Comparison of Double-Sideband and two-Single-Sideband Systems

for ALMA

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Summary. We compare a Double-Sideband (DSB) system with 4 IFs of 2-GHz bandwidth each (4 GHz times two polarizations = 8 GHz total) and the two-Single-Sideband (2SB) system with 8 IFs of 2-GHz bandwidth each (4 GHz times two polarizations times separated two sidebands = 16 GHz total) that has been proposed for the baseline ALMA.

We compare the sensitivity of these systems by adopting the state-of-art receiver temperatures and, for the DSB system, the conventional process of sideband separation in correlation by switching of first LO phase by p /2 or by fringe rotation. Under a good atmospheric condition (25-percentile atmosphere at Chajnantor), the sensitivity ratio (DSB/2SB) is 0.83 at 110 GHz, 0.98 at 225 GHz, 0.83 at 650 GHz and 0.86 at 950 GHz, in both continuum and spectral line observations. In general, the advantage of the 2SB system in sensitivity over the much simpler DSB system is only marginal. In reality, many of the observations at millimeter wavelengths may be executed under conditions that make submillimeter observations difficult. Through the 75-percentile atmosphere (225 GHz opacity of 0.12), the sensitivity ratio (DSB/2SB) would be 0.76 and 0.86 at 110 GHz and 225 GHz, respectively. In imaging extended sources, ALMA will rely on accurate single-dish data taken with the 12-m dishes. Unlike the 2SB system, the DSB system requires an accurate calibration of the sideband gain ratio for single-dish observing. This may be possible by an interferometry of a continuum source with known spectral indices, although its feasibility and the achievable accuracy need to be examined.

These considerations coupled with the currently limited availability of 2SB mixers for the ALMA bands and the simplicity of the DSB system makes the choice of the DSB system a viable option for the initial ALMA system.

1. Atmospheric Transparency at Chajnantor

We refer to the ALMA memo 334.1 (Radford and Chanberlin 2000) for the statistics of the 225 GHz atmospheric transparency as listed in Table 1. Here we assume that ALMA will be operated in such a way that submillimeter-wave observations (e.g., at 650 GHz and 950 GHz) are made under the best 25-percentile atmosphere while many of the millimeter-wave observations (e.g., at 110 GHz and 225 GHz) are executed under less ideal conditions represented by the 75-percentile atmosphere.

Table 1. 225 GHz optical depths at Chajnantor from 1995 Apr. to 2000 Jul.

Available time	Zenith Opacity
25 %	0.036
50 %	0.061

75 %	0.115

2. A ratio of the system temperatures between DSB and SSB systems

We refer to the ALMA memo 304 (Thompson and D'Addario 2000) to estimate a ratio of the system temperatures between SSB and DSB systems. For Trx[DSB], we take a midway in the range 2 hf/k – 4 hf/k quoted by them. We define a ratio of the system temperature as

$$\alpha = \text{(system temperature of double-sideband system)} / \text{(system temperature of single-sideband system)} = \text{Tsys[DSB]/Tsys[SSB]}.$$

For the atmospheric transparency at submillimeter-wave bands, we assume the 25-percentile atmosphere. For the millimeter-wave bands, we estimate a for both the 25- and 75-percentile atmospheres.

Table 2. Values of a

Frequnecy [GHz]		110		225		650	950
Zenith Opacity		0.05	0.10	0.05	0.12	0.80	1.5
Tant	ALMA memo 301	28.8	43.2	28.8	48.7	171.2	222.8
Trx[DSB]	3 hf/k	15.8	15.8	32.4	32.4	93.5	136.7
Trx[SSB](DSB equiv.)	4 hf/k (top data)	21.1	21.1	43.2	43.2	124.7	182.3
SSB Rejection Ratio [R]	+13 dB	20	20	20	20	20	20
Tsys[DSB]	Trx[DSB]+Tant	44.6	59.0	61.2	81.1	264.7	359.5
Tsys[SSB]	(1+1/R)(2Trx[SSB]+Tant)	74.5	89.7	120.9	141.8	441.7	616.7
Ratio of sensitivity (α)		0.60	0.66	0.51	0.57	0.60	0.58

3. Relative Sensitivity of SSB (1SB), 2SB and DSB systems

We compare the performance of 1SB, 2SB and DSB systems, where these present the same bandwidth of at the digitizer, by considering the number of IF lines. For the DSB system, we assume the conventional process of sideband separation in correlation by switching of first LO phase by $\pi/2$ or by fringe rotation. (ρ<<1).

