Sideband Noise Screening of Multiplier-Based Sub-Millimeter LO Chains using a WR-10 Schottky Mixer

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***Abstract*— A method is presented for measuring the AM noise of signal sources as a function of frequency offset from the carrier. This method is particularly helpful for local oscillator sources for sub-millimeter wave single-ended mixers with wide IF bandwidths. Measurements on ALMA LO sources are presented using the described tests. The measurements are compared to receiver noise measurements using a SIS mixer. Close agreement is seen, indicating that these measurements can be used to predict added noise of sub-millimeter wave local oscillators for SIS mixers with room temperature millimeter-wave measurements.**

I. Introduction

Due to the difficulty in fabricating precision submillimeter hybrids, mixers at these wavelengths are typically single-ended. This is the case, for example, for the SIS mixers used for ALMA. In a single-ended mixer, there is no suppression of noise on the local oscillator (LO). Therefore in a sub-millimeter low-noise heterodyne receiver, the LO is required to have a very high signal-to-noise ratio (SNR).

The LO power required by a SIS mixer is proportional to the frequency squared and can be calculated from Tucker's formula [1]. Typical LO power values, at the SIS junction, for the ALMA receiver bands range from 0.03 uW to over 1.0 uW for the highest frequency bands. Therefore, an appropriate unit to quantify noise on the LO signal is to express the noise as a noise-to-signal ratio (NSR) in K/uW. A LO signal with 10 K/uW NSR used to pump a mixer which requires 0.5 uW of LO power would contribute 5 K to the overall receiver noise. For the ALMA project it was determined that AM noise on the LO should not contribute more than a few percent to overall receiver noise for any receiver band. To achieve this, the ALMA LO systems were required to have a NSR of 10 K/uW, or alternatively, a SNR of 158.6 dB.

In order to verify that the ALMA LOs are meeting this specification, it has been necessary to use the LO under test to pump the actual SIS mixer in a receiver. This test requires the full sub-milllimeter cryogenic SIS receiver. Since this is a time and cost intensive task, and since the LO and SIS mixer development in ALMA are at different institutions around the world, it is highly desirable to have a simpler screening measurement which can be performed with room temperature test equipment at a lower frequency.

The final LO multiplication in ALMA is on the 77K temperature stage inside the cryostat. The warm LO components outside the dewar are housed in an assembly called the Warm Cartridge Assembly (WCA). Fig. 1 shows a block diagram of the typical ALMA LO. The output frequency of the WCAs range from 65 to 122 GHz, depending on the particular receiver band. It is at this frequency where it would be most convenient to measure AM noise. If the final cryogenic multipliers are properly pumped, then this is an accurate representation of the signal-to-noise ratio at the SIS mixer. However, in many cases the final multiplier is underpumped. If this is the case, the measured power characteristics of the multiplier can be used to estimate the degradation in SNR in the underpumped multiplier [2]. It has been seen that the AM noise from the LO is a strong function of the IF. Therefore, the AM noise measurement should also measure the noise versus IF.

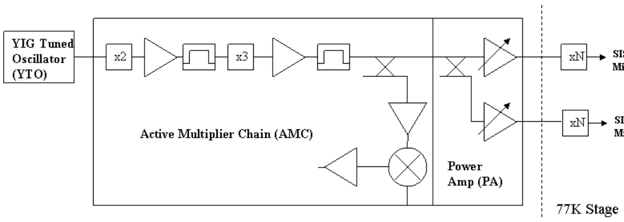

Fig. 9 Block diagram of typical ALMA first local oscillator chain.

II. Description of AM Noise Measurement

The goal of the measurements described here is to determine the level of AM noise present on a carrier signal. The measurement system must be capable of measuring sources with different output power levels and provide a fair comparison between these. The experimental setup used is the one presented in [3] and consists of a device under test (DUT), a level-set attenuator, and a radiometer. The radiometer is a single-ended mixer with a bias tee and subsequent IF amplifier to increase the signal level prior to detection (typically by a Spectrum Analyzer). The LO power induces a current in the mixer, which is used as a measure of the power delivered to the mixer by the DUT. By keeping the rectified current fixed, the power delivered to the mixer is kept constant, thus allowing for a comparison between DUTs possessing different output powers.

