4-x-00

Reply To Tony Kerr's Comments on Memo 301

It is apparent from Tony's comments on my ALMA Memo 301 "SSB vs. DSB for submillimeter receivers" that the memo is ambiguous in some respects, so I wish to clarify matters somewhat.

Firstly, regarding the class of image separation schemes that are addressed, it is stated in the abstract that *quasioptical diplexers* are considered. Despite this, the formulation of the problem is in fact more general and can be used for the phasing type mixer, as Tony has done in his comments. I was trying to get as general a formulation of the problem as possible to elucidate the effects of non-idealities in devices. However for the subject of the memo I restricted the numerical evaluations to the specific case of submillimeter quasioptical systems, using my best estimates for realistic values.

The main reason for considering quasioptical devices is that they have actually been implemented for submillimeter receivers and used, for example at 492 GHz by the Japanese on the Mt. Fuji telescope [1]. However, as I stated no waveguide or planar integrated sideband separating mixers have been developed. I am well aware of Tony's work on integrated mixers that has appeared in the ALMA memo series as well as the THz Symposium. I am also aware of the waveguide sideband separation scheme presented by Akeson *et al.* [2], but they are not *submillimeter* mixers, which is the topic stated in the title of Memo 301. At the Grenoble JRDG meeting in December 1999, Victor Belitsky, and Matt Carter and Bernard Lazareff also proposed waveguide schemes that should be amenable to extension to submillimeter wavelengths.

The reason I chose to concentrate on technology that has been demonstrated at submillimeter wavelengths is that, because of the size, timescale, and budgetary constraints of ALMA, we need to be on a very firm footing with the technology we propose to implement on the initial instrument which will be under construction in a couple of years. I was assuming that the integrated sideband separating mixer technology would be sufficiently mature at *millimeter* wavelengths since it will have had five years or more of development.

The arguments are actually deeper than whether or not it is possible in principle to build sideband-separating mixers at submillimeter wavelengths. If we can build 70 simple, fixed-tuned, single-ended mixers then we must either use quasioptical diplexers or make them DSB. If we use a diplexer then the advantage for single-sideband observations is marginal and there is a disadvantage for DSB observations (which could comprise a significant fraction of the observing). It would therefore seem prudent to avoid the complications of size and moving parts for a small or non-existent advantage. If we can build 140 of the simple mixers we could use them in a waveguide scheme for an image-separating mixer. However, even with the more optimistic numbers Tony quotes, the advantage is only of the order of ~1.3 for current receiver noise temperatures. This factor would apply to both SSB and DSB observations. By using the two mixers with a grid we would expect an improvement of 1.4 over a single mixer (maybe slightly less, allowing for losses in the grid) for both SSB and DSB. Furthermore, the simple system gives dual polarization measurements. While polarization observations may not be a large fraction of the science the capability may be useful for accurate calibration if the calibration sources are partially polarized.

It is only if we build 280 of the simple mixers with performance equal to or better than the state of the art that the image separating scheme has a significant advantage. Not only is this very challenging for mixer fabrication, but also for the LO since we need to pump four mixers at submillimeter wavelengths. Using balanced mixers can alleviate this, but the total number of simple mixers is now 560.

It was these considerations that led me to propose in the conclusion of Memo 301 that the initial receivers be a simple DSB variety, with development of waveguide or integrated sideband separating mixers going in parallel but not being on the critical path.

[1] LMSA D&D plan (Japanese plan for ALMA) presented at URSI General Assembly in Toronto, 1999 August, K; Kohno and LMSA Receiver Working Group, "Japanese receiver situation," http://www.nro.nao.ac.jp/~lmsa/ursi99-lmsadd/rx.pdf

[2] R. L. Akeson, J. E. Carlstrom, D. P. Woody, J. Kawamura, A. R. Kerr, S. -K. Pan, and K. Wan, "Development of a sideband separation receiver at 100 GHz," *Proc. Fourth International Symposium on Space Terahertz Technology*, UCLA, 1993.

Comments on James Lamb's memo, "SSB vs DSB for Submillimeter Receivers," (ALMA Memo 301)

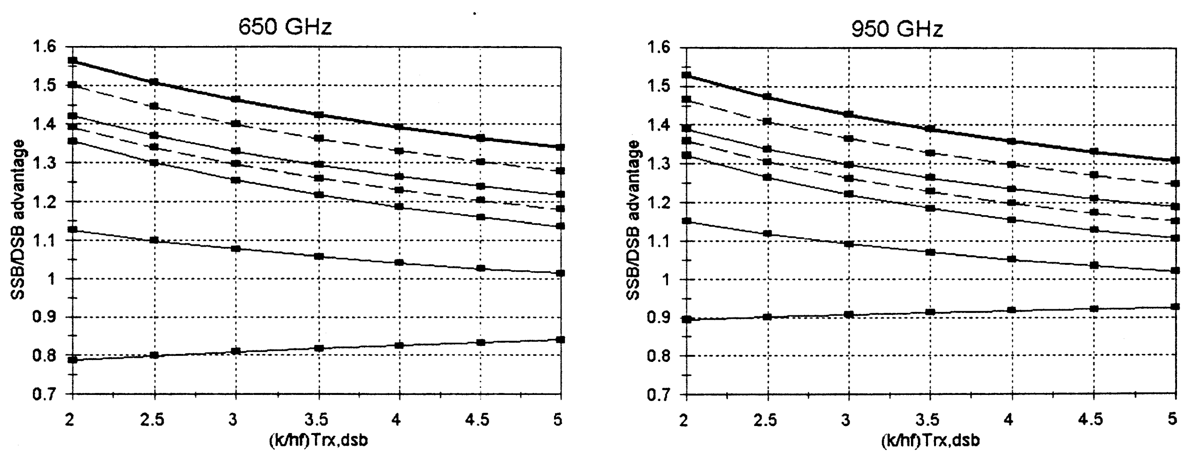
While Memo 301 admirably demonstrates the shortcomings of the input diplexer type of SSB receiver, readers not aware of the different types of SSB receiver will take it as applying to all SSB receivers. The title, *"SSB vs DSB for Submillimeter Receivers,"* implies consideration of the whole class of SSB receivers, which is not the case. Furthermore, the recommendation in the last paragraph of the paper is made without consideration of all the options.

