A Sideband-Separating Mixer Upgrade for ALMA Band 9

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***Abstract*—The ALMA band 9 (600–720 GHz) receiver cartridge, as currently being produced, features two single-ended (dual sideband) SIS mixers in orthogonal polarisations. In the case of spectral line observations in the presence of atmospheric backgound, the integration time to reach a certain desired signal to noise level can be reduced by about a factor of two by rejecting the unused sideband. A proof-of-concept sideband separating mixer has been successfully designed and produced over the past few years, the results of which have been presented earlier at this conference. At the time that the band 9 cartridge got its final form, however, this mixer was not yet ready for series production. Here, we present a design study that investigates the feasibility of upgrading the current ALMA band 9 cartridge to full dual-polarisation sideband separating capability, with minimal impact on the overall structure of the cartridge. The goal is to re-use as many of the parts and techniques of the existing cartridge as possible to provide a minimal-cost upgrade path, to be available in a couple of years.**

***Index Terms*—Sideband separating mixers, Submillimeter mixers, ALMA band 9**

I. Introduction

At the time that the current ALMA band 9 receiver cartridge was made ready for large-scale series production, it was not feasible with the then-current state-of-the-art to equip it with anything more sophisticated than single-ended double-sideband (DSB) mixers. Now that the series production is well under way, it seems to be a good time to consider future alternatives. The most obvious candidate, since it promises an immediate improvement in the quality of observations, is replacing the double-sideband (DSB) mixers with sideband-separating (2SB) mixers.

In a DSB mixer, both the RF frequencies are detected that satisfy $\omega_{IFb} \leq (\omega_{RF} - \omega_{LO}) \leq \omega_{IFt}$ and $\omega_{IFb} \leq (\omega_{LO} - \omega_{RF}) \leq \omega_{IFt}$, with ω_{RF} and ω_{LO} respectively the antenna input and local oscillator frequencies, and ω_{IFt} and ω_{IFb} the top and bottom of the IF band. In other words, any signals that end up with negative frequencies during the downconversion process overlay those with positive frequencies. Especially for high frequency bands like band 9, this is a significant handicap because of the relatively high absorption (and therefore emission) of the atmosphere, even under the best of observing conditions. Removing the atmospheric noise from the image band can reduce the required observation time by a factor of the order of two, depending on the relative intensities of the spectral lines and the background.

Manuscript received 20 April 2009. This effort is supported by the European Community Framework Programme 7, Advanced Radio Astronomy in Europe, grant agreement no.: 227290, as well as by the NOVA3 program of NOVA, the Dutch Research School for Astronomy. A.M. Baryshev is supported by a personal NWO/STW VENI grant "Advanced Heterodyne Mixers for THz Applications".

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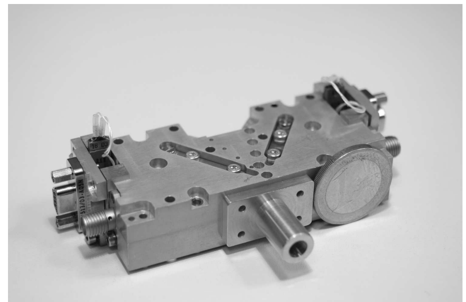

Fig. 1. Photograph of the original prototype 2SB mixer block.

The baseline of the design study presented here is a minimal-impact upgrade for the as-produced band 9 cartridges. This means that we try to reuse as many of the existing components (especially the expensive and long lead-time items). Also the per-cartridge effort to do the upgrade itself is intended to be minimized.

II. History

Several years ago, an effort was initiated to investigate the possibility to provide 2SB mixers for ALMA band 9 [1]. A design for a proof-of-concept mixer block was prepared [2], fabricated in several ways [3], [4] and characterized. A full account has been submitted for publication [5]. Here we will just summarize some key features and results.

The original 2SB mixer (Fig. 1) was a monolithic split-block design containing the RF hybrid, LO couplers, LO horn, matched loads, SIS junctions, magnet coils and magnet conductors for Josephson suppression and DC bias tees. The corrugated RF input horn is bolted as a separate component to the mixer block.

A conventional scheme is used for sideband-separation (shown in figure 2): a 90° RF input hybrid, -9dB LO couplers, two SIS mixers and a 90° IF output hybrid. The waveguide implementation of this scheme is shown in figure 3.