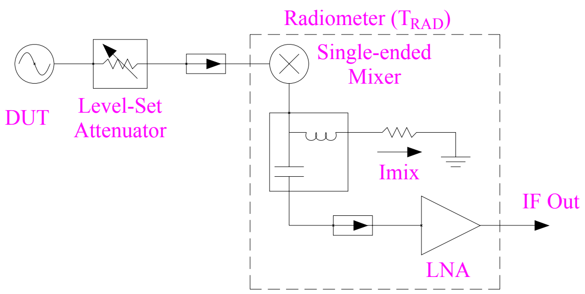

Fig. 10 Block diagram of AM noise measurement system.

One key decision is how to set a reference level for the radiometer. If an isolator is used between the mixer and the LNA, then a measurement of the radiometer output power with no LO power can be used as the reference. With no LO power, the mixer has a high impedance, and the isolator then provides a matched termination at the input to the IF amplifier. By this method we assume that the output noise for a mixer driven by a noiseless LO (with 290 K at its RF input) is the same as that produced by a matched load. By measuring an LO source that is believed to be clean we can gauge the accuracy of this assumption, as described below.

However, it is often desirable to measure the output noise over an IF bandwidth that is wider than can be obtained with an isolator (which is typically not much more than an octave of bandwidth). Without an isolator the input noise to the IF amplifier with no LO power is not well determined, and so this is not necessarily a useful reference. Instead, we can use a matched termination at the IF amplifier input to set the reference level. A mechanical coaxial switch at the LNA input can be used to easily switch from the mixer to the reference termination. The reference level in this case is the same at that described above for the isolator.

Once we have decided upon our reference level, T_{REF}, the noise of the DUT can be determined by using a Y-factor method, and is found to be

$$T_{DUT} = T_{RAD}(Y-1) + YT_{REF}$$

Alternately, we can measure the excess noise above T_{REF}, which is given by

$$T_{DUT,excess} = (T_{RAD} + T_{REF})(Y-1)$$

The DUT NSR can then be calculated by dividing this by the DUT output power.

III. Measurements

In order to verify that a room temperature Schottky mixer is sensitive enough to detect AM noise sidebands at the levels of concern to the ALMA LO, a prototype testset was assembled from a VDI WR-10 single-ended Schottky mixer, two Miteq 0.1-12 GHz low-noise amplifiers (AFS3-00101200-42-LN), and a spectrum analyzer.

The mixer conversion loss is relatively flat over a 6dB range of LO drive. At 8dBm of LO drive, the dc voltage across the 50 ohm bias resistor of the mixer is 100 mV. Therefore, to ensure constant LO power across the LO frequency band, a variable attenuator is used to keep the bias voltage constant at 100 mV. In the production testset, a directional coupler will be used to monitor the actual LO power going into the mixer.

The noise temperature of the IF amplifiers is specified by Miteq to be 475K. An isolator was not used between the mixer and IF amplifier for these measurements. For this particular broadband amplifier, it seemed that its effective input noise temperature was independent of the source impedance. In general, this will not be the case, and an isolator (or alternatively a switched termination) should be used as the reference.

Multiplying the IF amplifier noise temperature by the conversion loss of the mixer gives a 7500K noise temperature estimate for T_{RAD}. Dividing this by the 8dBm LO power gives a 1.2K/uW NSR referenced to the front of the mixer. T_{REF} is assumed to be ambient temperature, 297K. Measurement of an ON/OFF Y-factor (where the ON and OFF refer to the LO DUT being turned on or off) is then used to calculate the NSR of the DUT.

For example, a 10 dB ON/OFF ratio gives a [(7500K+300K)*(10-1)] / 8dBm = 11.1K/uW NSR for the LO under test. For verification, a Gunn oscillator, which should have minimal AM noise content at 4-12 GHz IF was measured at 77 GHz, see Fig. 3. The photograph of the prototype AM noise test set is shown in Fig. 4.

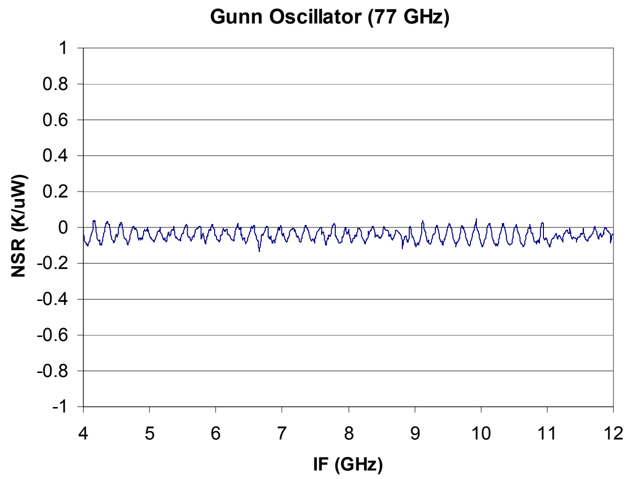

Fig. 11 Measured NSR of a Gunn oscillator output at 77 GHz.

