Notes from LO Working Group Meeting held on Friday, July 9, 1999 in the Ivy Road Conference Room from 9 am to noon.

Attending: Skip Thacker, Kamaljeet Saini, Richard Bradley, John Battle, Dick Thompson

N square or N

Which LO errors go as N squared and which go as N	Richard Bradley
How does this affect the reference frequency.	Skip Thacker

Very briefly, for a given oscillator followed by an N times multiplier the RMS phase fluctuations goes as N, the phase noise power spectral density go as N squared, but you take the square root of the power spectral density to get rms; therefore, the rms noise goes as N. In reality it is worse than N due to other effects but can't get any better than N.

All Phase is divided into two parts

Correlated phase and uncorrelated phase	Skip Thacker
How much of each kind can the MMA tolerate	Dick Thompson

It is helpful to discuss phase drift as separate from phase noise. Phase drift is long term phase variations that can be corrected for by astronomical calibration schemes. Phase drift can be specified as the time that it takes the array to drift a specified phase. Whenever possible we would like this time to be dominated by the atmosphere instead of the array electronics. Note that the fast switching calibration scheme corrects for both the atmosphere and the electronics while the radiometric method (either 22 or 183 GHz) corrects for the atmosphere only. The number from Brundage's email, "Bryan Butler estimates from 6 mm and 1.2 cm observations that the VLA instrumental phase stability is close to 0.5 degrees per GHz of observing frequency per 10 minutes of integration between phase calibrations," is an example of phase drift not what I call phase noise. Phase noise is the short term phase fluctuations (zero mean) and contributes to the decorrelation of the signals from the antennas. This results in a loss of signal to noise ratio of the array and can be expressed as a maximum allowable loss of signal to noise ratio versus frequency. This is sometimes expressed as an rms time error in the LO. I prefer the specification to be a steeper function of frequency than the linear function implied by a constant time error. The time error specification ignores the fact that each stage of multipliers adds time errors and in order to keep the specification from being driven by the requirements of the highest frequency we should allow more error at the highest frequency. (Skip)

The group discussed phase noise as divided into five parts.
For a 3 km array, looking at the horizon we have 10 microsecond delay across the array, which means that the part of the phase noise at offset frequencies above 100 kHz are uncorrelated no matter whether they arise from the common portions of the LO or at each antenna. Phase noise

below 100 kHz offset from the carrier can be correlated if it arises from the common portion of the LO chain. To first order phase noise that is correlated at the antennas doesn't count toward phase errors. This drives one to use as high a reference frequency as possible to distribute the LO phase information to the antennas because it puts as much of the multiplication in the common part of the LO chain as possible. Phase noise from a common laser does not contribute to the uncorrelated phase so one powerful laser is better than several independent lasers that are locked to a common reference to the extent that laser noise is a measurable part of the common phase noise. Shot noise in the laser receiver photo diodes is uncorrelated and contributes to the uncorrelated phase. Noise generated in the fibers or other components such as light amplifiers that are not part of a common laser are uncorrelated and contributes to the uncorrelated phase. It is believed that a significant part of the uncorrelated noise in the fiber is at a sufficiently low frequency that it can be corrected for by a round trip fiber correction scheme and is for the purposes of these comments considered phase drift.

Phase noise as a function of offset frequency from the carrier

0 to 100 Hz	Totally correlated. Fiber corrected with round trip. Uncorrelated part of laser receivers and multipliers are small.
100 Hz to 100 kHz	Correlated except for noise in laser photo diode receivers and high frequency multipliers (ie above 100 GHz) which are outside of reference loop. *(A major goal of the LO sources effort will be to measure the noise added by the high frequency multipliers which is uncorrelated noise. Skip)*
100kHz to 1 MHz	Uncorrelated, must be made very small either by sending low noise reference signal across the FO link and locking to it or using clean up oscillator at each antenna, YIG tuned FET NOT good enough in this range.
1 MHz to 5 MHz	Uncorrelated, determined by YIG tuned FET oscillator. This is the major portion of uncorrelated phase error budget. MicroLambda YIG looks good enough in this frequency range. The 1 MHz break point is somewhat arbitrary and will depend on the detail noise spectra for the reference and the YIG.
Above 5 MHz	The phase noise from the YIG above 5 MHz offset is small enough to be ignored. Amplitude noise of the LO, which is the dominate mechanism above 5 MHz, was not considered during this meeting

LASER Relative Intensity Noise

RIN, a definition of — Richard Bradley

How does RIN affect the phase noise for the two different kinds of modulation (external am and the phase lock of two lasers)? — Open discussion