The most important results (noise temperature and separation efficiency) that were obtained with this mixer block are

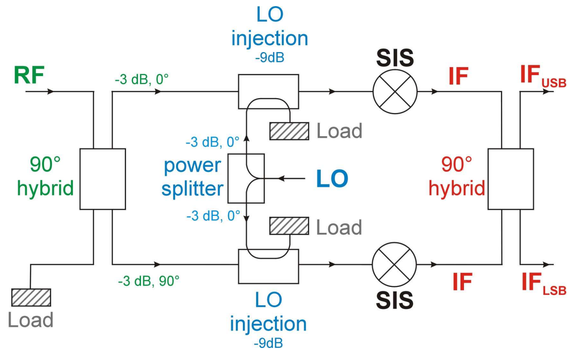

Fig. 2. The mixing scheme employed in both the original prototype and new design.

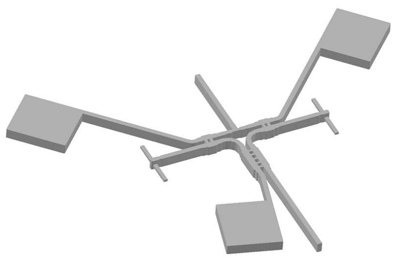

Fig. 3. The waveguide structure, shown in negative, of the RF part of the prototype 2SB mixer. The RF input is in the front, the LO input on the rear. The large square cavities contain the matched loads.

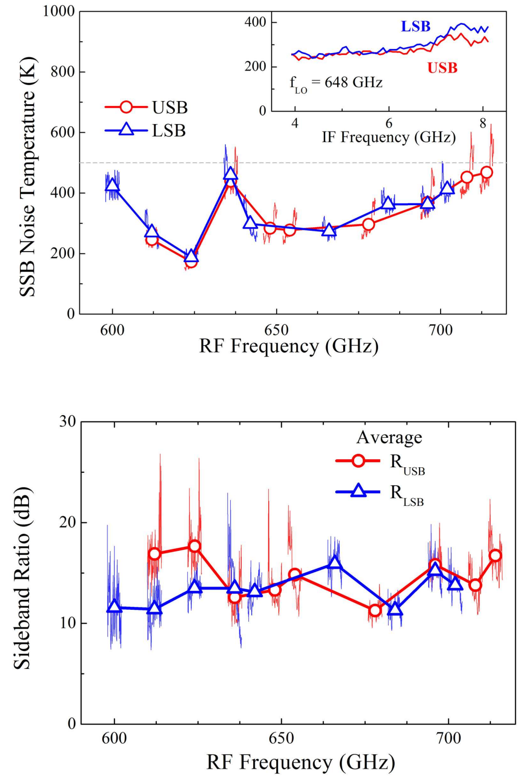

Fig. 4. The noise temperature and sideband-separation performance as obtained with the prototype mixer block. The ALMA requirements are 335K SSB noise temperature over 80% of the band, and 500K over the entire band; the separation should be better than 10dB.

shown in figure 4. As can be seen, even in its prototype state, the performance is already within ALMA specs for most of the frequency band.

III. Design Concept

One of the main lessons learned from the implementations of the original 2SB mixer block is the importance of a modular design, for several reasons. In the first place, because of the high complexity of the mixer block, involving machining on vastly different scales, it turned out to be very difficult to obtain blocks of satisfactory quality. Many times, in a late stage of production, small mistakes or accidents happened, ruining all the machining effort that had been put in already. In a more modular design, production is still critical, but the consequences of errors will be much more contained.

Another serious handicap that turned up in the monolithic design was the inability to replace mixer devices individually. To obtain a high sideband separation, not only the hybrids have to be of high quality, also the junctions (especially their gain) must be balanced as much as possible. Removal of a mixer device from the monolithic 2SB block involved dissolving the glue that held the device, and this turned out to be impossible without losing the other junction, which was only a couple of millimeters away. This made the matching of junctions a very laborious and time-consuming process. In the new design it will be possible to exchange the mixer devices independently.

Even a modular design of a mixer block does not automatically imply ease of assembly. Therefore, additional design criteria were defined, such as that a minimum number of components have to be removed to replace junctions, no wires have to be unsoldered, PCBs removed, etc.

Because this design study targets a minimal-impact upgrade of the currently produced receiver cartridges, compactness is an important issue. Especially the optics package, which in the production cartridges consists of two closely integrated blocks that contain all the mirror surfaces, is an expensive and critical part. The initial intention is to keep the current optics blocks, possibly with minor reworking. Other parts, like the optics mounting bracket (“cradle”) are easier and cheaper to manufacture again, and less effort shall be spent to try to reuse those.

Other expensive or long-lead time parts are the 4–12GHz cryogenic isolators and low-noise amplifiers. Whether these can be kept depends for a large part on the chosen IF configuration, which in turn is determined by the capabilities of the back-end and correlator, and, last but not least, the preferences of the observer community.

IV. Configurations

One of the requirements for any ALMA receiver cartridge is that the total bandwidth is 8 GHz. Currently all bands employing 2SB mixers output both upper and lower sidebands, both over a band of 4–8 GHz. Band 9 is the only production band with DSB mixers, so there an IF band of 4–12 GHz is required to meet the total bandwidth specification.