Fig. 12 Photograph of prototype AM noise test set.

A. ALMA Band 8

The ALMA band 8 receiver uses a single-ended SIS mixer to cover 385-500 GHz with a 4-8 GHz IF, therefore the LO needs to tune from 393-492 GHz. The warm portion of the LO, the WCA, generates 65.5-82.0 GHz and is followed by a cryogenic sextupler from VDI.

Fig. 5 shows AM noise measured at the warm power amplifier output from 65.5-82.0 GHz, with the legend showing the scaled LO frequency at the SIS mixer.

Fig. 6 shows the measured receiver noise of the band 8 cartridge using a WCA of the same design as that used for the measurements in Fig. 5. These measurements were performed by the band 8 cartridge group at NAOJ (National Astronomy Observatory of Japan). The measured noise is shown for a LO frequency of 450 GHz. Similar levels of noise are seen at other LO frequencies across the band and correspond fairly closely to the AM noise measurements seen in Fig, 5 at the WCA output.

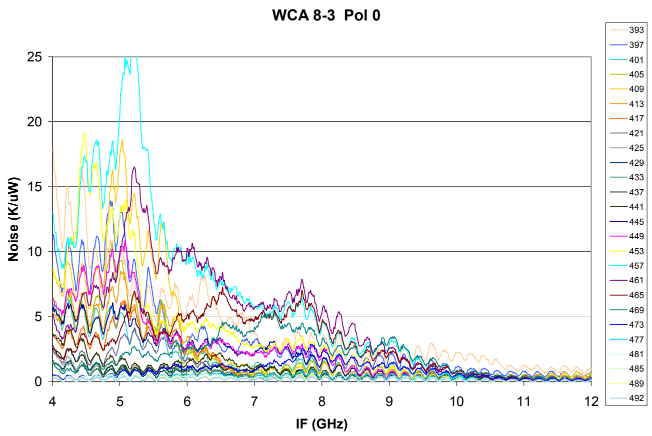

Fig. 13 Measured NSR of an ALMA Band 8 WCA.

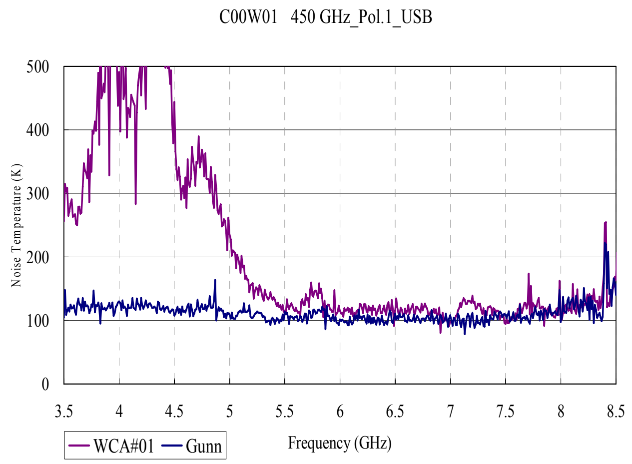

Fig. 14 Measured receiver noise termperature at 450 GHz LO for an ALMA Band 8 receiver with a Gunn LO and with a WCA LO.

B. ALMA Band 9

The ALMA band 9 receiver uses a single-ended SIS mixer to cover 602-720 GHz with a 4-8 GHz IF, therefore the LO needs to tune from 610-712 GHz. The warm portion of the LO, the WCA, generates 67.8-79.1 GHz and is followed by a cryogenic nonupler from VDI.

Fig. 7 shows the measured receiver noise of a band 9 receiver as a function of LO frequency and IF, indicating excess noise from the LO at LO frequencies between 670-700 GHz at IFs below 6 GHz. These measurements were performed by the band 9 cartridge group at SRON (Netherlands Institute for Space Research).

