ALMA Memo No. 376

Integration of LO Drivers, Photonic Reference, and Central Reference Generator

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These measurements represent the first test of a local-oscillator (LO) driver based on a multiplied YIG-tuned oscillator (YTO) locked to a variable frequency photonic mm-wave reference. The reference is provided as a beatnote between two optical signals and is carried from a remote location by 10 meters of optical fiber to a photomixer at the LO driver site. Phase noise measurements were performed at about 80 GHz. A pre-prototype of the Central Reference Generator (CRG) developed in Socorro was also used in the tests as the fundamental reference from which all other sources were synchronized.

1. Introduction

This memo summarizes a series of measurements performed recently on the ALMA LO system. These were the first measurements incorporating all the essential subsystems of the first LO except the cold frequency multipliers. Until now, all the development has been done at three different sites: the LO drivers in Charlottesville, the photonic reference in Tucson, and the central reference in Socorro.

The ALMA project book and several ALMA memos detail aspects of these various subsystems [1-5]. This memo presupposes some familiarity with these subsystems.

The goal of this series of measurements was to ensure understanding of the interfaces between the various subsystems, gain insight as to how the subsystems interact, and to make sure there were no unexpected surprises when these subsystems were connected. A secondary goal was to measure the baseline phase noise of the first LO in its current state of development. As each of the subsystems is still under development, these measurements should not be regarded as an indication of the expected final performance of the ALMA first LO. In particular, the phase noise of the photonic reference is expected to improve dramatically from what was available for these tests. Further improvement in the photonic reference phase noise will be addressed in a future ALMA memo. These tests demonstrate that the phase noise of the first LO is directly dependent on the photonic reference phase noise as expected.

Several measurements were made over the course of a week. Only the most interesting and relevant to the wider ALMA system are described here. The first measurement was of the driver output locked to a microwave reference. This is similar to the measurements done in earlier work [1] and yielded almost exactly the same result. In this case, the microwave reference was provided by the 2-GHz output of the CRG pre-prototype. This served as a baseline against which to compare the case of the photonic reference. Next, the phase noise of the driver with the mm-wave photonic reference was measured, as well as the microwave synthesizer used to obtain that reference. From this comparison, it is shown that a better microwave synthesizer is needed. A cavity oscillator with better phase noise performance was used as a replacement for the microwave reference in the laser phase lock loop, yielding significantly better results. Some quick modifications were done on the driver phase lock loop to optimize the phase noise performance of the entire system with encouraging results. In summary, the subsystems developed at the different sites worked as expected, and the interfaces appear to be well understood by the different groups. In addition, the results of the measurements confirmed that the photonic phase lock circuit is critical to the overall

