Starting Point for Planning Development of an Alternative LO System

The purpose of this development is to provide a backup to the Baseline Local Oscillator System should technical difficulties occur during the stages remaining to bring it into operation. Areas in which problems could occur with the baseline include: 1) "glitches" or other errant behavior due to temporary loss of fringes or other instabilities, 2) residual phase drifts[1], 3) excess short-term phase noise, 4) insufficient range of adjustment in the case that the changes in the effective lengths of the fibers prove to be larger than expected – this would mean that the system would need to be reset more often than the once per hour that is presently planned, and 5) unreliability – it is for example possible that the baseline design will need an excessive amount of "tweaking" and maintenance to keep it working properly. This list of possible problems not exhaustive – other problems could be imagined, including long delays in obtaining critical components. It has been given in roughly the order of how serious the consequences would be for ALMA's functionality, although the seriousness of any given effect obviously depends on its magnitude. It should be emphasized that none of these problems are actually expected to occur, or even thought to be very likely – a great deal of work has been put in on the baseline design to avoid all of them. Clearly the new development should be focused on approaches that hold the promise of avoiding as many of these problems as is practical.

The position is that we have a well-documented proposal for an alternative system (refs 1-3) which has been shown to work very well in the form of laboratory prototype. The core of the development program is therefore to take this through to the stage of having a demonstration version that is compatible with the rest of the ALMA system and can be used to do real tests in Chile. There are however some remaining issues (outlined below) about how to implement it in a way that meets all of ALMA's requirements. This has led to discussion of a number of different forms of alternative LO system. Given that this is a risk-mitigation exercise rather than a research project to develop the best possible system, it would be appropriate to develop only one coherent alternative approach, or at most two or three variations on a single theme, rather than spreading the effort over a wide range of possible solutions. The first task therefore is to decide what work needs to be done to resolve these issues.

The three critical elements of the system are: 1) the "Laser Synthesizer" that generates the two optical signals with frequencies differing by exactly the amount required for the LO reference, 2) the device that measures the round-trip propagation path through the fibres, 3) the system that corrects for the variations in this propagation path.[2] In the baseline system items 2) and 3) are combined in a single device – the Line Length Corrector – but logically they are distinct. Here, in simplified form, are the options presently under consideration:

1) The alternative laser synthesizer uses a single laser with a Mach-Zehnder Modulator instead of two lasers in a master and slave arrangement. The MZM is a more direct way of generating the two signals and it should provide lower short-term phase noise. In its simple form, however, its use means that both optical frequencies change when the LO reference frequency changes and this has implications for the design of the rest of the system, as discussed below.

2) The alternative path-measurement system finds the round-trip phase of the beat between the two optical frequencies instead tracking the round-trip phase of just one of optical signals. Phase ambiguities therefore only occur for much larger changes of path (~1.5 millimeters instead of 0.7 microns) so "glitches" should not be an issue. It is also true that one is measuring the optical group velocity, which is what one actually wants, instead of the phase velocity, so the effects of dispersion are removed.

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[1] Note that drifts could arise from a) failure to correct all of the changes introduced by the long fiber, e.g. due to dispersion or polarization effects, or b) from phase errors introduced by the line length correction system itself, i.e. there could in principle be phase drifts even when the fiber itself is not changing.

[2] There are several other critical items in the overall LO system including: the signal distribution systems; the photo-mixers that convert the optical signals into the LO reference; and the WCA system that actually generates the LO signal which is locked to the reference. It is here assumed that the risks in those areas have now been retired. It is of course required that any alternative system be compatible with these items.

3) In the baseline system a length of fiber is stretched physically to compensate for the path-length changes in the rest of the system. Changes of up to about 5 mm can be compensated. Here several alternatives have been suggested: a) the use of an air-gap path compensator, b) the use of an optical phase shifter operating on one of the two optical frequencies, and c) correction for the path-length changes in software. The software correction would be applied to the phase of the astronomical signals at the output of the correlator, normally at a 2 Hz rate[3]. Option a) could provide a larger range of compensation than the stretcher, while options b) and c) provide unlimited range. Option b) has the problem that it does not correct for the effect of path length changes on the reference frequency which is used to make the second LO and the digitizer clock, because this is on a separate optical carrier at a different wavelength. It may be possible to correct that with a separate phase shifter. Option c) will miss any path changes that occur on times of less than half a second.

There are some interactions between these different choices. For example, correction in software (option 3c) requires that the output of the measurement system (item 2) is in the form of an accurate value for the change in the path length, whereas for the other cases (and in the baseline) the output is only used to close the loop in a servo and therefore just needs to take the form of a voltage that is proportional to the path change over a limited range. Another example is that closing the loop on the beat frequency requires a larger range of compensation, especially when the low reference frequency required by Band 1 is taken into account[4].

The issue that has caused the most discussion is that if we use an MZM the round-trip phase changes each time the reference frequency changes. This may happen as often as twice every 10 seconds when we are doing fast-switching and using different receiver bands for the source and the reference. This is likely to cause errors if the MZM is used together with the baseline Line Length Corrector[5]. When the MZM is used with the alternative path length measurement scheme in a closed-loop servo, it means that the stretchers or air-gap compensators have to make frequent large excursions, which might limit their operational lifetime. Options 3b) and 3c) would avoid this problem.

Clearly to decide on the way forward we need more analysis, or, if data is lacking, further tests and the important thing is to get the testing and analysis underway quickly so that can arrive at an agreed design and start its implementation. Skip Thacker has been given the task of leading this activity. Weekly or bi-weekly telecons involving the "usual suspects" might be appropriate until we get through this phase.

The immediate deadline is the Board meeting on Nov 13th and 14th. We really don't want to have to go to them and again say that we are "concerned" about this but we don't have a plan for what we are going to do about it.

REH 5th Oct 2008 (+ minor edits 8th Oct)

References:

[1] H. Kiuchi and M. Ishiguro, "An alternative scheme of round-trip phase correction", ALMA Memo No. 519, Feb 2005.

[2] H. Kiuchi, T. Kawanishi, M. Yamada, T. Sakamoto, M. Tsuchiya, J. Amagai, and M. Izutsu, "High extinction ratio Mach–Zehnder modulator applied to a highly stable optical signal generator," IEEE Trans. Microw. Theory Tech., vol. 55, no. 9, pp. 1964–1972, Sep. 2007.

[3] H. Kiuchi, "Highly Stable Millimeter-Wave Signal Distribution With an Optical Round-Trip Phase Stabilizer", IEEE Trans. Microw. Theory Tech., vol. 56, no. 6, pp. 1493–1500, Jun. 2008.

[3] This is the point in the system where the corrections for atmospheric phase fluctuations derived from the water vapour radiometers are going to be applied.

[4] The nulls are separated by half a wavelength of the beat frequency. Note that it is questionable whether it is necessary to accommodate Band 1 in the present back-up planning since this Band doesn't yet exist and its LO requirements could be met in other ways.

[5] This is controversial. REH believes that errors are unavoidable and that this rules out using the combination of the MZM and the baseline LLC, but the experts do not agree with him.