Table 3. Relative Sensitivity of 1SB, DSB and 2SB systems

	Continuum Source	Spectral Line Source
1SB (SSB 4IF)	1	1
2SB (SSB 8IF)	$\sqrt{2}$	1
DSB (DSB 4IF)	$1/(\sqrt{2}\,\alpha)$	$1/(2\alpha)$

4. Relative Sensitivity of 2SB and DSB systems

We can renormalize Table 3 to give the sensitivity ratio between 2SB and DSB systems.

Table 4. (Double-Sideband Sensitivity)/(Two single-Sideband Sensitibity)

	Continuum Source	Spectral Line Source
2SB (SSB 8IF)	1	1
DSB (DSB 4IF)	1/(2α)	1/(2 α)

5. Relative Sensitivity of DSB and 2SB systems for ALMA

By adopting a values in Table 2, we derive the Relative Sensitivity of DSB and 2SB systems for ALMA. The ranges of values for 110 GHz and 225 GHz show the cases of 25-percentile (higher values) and 75-percentile (lower values) atmospheric transparencies.

Table 5.Relative Sensitivity of DSB and 2SB systems for ALMA

	Continuum Source				Spectral Line Source			
	110 GHz	225 GHz	650 GHz	950 GHz	110 GHz	225 GHz	650 GHz	950 GHz
2SB (SSB 8IF)	1	1	1	1	1	1	1	1
DSB(DSB 4IF)	0.76-0.83	0.88-0.98	0.83	0.86	0.76-0.83	0.88-0.98	0.83	0.86

For Band 1 in ALMA, on the other hand, we must compare a Double-Sideband (DSB) system with 4 IFs of 2-GHz bandwidth each and the two-Single-Sideband (1SB) system with 4 IFs of 2-GHz bandwidth. The range of values for 40 GHz also shows the cases of 25-percentile (higher values) and 75-percentile (lower values) atmospheric transparencies.

Table 6.Relative Sensitivity of DSB and 1SB systems at Band 1 for ALMA

	Continuum Source	Spectral Line Source
	40 GHz	40 GHz
1SB (SSB 4IF)	1	1
DSB(DSB 4IF)	0.88-0.94	0.63-0.67

Under the good atmospheric condition, the advantage in sensitivity of the 1SB system over the much simpler DSB system is only marginal, except for spectral line observations at 40 GHz. In the worse conditions, the relative advantage of the 1SB system becomes larger.

6. Calibrating Sideband Gain Ratios in the DSB System

In imaging extended sources, ALMA will rely on accurate single-dish data taken with the 12-m dishes. Unlike the 2SB system, the DSB system requires an accurate calibration of the sideband gain ratio for single-dish observing (see, e.g., Kerr, Pan and Effland 2001, ALMA memo 357). This may be possible for DSB mixers by an interferometry of a continuum source with known spectral indices (D'Addario 2000, ALMA memo 287), although its achievable accuracy need to be examined.

7. Future Expandability of the DSB System

If we design carefully and choose the bandwidth of the fiber link to be able to accommodate the 2SB system, the DSB system can be expanded to 2SB by simply adding more frequency converters, E/O converters, and digitizers. The total cost in this later-expanded 2SB system would not be excessively large compared with the budget for installing the 8-IF 2SB system from the beginning.

Another interesting option is to implement the correlation scheme with a wavefront clock, which will double the continuum sensitivity of the DSB system (i.e., 1.5 - 2 times better than 2SB) for a limited field of view.

8. Concluding Remarks

The above considerations indicates that implementing 2SB system into ALMA achieves a modest increase in scientific capability in a limited number of receiver bands for which 2SB mixers are available. This, on the other hand, introduces the complexity of the receiver frontend system and a significant increase in the total cost. James W. Lamb (2000, ALMA memo 301) has noted this for the ALMA submillimeter bands. We confirm his point and extend it also to the millimeter bands. The DSB IF system (4 IF lines) can be designed to enable later expansion to 2SB (8 IF lines). The DSB system is a viable option to be considered seriously for the initial ALMA system.