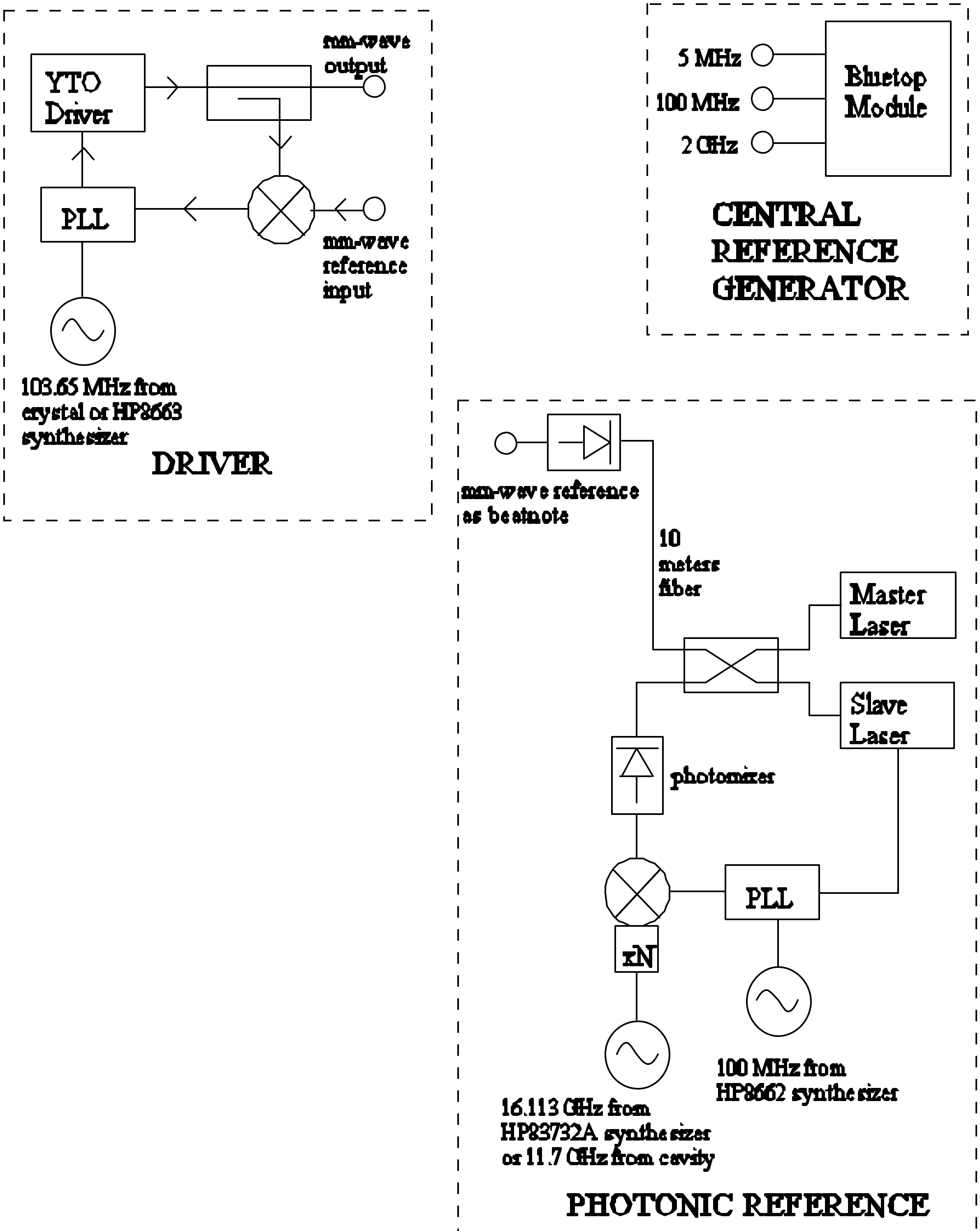

Figure 1 Block diagrams of the three subsystems integrated in this set of measurements: the driver, being developed in Charlottesville, the central reference generator, being developed in Socorro, and the photonic reference, being developed in Tucson.

phase noise of the first LO. In particular, the lowest possible phase noise on the microwave reference to the phase lock circuit is recommended, and further improvements to the wideband phase locking of the lasers are needed.

2. Phase Noise Measurements

Block diagrams of the three subsystems brought together here are shown in Fig. 1. The driver uses a YIG-tuned oscillator (YTO) as its fundamental source. In this particular setup, the driver consists of a YTO which is doubled, amplified, doubled, and amplified again up to approximately 80 GHz. Part of this W-band signal is then coupled off and mixed with a mm-wave reference provided by either the photonic reference or a harmonic of a microwave reference. The resulting IF is filtered, amplified, and compared in phase to a fixed RF reference (103.65 MHz in this particular case) in the phase-lock loop (PLL). The output of the driver is measured by the HPE5500 phase noise measurement system. For more information on the driver and the phase noise measurement procedure, see ALMA Memo #311 [1].

The photonic reference provides the variable mm-wave reference signal used by the driver. This reference is delivered to the driver on optical fiber as the phase-locked difference frequency between two optical carriers. The optoelectronic conversion of the laser beatnote to a mm-wave beatnote is done by a high-speed photomixer which terminates the fiber.

