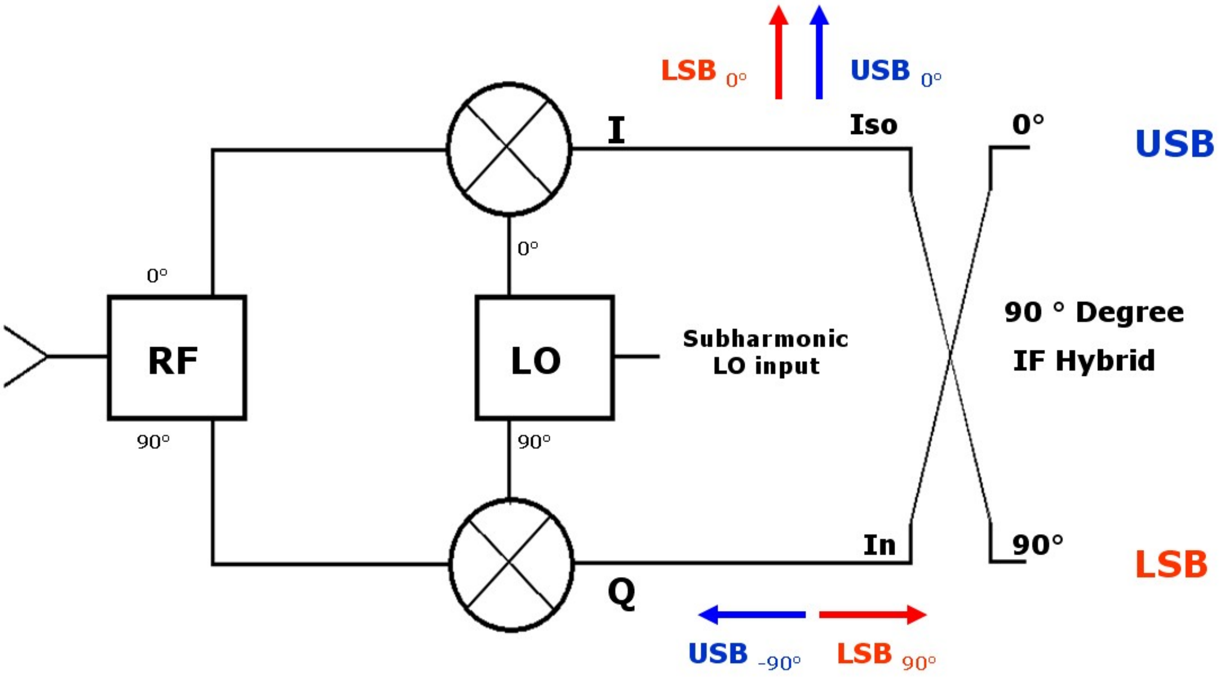


Figure 4. Photo of the medium power Schottky doubler based LO chain (left), and measured output powers from the W-band multiplier with an extra amplifier stage (top right) and from the Schottky doubler (bottom right).



$$I = \sin\left(\omega_{RF,USB} - 2\omega_{LO}\right) + \sin\left(2\times\omega_{LO} - \omega_{RF,LSB}\right)$$

$$Q = \sin\left(\omega_{RF,USB} + 90° - 2\times\omega_{LO} - 2\times 90°\right) + \sin\left(2\times\omega_{LO} + 2\times 90° - \omega_{RF,LSB} - 90°\right)$$

Figure 5. Schematic of the proposed image rejection topology that uses 90 degree RF and LO hybrids.

IV. NOVEL SUBHARMONIC SIDEBAND SEPARATING TOPOLOGY

A novel sideband separation scheme has been developed for subharmonic mixers, see figure 5. The image rejection mixer topology uses 90 degree hybrids for both the RF and LO and is therefore more resilient to poor matching of the RF and LO ports which often is the case for submm-wave mixers. More important, standing waves can be a major source to ripple in the image rejection response, but also complicates the interconnection to adjacent LO and RF subsystems and could in worst case lead to system instabilities and system failure.

The RF and LO hybrids can easily be realised in waveguide technology with relative small losses, we have chosen to use oversized branch guide coupler hybrids that have been designed using the FEM based 3D-EM simulation CAD tool HFSS and machined in a EVO NCR system from Kern with a final block precision of 5 um or better.

