LAMA Memo 807

THE USE OF EQUAL LO TRANSMISSION LENGTHS to all antennas.[1]

Darrel Emerson, NRAO Tucson

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ABSTRACT:

There is NO proposal under serious consideration for equalizing the lengths of fiber carrying the ALMA LO reference signal from a central location at the Chajnantor site to each individual antenna. However, since there has been a little discussion and a lot of rumor about the topic, these notes have been written to explain the background.

CURRENT PLAN

The current plan, and there is no proposal to change it, is that the LO reference signal will be carried via individual fibers, from some central location to each individual antenna station. Each of these lengths of fiber will be controlled by an active line length correction scheme, to compensate for changes in propagation delay along each fiber that might be caused by thermal or mechanical effects.

POTENTIAL ADVANTAGES OF EQUALIZING LO FIBER LENGTHS:

For the case of the ALMA array looking at a source at the zenith, if all the LO paths from the central LO source are equal, then there are certain common-mode LO instabilities that cancel.

- Central LO source frequency instabilities and phase noise cancel (**but see NOTE below**), because the same instabilities appear at all antennas and so these common-mode effects have no effect on the derived interferometric phases.

- Common mode thermal effects: if all LO paths are equal, and if each LO fiber is subject to the same thermal change, then the resultant changes in propagation delay are all common mode, and so, as with LO source instabilities, these thermally-produced phase instabilities cancel in derived interferometric phases.

[1] This memo has not been subjected to any review before posting, and its content is the sole responsibility of its author. Opinions expressed are not necessarily those of the NRAO, AUI, or any other organization.

Note that if the equalizing lengths of fiber are on spools in some central lab, the thermal environment of the spools is unlikely to mirror that of fiber buried in the ground. If the equalizing lengths make use of unused fibers in a buried bundle, there may be somewhat better thermal compensation. However, these thermal changes are likely to be relatively slow, so will be taken out by astronomical calibration measurements anyway.

- Because many of the potential phase changes in the LO signal are common-mode, the active line length correctors might not need to work so hard - in fact it might be found that line length correctors were unnecessary.

****NOTE**.** With an astronomical source at the zenith, and equal LO transmission paths, these common mode instabilities will cancel well. However, in directions other than at the zenith, the signal processing inserts additional delays on each antenna, in effect to cancel out the additional free-space propagation delay from the astronomical source to the antennas furthest from the source. This means there will be an extra time delay in the relative propagation through the IF & digital signal path of common-mode changes of the LO distribution system, by the time the signals reach the correlator. This means that rapid common-mode effects (such as phase noise on the master LO source) will no longer cancel at the correlator, because of the different differential signal propagation delays. In the limit of an astronomical source near the horizon, with an antenna configuration of +/-15 km baseline, the common-mode effects will not all match in the far out antennas pairs for common-mode fluctuations on timescales less than 100 microseconds. (+/-50 microseconds is the free-space propagation time over +/-15 km). In other words, master LO phase noise beyond about 10 kHz will not cancel in the far-out antennas, even with equal LO paths, if the array is looking near the horizon.

POTENTIAL TECHNICAL DISADVANTAGES OF EQUALIZING FIBER LENGTHS:

- If the LO fiber length to all antennas is made equal, then of course that means that most antennas will end up with a longer LO fiber length, with potentially greater changes in propagation delay. Therefore each antenna LO phase, before correction, suffers bigger phase excursions (time delays) that need to be corrected by the line length compensator. Therefore the line corrector has to work harder, and may not be so effective.

- Because the total length of fiber is longer to most antennas, the signal-to-noise of the transmitted LO signal will on average be poorer, because of attenuation along the fiber, itself causing the LO line corrector to possibly work less effectively.

- The chosen LO transmission system, using the beat frequency of two lasers, relies on the long coherence time of the lasers chosen for the photonic system. Longer lengths of fibers will, on average, be more demanding on the laser time coherence, again resulting in poorer signal to noise of the LO signal and in operation of the active line correctors.

- VLBI. Not a disadvantage as such, but just to point out that equalizing the fiber lengths to minimize effects of Master LO instabilities will be no help to eventual ALMA VLBI observations.

So, overall, we may end up with bigger errors in corrected LO propagation delays, which could conceivably cause a bigger degradation in interferometric phase stability than the gain by achieved by rejecting common mode LO phase noise and common mode thermal changes.

OTHER POTENTIAL DISADVANTAGES OF EQUALIZING FIBER LENGTHS:

Cost: Actually cost impact is very low: just spools of cheaper (unarmored) cable, less volume cheaper than the cable being put in the ground. Even that may not be necessary, because can loop back and forth along unused fibers in the buried bundle of fibers. So, would probably not be a deciding factor, should there be a real advantage.

Schedule: Someone has to think through the revised LO distribution system, and make a technical evaluation of the expected gain. Probably not a big effort - maybe 2 man-weeks for 1 scientist and 1 week for an engineer?

STUDIES:

In an ideal world, a detailed study would be made, offsetting the potential advantages and disadvantages as outlined above, estimating the extra cost and schedule impact, if any, should there turn out to be a significant technical advantage. This study would involve the statistics of how much time will be spent observing at what angles from the zenith, the statistics of the Master LO frequency and phase instabilities and their timescales, the coherence length of the lasers, signal-to-noise of LO line length correction, the efficacy of the active line length correction, the statistics of how balanced thermal and other effects will be in the different fibers of equal lengths, and so on. If a real gain were found from the technical study, then the cost, schedule and technical gain estimates would be compared with other aspects of the overall system, to decide if it would be justified to make such a design change. Only then would a formal change proposal submission to the CCB be considered.

Such a study, if done properly, would not be an entirely trivial undertaking. The "gut feeling" of a number of people who have taken part in this discussion is that the technical gain, if any, would be very small, and there is some risk that, technically, more harm could be done than good. If a LATER study were to find, on the contrary, that the potential gain would be high, a system modification (adding extra lengths of fiber into the LO paths to each antenna) could be made later without significant impact on the rest of the system.

CONCLUSION:

The estimated gain of equalizing the fiber lengths is questionable, and may even be negative, so available manpower at present is better applied to other issues within ALMA, rather even than performing the needed detailed study.

There is NO proposal being considered further, to equalize LO transmission path lengths.

Darrel Emerson, April 19 2004.