In the photonic reference subsystem, the outputs of the master and slave laser are combined on one fiber by the optical quadrature hybrid. The difference frequency is then detected by a photomixer and mixed with a harmonic of a microwave synthesizer. The RF output of this mixing process, 100 MHz in this case, is filtered, amplified, and compared in phase to a 100-MHz synthesizer in the PLL. The output of the PLL is used to tune the slave laser, phase locking the difference frequency. For more details on the photonic reference subsystem, see ALMA Memos #200 [2] and #267 [3].

The central reference generator provides the master references for all these subsystems. For these tests, we are using a pre-prototype of the central reference generator, with several low-phase-noise references provided by a Wenzel Bluetop module. The 100-MHz output shown in Fig. 1 was generated by the doubled and filtered 50-MHz module output specifically for these experiments. For more information on the central reference generator, please consult chapter 7 of the ALMA project book [4]. For information on all these subsystems, see the ALMA project book.

The initial task was to synchronize all the various sources and synthesizers to the same standard (for the ALMA array, this standard will be a hydrogen maser). For these measurements, everything was locked to the 5-MHz output of the pre-prototype CRG. If the sources are not locked, measurements are difficult because of the varying drift rates between the synthesizers. The synthesizers lock to the 5-MHz signal with a narrow (a few hundred Hz) loop bandwidth, so the phase noise spectrum is not affected. The only sources which are free running are the lasers. The beatnote between the two lasers is, as mentioned eariler, locked to a standard, but the master laser itself is not.

2.1. Bluetop Module as Microwave Reference for Driver

We first verified the measurement setup and specifications of the pre-prototype CRG by measuring its 2-GHz output. The measured data indicated that the CRG has equal or lower phase noise than the HPE5500 downconverter as predicted by their respective specifications. Incidentally, the base 10-MHz crystal in the HPE5500 test set is also a Wenzel crystal.

We then used the 2-GHz output reference from the CRG to drive a Pacific Millimeter harmonic mixer used as a harmonic generator. The driver frequency was set to 80.10365 GHz and the 40^{th} harmonic of the 2-GHz signal was used as the mm-wave reference. The resulting phase noise spectrum is shown in Fig. 2. There are a few interesting features on this plot to point out. The spurs at frequencies below 1 kHz are mainly power line related. The spur at roughly 20 kHz looks suspiciously like a switching power supply, though this was never verified. The spur at roughly 3 MHz at -70 dB is likely pickup of a stray RF signal. Proper shielding should eliminate all these anomalies. Also note the hump at about 300 kHz corresponding to the corner frequency of the loop. The -110 dB level at 1-MHz offset is roughly what we expect from the YTO itself. The YTO itself has roughly a 25dB/decade slope reduction in