Memo 301 considers only the type of SSB receiver with a four-port image-separating diplexer, typically a Martin-Puplett interferometer, in front of the mixer. The other, generally superior, type of SSB receiver uses the phasing type of sideband separating mixer and requires no input diplexer. The mixers use quadrature and 180° hybrids, either in the signal and LO waveguides or integrated into the SIS mixer chip. This is mentioned only in passing in the conclusion of Memo 301: "*...In the long term it is likely that image separating mixers will be developed in a compact (waveguide or planar integrated) form...*" Apparently the author is not aware of the 210-270 GHz single chip sideband separating mixer developed several years ago at NRAO and reported at the 1998 THz Symposium.

Memo 301 elucidates some of the practical disadvantages of the input diplexer type of SSB receiver, in particular: (i) The inevitable signal loss in the diplexer strongly affects the system sensitivity. (ii) The physically large diplexer and its cold image load must be cooled to 20 K or lower. (iii) An image rejection ratio of at least 10 dB is needed, which, because of the frequency characteristics of the typical diplexer, can only be achieved over a limited IF bandwidth. (iv) The precise cryogenic tuning mechanism increases the complexity of the receiver and compromises reliability. It was for precisely these reasons that the CDL began development several years ago of sideband separating mixers of the phasing type based on planar and waveguide hybrids.

The phasing type of sideband separating receiver, overcomes most of the shortcomings of the input diplexer type: (i) It is contained within the normal size mixer block, and therefore adds little volume to the receiver. (ii) Being in the mixer block, the internal image termination is held at a low and very stable temperature ~4 K. (iii) Very little loss is added in the signal path. (iv) The IF bandwidth is not limited by the RF diplexer. (v) Mechanical tuning is not required.

The curves below compare the performance of the phasing type of SSB receiver with that of the Martin-Puplett diplexer type.



In each graph the upper solid curve is for ideal SSB receiver of any kind. The solid curves are for a Martin-Puplett diplexer type of SSB receiver and reproduce those in Memo 301, Figs. 3 and 4. The dashed curves are for the hybrid type of SSB receiver with the following parameters:

Upper dashed curve: Hybrid loss 0.1 dB, image rejection R = 15 dB.
Lower dashed curve: Hybrid loss 0.2 dB, image rejection R = 10 dB.

To compare the input loss of the phasing type of sideband separating receiver with that of the corresponding DSB receiver requires consideration of two factors:

> To add a waveguide hybrid in the mixer block (or on the mixer chip) requires an additional length of waveguide of about one wavelength. From the waveguide loss figures below, the added loss will be very small, even at 700 GHz.
>
> In the phasing type of receiver, the LO coupler is built into the mixer block (or mixer chip). DSB receivers usually have a room temperature quasioptical LO coupler or a cold waveguide coupler ahead of the mixer. Integrating the LO coupler into the mixer block (or chip) should result in reduced input loss.

The excess input loss of the phasing type of sideband separating receiver, relative to the corresponding DSB receiver, can be kept small as long as excessive runs of waveguide (or CPW) are avoided. It is unlikely that the difference will exceed 0.2 dB at the higher frequencies and 0.1 dB at lower frequencies, and this is cold loss at ~4 K. Depending on the LO injection scheme for the DSB receiver, the phasing SSB receiver could even have less input loss (consider the LO couplers in the 12-m rocket modules, which add about 1 inch of waveguide ahead of the mixer).

<u>Waveguide and Planar Circuit Loss</u>:

For room temperature copper or coin silver WR-10 at 100 GHz, 0.1 dB/in is typically measured. For a given f/fc (e.g., at midband), the loss of a waveguide goes as f^(3/2). Scaling from 100 GHz gives (for the appropriate size waveguide):

100 GHz	0.1 dB/in	0.012 dB/λ_0
200	0.28	0.017
300	0.52	0.020
600	1.5	0.030
700	1.9	0.032

Cooling reduces the loss but I don't have any data on that.

The loss of a planar quadrature hybrid using capacitively-loaded coplanar waveguide can be estimated approximately from the Mattis-Bardeen theory. Pan has calculated that a 50-ohm Nb CLCPW should have 12 dB/in at 720 GHz, which corresponds to 0.20 dB/λ_0. Probably the loss of a planar mixer would not be prohibitive, but other factors may make the waveguide configuration preferable at 700 GHz. We have ordered a 602-720 GHz waveguide quadrature hybrid from Custom Microwave for evaluation.

A. R. Kerr 19 April 2000