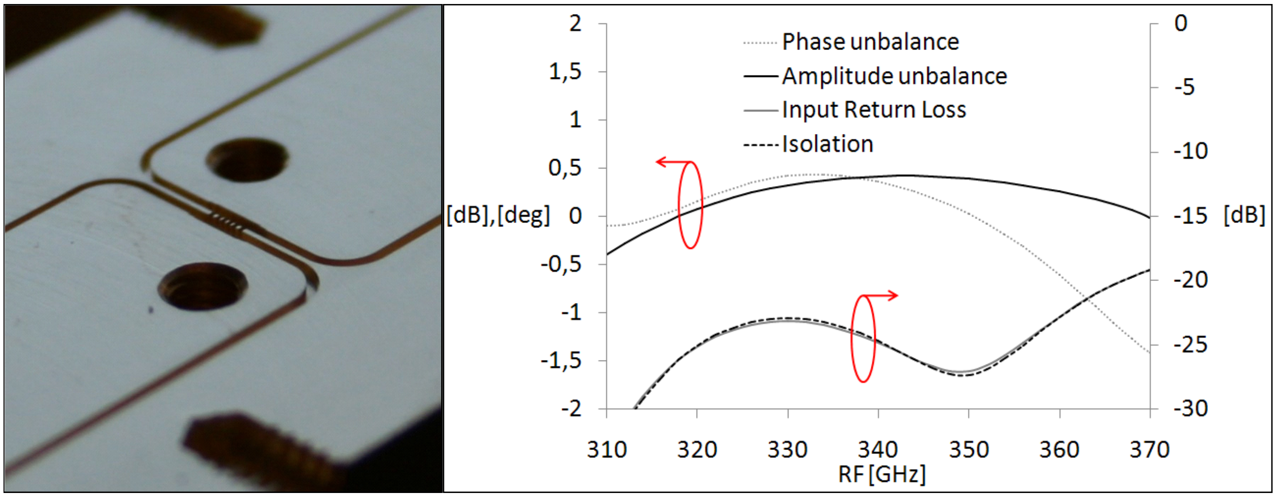


Figure 6. Photo of the WR-2.8 E-plane splitblock branch guide coupler hybrid (left) that was machined in brass using a 160 um diameter tool, the xyz-dimensions were measured in a digital microscope and are within 5 um. 3D-EM simulated performance using H-plane symmetry (right).

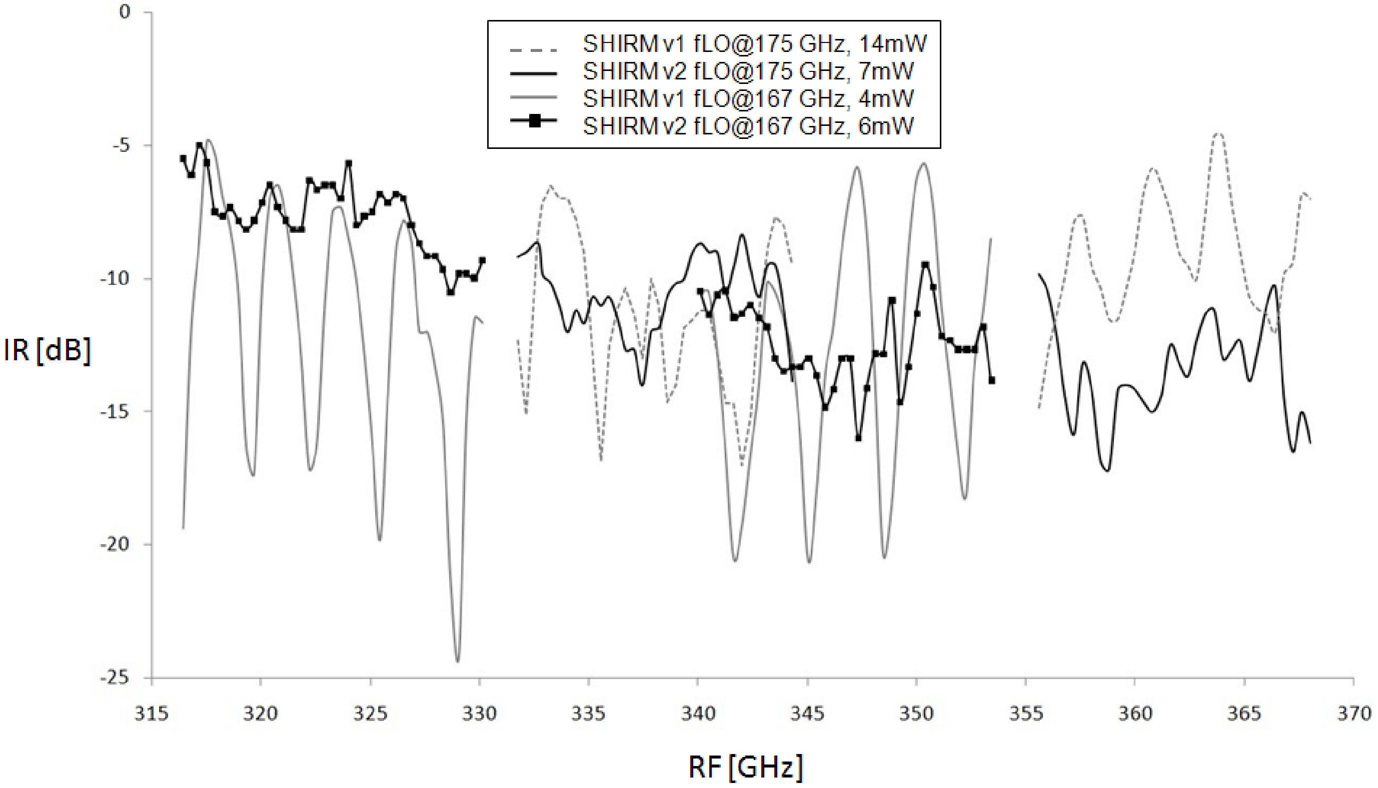


Figure 8. Measured sideband suppression vs. RF frequency of the novel (SHIRM v2, black) and previously proposed (SHIRM v1, grey) image rejection topologies at 167 GHz and 175 GHz LO frequency.