When moving from a DSB to 2SB scheme, two different IF configurations can be envisioned.

- True 2SB, exporting both lower and upper sidebands, each over 4–8 GHz at the output of the cartridge.
- Effective SSB, terminating one of the sidebands in a 50 Ω load, exporting the other one over a 4–12 GHz IF band.

The SSB option has the advantage that expensive items like the IF isolators and cryogenic low-noise amplifiers (LNAs) can be reused, provided that the IF output hybrid of the 2SB mixer is of sufficient quality that a single isolator can be placed after it, instead of two in between the mixers and the IF hybrid.

In the case of the true 2SB option, new 4–8 Ghz isolators and LNAs have to be procured, which, although they are less expensive than their 4–12 GHz counterparts, still constitute quite an expense, especially since four of each are needed per cartridge. On the other hand, since 4–8 GHz components are easier to produce with high performance than 4–12 GHz components, the overall system noise temperature may be slightly better in the 2SB case.

Note that in the SSB case, it is still possible to choose which sideband is presented at the output, simply by reversing the bias of one of the mixers. It is therefore not necessary to extend the LO range to cover the entire 600–720 GHz RF band.

Sometimes, it can be an observational advantage to have two sidebands some distance apart, so two widely-spaced spectral lines can be observed at the same time, one in each sideband. On the other hand, if the lines are less than 8 GHz apart, the SSB option is more favorable. It should be clear that the final decision has to be made in close collaboration with the observing community.

There is of course a third possibility, which involves exporting both sidebands over 4–12 GHz. At the moment (to the best of our knowledge) neither the back-end nor the correlator can handle a total bandwidth of 16 GHz. However, if there is an opportunity to extend those systems in the future, a 4-12 GHz 2SB option can be considered. It might be feasable to make the design in such a way that the additional isolators and amplifiers can be retrofitted at a later stage.

V. Modular Hybrid - Mixer Block

Since the current production of single-ended mixers for the ALMA band 9 cartridges involves testing and characterisation of many devices, it was decided to design the new 2SB mixer block around the standard band 9 junction holders ("backpieces"). These are compact, easy to mount on a standard horn for testing and matching, reusable, and, because of the high production volume, relatively cheap. The mounting and unmounting of mixer substrates is routinely done in-house. And, finally, since the junctions are in the same RF environment as the single-ended band 9 mixers, no new junction design is necessary; in fact, the 2SB mixer development effort benefits immediately from improvements and developments in the current production devices.

Figure 5 shows a cross-section through the proposed 2SB mixer. All parts are arranged around the central hybrid block.

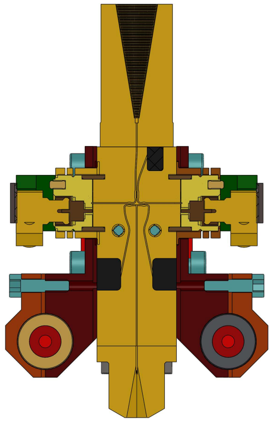

Fig. 5. Cross-section of the new 2SB mixer block. The RF input horn is at the top, the LO horn at the bottom. Left and right of the hybrid are two standard ALMA band 9 mixer backpieces, below them the magnet coils.

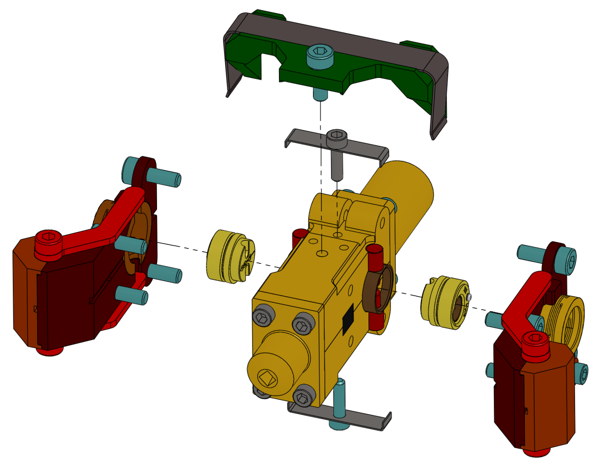

Fig. 6. Exploded view of the new 2SB mixer, showing the way it is disassembled to replace the mixer backpieces.