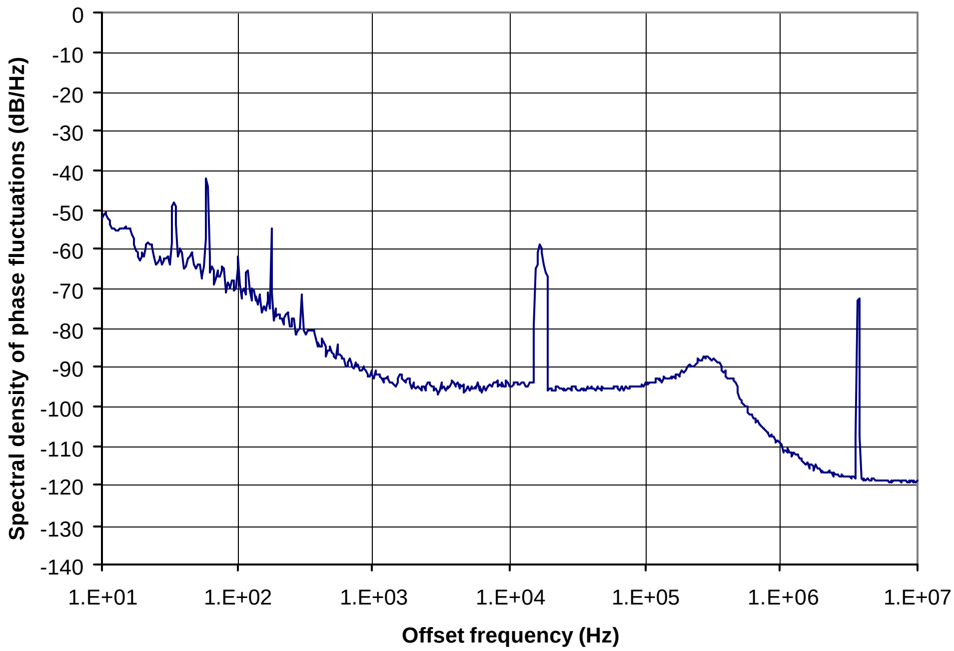

Figure 2 Phase noise measurement of the 80.10365-GHz driver phase-locked to the 40th harmonic of the 2-GHz Bluetop module output.

phase noise versus offset frequency. The -88 dB level at 300 kHZ is several dB higher than what we expect from the YTO at this point and indicates probable underdamping in the loop. This is not unexpected since the loop filter was not optimized for any of these particular measurements (this was not feasible in the limited amount of time available). Finally, the -95 dB "floor" inside the loop bandwidth from roughly 1-100 kHz is considerably higher than an ideal multiplication of the 2-GHz reference. This represents either a limit due to phase noise in the IF and dc portions of the PLL or a signal-to-noise limit (LO starved condition) at the W-band mixer. (The Pacific Millimeter harmonic mixer is not specifically designed to act as a 40th harmonic generator.) Nevertheless, this is considerably less phase noise than what we expected and measured with the photonic reference. As the photonic reference phase noise is improved, we can expect to approach this noise level.

2.2. YTO Driver Phase-Locked to Photonic Reference Phase-Locked to HP83732B Synthesizer

The photonic reference itself has a microwave reference, to a harmonic of which the beat frequency is locked. For ALMA, this microwave reference will be tunable and in the range 8-12 GHz. This microwave reference synthesizer has not been designed or even fully specified for ALMA and so was not available for these tests, so a commercial synthesizer (HP83732B) was used. For the 80-GHz measurements we wished to make, it was found that the photomixer/adapter combination worked best at 80.665 GHz. The HP83732B was set to one-fifth of that frequency minus the 100-MHz offset in the PLL, or 16.113 GHz. The phase noise of the HP83732B alone at 16.113 GHz was measured with results shown in Fig. 3(a) The best possible phase noise performance of the photonic reference using this synthesizer as a reference is represented by the second line on this plot, (b), which is just the measured spectrum at 16.113 GHz plus the ideal multiplication factor of 20log(5) dB.

The phase noise of the photonic reference subsytem locked to the HP83732B was measured with a loop bandwidth of roughly 300 kHz. This is about as high as loop bandwidth as can be achieved with the current setup due to phase margin instabilities resulting from the limited bandwidth of the current modulation port of the slave laser. This beat frequency is then the reference for the driver. The resulting phase noise measurement at the output