In order to evaluate both image rejection topologies a RF matched Y-junction was also designed and one of the LO hybrid sides comprised a 45 degree 3-stub loaded differential line phase shifter. In this way it could either be used as a 45/135 degree hybrid in one direction or as a 90 degree hybrid in the other direction. Both the RF Y-junction and the LO hybrid have measured a loss extending 1 dB due to the long waveguides used to separate the flange interconnects, the insertion loss of the developed RF 90 degree hybrid, see figure 6, is expected to be slightly higher as the input waveguide is longer.

V. RESULTS

Two mixers were assembled showing a divergence in receiver DSB noise temperature starting at 12 GHz IF, see figure 7. The commercial LNA's performance clearly affects the total receiver noise temperature comparing to the result obtained when using the same mixer design together with a custom 1-12 GHz MMIC LNA, with a typical noise temperature of about 75 K, developed at Chalmers University of Technology. The mixer conversion loss including waveguide, horn antenna and substrate losses has been estimated to around 9 dB broadband using a 3dB attenuator in between the mixer and LNA in a hot(RT)/cold(LN) load measurement setup.

The pair of assembled mixer modules was used to evaluate the two different SHIRM topologies at a LO frequency of 167.5 GHz (Schottky x2 based LO chain) and 175 GHz (HBV x5 LO chain) with an LO power of about 7 mW and 14 mW respectively, covering a RF bandwidth of 315 GHz to 365 GHz. Three IF hybrids from Anaren Inc were used to cover the 6-18 GHz band together with phase matched semi-rigid SMA cables and two broadband SMA packaged MITEQ amplifiers. A WR.2.8 comb generator from Virginia Diodes Inc was used to generate the RF signals.

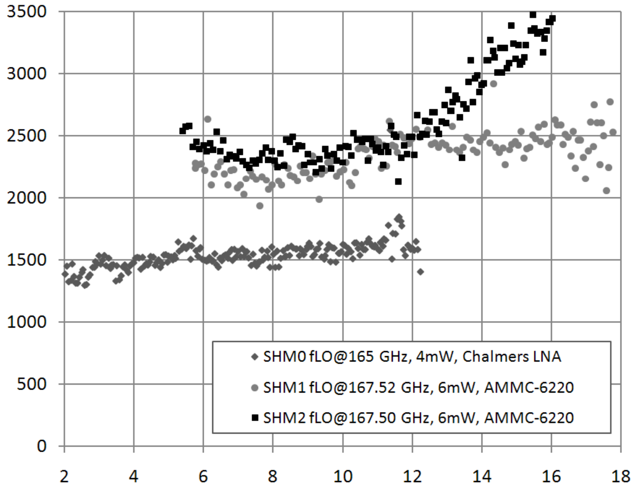


Figure 7. Receiver DSB noise temperature for three different mixer modules using Y-factor measurements.

The two sideband separation mixer prototypes are showing sideband suppression levels of -5 to -15 dB over the RF band, see figure 8, where a satisfactory level can be considered to be -15dB or better. The ripple of the previously proposed topology coincides well with the half wavelength distance in between the mixers. A quick check to confirm that this ripple was in fact coming from a standing wave in between the two mixer RF ports, two WR-03 1" long waveguide pieces were inserted in between the mixers and the RF hybrid, leading to an equally relative increase of the ripple in the image rejection response. Furthermore the novel topology had an improved image response in terms of ripple over the entire band and suppression level was improved over the upper half of the band. A test of the mixer IQ amplitude unbalance was showing no more than a 1.5 dB difference with typical values of around 0.5 dB suggesting the presence of a phase unbalance of about 40 degrees.

VI. CONCLUSIONS

The current Schottky doubler based LO chain is capable of pumping two mixers at optimum conditions, a high power Schottky doubler would however encompass variations in between the individual receiver chains and would therefore give better safety margins.

The developed HBV based LO chain, optimized for high power, makes an attractive alternative for pumping mixer arrays and image rejection mixers. The novel compact topology could also be optimized for medium to low power outputs to better match the requirements of a single receiver unit.

The receiver noise temperature could be improved further by cooling (about -60C degrees) but it is not yet clear whether a noise temperature of 2000 K DSB can be reached. By using a custom LNA design with similar performance as with the Chalmers 1-12 GHz MMIC LNA, we estimate that a DSB receiver noise temperature of less than 1700 K over the whole band can be reached.

The novel image rejection topology is showing a potentially improved performance compared to the other topology, however it needs to be evaluated further and acceptable sideband suppression levels must be reached. By better understanding the source of unbalance, further steps towards an improved performance can be taken. The RF hybrid design will be verified and more mixer modules must be assembled in order to assure a good balanced mixer pair. Integration of the hybrids with the mixers should of course remove any uncertainties coming from flange interconnects and long waveguides in the current setup. This would also reduce LO and RF losses significantly leading to a lower noise.

VII. ACKNOWLEDGMENTS

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