Richard presented a definition of RIN from the book Fiber Optic Communication Handbook, edited by Federico Tosco. I have scanned in one of the salient paragraphs and equations in the hope that this will help end confusion. The RIN as thus defined does not give any information about the phase or frequency fluctuation of the laser and does not characterize the phase or frequency fluctuations of a reference signal that is transmitted unless the modulation scheme and transmission media is also specified. The rest of the discussion focused on the difference between intensity modulation and amplitude modulation and the different ways the laser noise affected the external intensity modulation and the photonic scheme. Questions raised were: What loop bandwidth is the photonic laser locked with? What is the loop bandwidth of the round trip phase measurement system. In general the group was not to concerned with the laser noise in that several people have said that it should be very good and the impression is that since it is common to all antennas it should not be a significant source of noise. We do want to see the noise spectra of the reference signal at the output of the photo detector for an externally modulated laser FO system and the output of a photo mixer in the photonic LO system in the range of 50 KHz to a few MHz to answer the question once and for all about the need for a clean-up loop.

From the book Fiber Optic Communication Handbook, edited by Federico Tosco

The emission of light sources is a statistical process that is characterized by the average value of the emitted power, P, and by the spectral density of the power fluctuations, $\delta P(\omega)$. The amount of noise affecting laser emission can be described well by the "relative intensity noise" (RIN), defined as [147]:

$$\mathrm{RIN} = \frac{\langle |\delta P(\omega)|^2 \rangle}{P^2} \tag{5.153}$$

Since RIN is a ratio between an average power and a noise power spectral density, it should be expressed in Hz^{-1}; conventionally (although somewhat improperly) it is often expressed in dB/Hz, according to:

$$\mathrm{RIN}\ (\mathrm{dB/Hz}) = 10 \log \mathrm{RIN}\ (1/\mathrm{Hz}) \tag{5.154}$$

However, it should be stressed that the RIN in a given bandwidth B is not obtained by multiplying the value in dB/Hz by B, but by 10 log B.

RIN values of laser diodes range from 10^{-10} to 10^{-16} Hz^{-1}, depending on bias current and frequency. RIN also depends heavily on optical reflections. Figure 5.79 shows the result of a RIN measurement of a packaged DFB laser diode.

Are any of the MMA phase specifications driven by the spectral line requirements?

Dick seemed to think that this wasn't a problem since the resolution bandwidth needed for a 1 km/sec resolution went as the sky frequency.

More analysis is needed for a full understanding on my part but it probably is not a problem as the following worst possible model analysis shows. Sideband noise which goes as N squared affects spectral line work as well as rms phase. General specification is to look at 1 km/sec velocity resolution. (v/c= df/f for 30 GHz df=100 kHz) Note the YIG is typically L(f) = -110 dB/Hz at f = 100 KHz from carrier at 30 GHz. Adjacent channel rejection = approx L(f) + 10log(NxN) + 10log(df) = -16 dB using 3.2MHz df and N=31. Which is still ok but getting marginal. Since this analysis is worst case in the sense that it may be in error to use the L(f) = -110dB and that I should use L(3.2MHz) = -140dB . Also, the locked YIG L(f) at 100 KHz to 3 MHz will be better than the unlocked YIG in order to meet phase noise specification. I note that the HIFI phase noise specification was -108.5 dBc/Hz at 100 KHz for their 26 GHz oscillator for their 950 GHz band. (Skip)

Frequency	*Delta F for 1 km/s*	*N*	*NxN*
30 GHz	*100 kHz*	*1*	*1 (0dB)*
100 GHz	*333 kHz*	*3.3*	*11 (10.4dB)*
950 GHz	*3.2 MHz*	*31*	*1000 (30dB)*

What Specification do we need to know in order to efficiently proceed with the design and which ones would we like to leave open until we have more experimental data?

Actual frequency bands of the array

Most of the work done by this group doesn't need actual frequencies at this time. Indeed, the multiplier work may limit or suggest different bands;

Frequency of the reference distributed to the antennas

As high as possible. For the intensity modulated scheme something in the 20 to 30 GHz would be better than the 13 GHZ or 15 GHz that some drawings show. This may mean a more complicated divider (or mixing scheme) to count the LO, but will reduce the uncorrelated fluctuation and is worth the additional complexity at the central building. As high as possible means changing to the 100 GHz photonic reference as soon as it is demonstrated.

Resolution required for the first LO

Very important specification. Will determine basic structure of the synthesizers. Need to know as soon as possible.

Uncorrelated phase noise specification as a function of observing frequency

Target values would be helpful, but we have a pretty good idea of what is possible.

Correlated phase noise specification

This is a good one to leave till as late in the development as possible. It only affects the "one of" set of things at the central building and can be taken care of last with the latest technology.