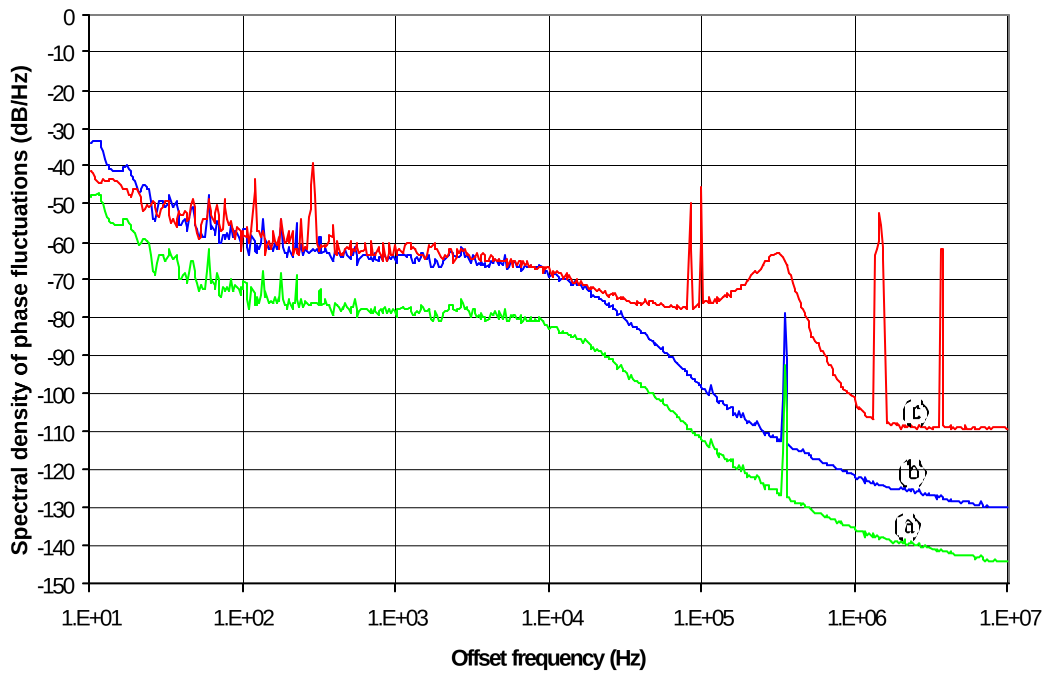

Figure 3 Phase noise measurement of (a) HP 83732B synthesizer at 16.113 GHz, (b) 16.113-GHz measurement plus ideal multiplication factor of 20log(5) dB, and (c) 80.561-GHz driver phase-locked to photonic reference which uses the fifth harmonic of the HP 83732B at 16.113 GHz as its reference.

of the driver is the remaining trace, Fig. 3(c). The overlapping of the two traces below about 20 kHz indicates that we are limited by the HP83732B synthesizer in this range. From below 100 kHz out to almost 1 MHz, we are limited by phase noise from the free-running laser.

At this point, there were two possible approaches to improving the phase noise performance of the overall system. First, increasing the bandwidth of the photonic PLL would reduce the noise within the loop. However, as already mentioned this is non-trivial and the subject of ongoing development. Second, a cleaner microwave reference to replace the HP83732B will improve the phase noise below 100 kHz. This second avenue was the only alternative available to us during these tests, so we repeated the measurement with a cleaner microwave reference and modified the YTO loop parameters to reduce the phase noise in the 100-kHz to 1-MHz portion of the spectrum.

2.3. Driver Phase-Locked to Photonic Reference Phase-Locked to 11.7-GHz Cavity Oscillator

An 11.7-GHz cavity oscillator was found to be a cleaner microwave reference, and was locked to the 100-MHz output of the CRG. The seventh harmonic of this oscillator falls conveniently at 81.9 GHz, within the range of the measurement setup. The locked cavity was measured by itself. This measurement, plus the ideal multiplication ratio of 20log(7) dB is shown in Fig. 4(a). Note that this oscillator is over an order of magnitude better than the HP83732B in the 1-20 kHz range. Of course, the cavity oscillator is not a tunable reference, but it should prove the point. The cavity oscillator was then inserted into the photonic reference subsystem. The resulting phase noise measurement at the output of the YTO driver is shown in Fig. 4(b). Note the significant improvement at frequencies below 100 kHz. As expected, the free-running laser phase noise from 100 kHz to 1 MHz has not been significantly affected, but we have shown improvement in the lower part of the spectrum as we expected. As one final test of our understanding, the driver lock loop was modified for a smaller loop bandwidth. Since the YTO phase noise at 300 kHz is over two orders of magnitude better than the photonic reference (see Fig. 2), reducing the corner frequency of the driver PLL should significantly lower the peak at 300 kHz. The resulting measurement is shown in Fig. 4(c). The