Two band 9 backpieces mate to the waveguides coming from the LO couplers. The alignment of the waveguides to the backshort cavity in the backpieces is done by a centering ring, a proven concept used in the single-ended band 9 mixers. It allows for easy exchange of the mixer devices without need of any special tools or even a microscope. The backpieces are held in place by spring-loaded retainer caps, also adapted from the DSB mixers. The magnet coils for the suppression of the Josephson current are integrated into the backpiece covers, together with the magnetic field conductors that guide the field

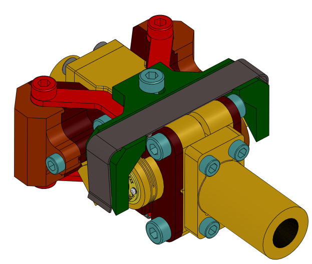

Fig. 7. The new design in its assembled state.

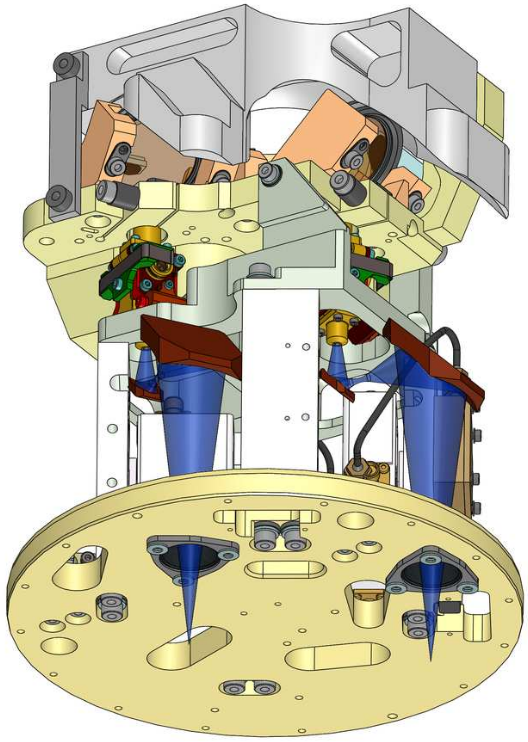

Fig. 8. The two 2SB mixers in place in the original optics assembly. The LO beams are diverted and refocussed onto the LO input horns.

to the junction. Figure 6 shows how the assembly is done. A few clips mounted on the top and bottom of the blocks provide pressure to the field conductors and the cable-mounted GPO IF connectors. The entire 2SB mixer block is shown in its assembled state in figure 7. A few auxiliary parts, like temperature sensors and DC connectors are not implemented yet, since their placement depends on space restrictions around the mixer, which have not been considered in detail yet.

VI. LO INSERTION

The LO insertion into the mixer block is mainly a geometrical problem. Two slow LO beams, one for each polarisation, are formed on the 90 K deck of the cartridge and pass upwards through the 12 K and 4 K decks. In the original DSB cartridge, they are then intercepted and horizontally focussed into the mixer horns by way of two 45° beamsplitters.

In the new design, the LO beams have to be diverted to axes diametrically opposite to the RF input horns. Because the optical pathlengths are now different from the original design, the beams have to be refocussed before they can couple to the LO horns in the mixer blocks. A design concept is shown in figure 8. Not worked out yet are the exact shapes of the mirrors and their mounting fixtures.

VII. IF HYBRID

One of the conclusions from the measurements on the original 2SB mixer block is that the sideband-separation performance was probably mainly limited by the quality of the IF output hybrid [5]. No commercial hybrids were found that would perform satisfactorily at 4K. An in-house effort involving a three-layer PCB to obtain a coolable 90° hybrid was somewhat successful performance-wise, but turned out to be a real challenge to produce even in a single copy.

Since the IF hybrid performance is of key importance to the 2SB mixer, especially in the 4–12 GHz case, we intend to construct a new hybrid, probably based on some form of interdigitated microstripline structure [6], made out of a superconducting film on a high-epsilon substrate, such as silicon. This should provide a compact and essentially lossless device. The technology to produce these, including the necessary bridges over the striplines is available in-house nowadays. The intention is to integrate the DC blocks, bias tee and eventual filter structures on the same substrate.

As an aside, a completely different solution (obviously out of the question for an ALMA cartridge upgrade) would be in the form of a real-time digital back-end performing the function of the IF hybrid, in which case it would even be possible to correct for rather large phase errors in the RF input hybrid.

VIII. OTHER IMPROVEMENTS

If it is decided that an upgrade of the produced cartridges is to go forward at a future date, it would of course be a good opportunity to look for other possible improvements. One of the most interesting ones would be an improvement of the cross-polarization performance, which leaves something to be desired in the current production cartridges. Since this would involve a major redesign of the entire optics package, we cannot speak about a minimal-impact upgrade anymore, and the cost would be substantially higher. We intend, in time, to present different options, with their estimated price-tags to the project, of course in close contact with the observing community. Actually, since most of these things will take several years to develop, about now would be the perfect time to start voicing ideas, suggestions and requests for future upgrades.

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