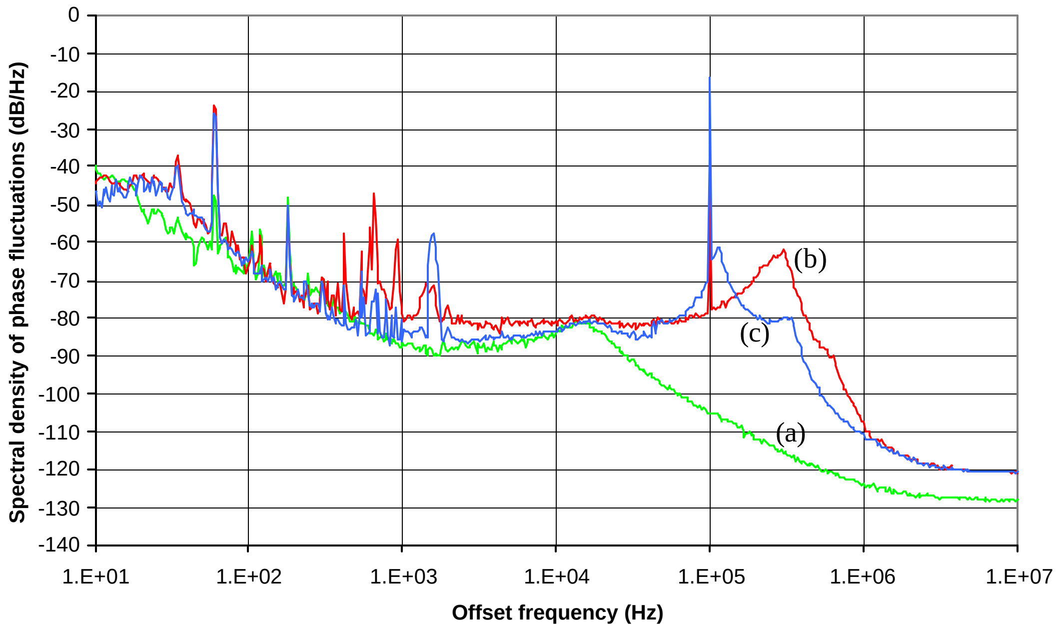

Figure 4 Phase noise measurement of (a) the 11.7-GHz cavity oscillator locked to the 100-MHz Bluetop module output, (b) the 81.896-GHz driver locked to the photonic reference which uses as its reference the locked 11.7-GHz cavity, and (c) the same setup with the driver PLL modified for a narrower loop bandwidth.

peak at 300 kHz has been reduced almost 20 dB. The peak and spur at 100-kHz offset is the result of an instability in the driver PLL resulting from the hastily modified design. With more time and a careful loop design we should see something close to a straight line connecting the -85 dB level at 30 kHz to the -80 dB point at 300 kHz.

4. Conclusions

Phase noise measurements were performed on a 80-GHz YTO-based driver locked to a photonic reference delivered to the driver as a beatnote on an 10-m optical fiber. The measurements prove the basic viability of the baseline photonic reference approach for the ALMA LO and clarify where the areas of further development need to be. A pre-prototype of the central reference generator was used as a reference for the entire measurement setup.

5. References

[1] E. Bryerton, D. Thacker, K. Saini, and R. Bradley, “Noise measurements of YIG-tuned oscillator sources for the ALMA LO,” ALMA Memo No. 311, August 2000.

[2] J. Payne, L. D’Addario, D. Emerson, A. Kerr, and B. Shillue, “Photonic local oscillator for the millimeter array,” ALMA Memo No. 200, February 1998.

[3] J. Payne, B. Shillue, and A. Vaccari, “Photonic techniques for use on the Atacama Large Millimeter Array,” ALMA Memo No. 267, June 1999.

[4] ALMA Project Book, http://www.alma.nrao.edu/projectbk/construction

[5] D. Thacker, E. Bryerton, K. Saini, and R. Bradley, “Drift measurements of YIG-tuned oscillator sources for the ALMA LO,” ALMA Memo No. 335, to be submitted.