The WCA used in these measurement was then returned to the LO group and was measured using the prototype AM noise measurement test set described in this work. The results at a frequency corresponding to a LO frequency of 678 GHz are shown in Fig. 8. A narrower bandpass filter was then installed in the warm LO and the LO source was remeasured, showing less noise. The modified warm LO was sent back to SRON where it was reconnected to the band 9 SIS receiver and remeasured. The new measurements are shown in Fig. 9 and show that the excess LO noise has been significantly reduced, as predicted by the warm AM noise measurements.

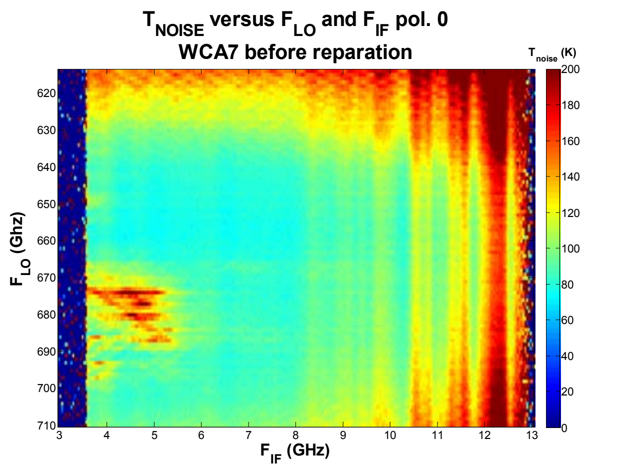

Fig. 15 Measured receiver noise of an ALMA Band 9 receiver using a noisy band 9 LO.

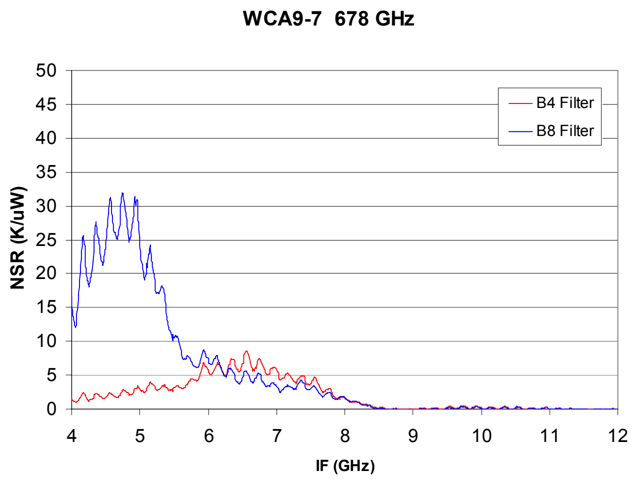

Fig. 16 Measured NSR of an ALMA band 9 WCA at a frequency scaled to a LO frequency of 678 GHz before (blue line) and after (red line) installing a narrower bandpass filter.

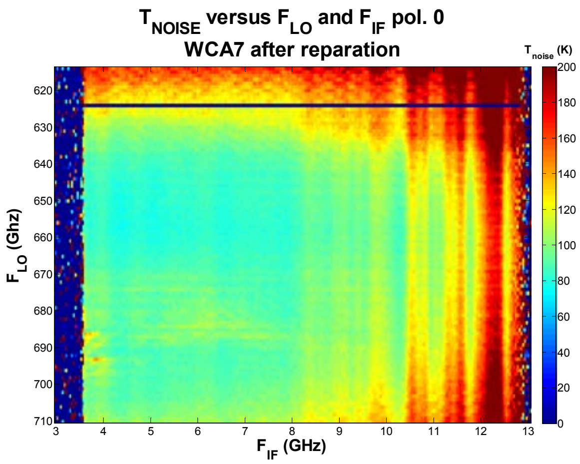

Fig. 17 Measured receiver noise of an ALMA Band 9 receiver after installing a narrower bandpass filter in the LO.

Conclusions

AM noise measurements using the method described in this paper were presented for ALMA band 8 and 9 local oscillators. Comparisons with receiver noise measurements using the sources under test as local oscillators for SIS mixers show high correlation. This indicates that these AM noise measurements can be used as a screening test to show sources that will add excess noise to the overall receiver without the delay and expense of measuring every LO source with a SIS receiver. Measurements of other ALMA bands have also been performed. We have yet to see an instance where LO noise seen with a SIS receiver was not also seen using the AM noise measurements before the final multiplier presented here.

We are currently in the process of automating these AM noise measurements and integrating them with the suite of acceptance tests for the ALMA LOs. Instead of a spectrum analyzer, a YIG tuned filter and power meter will be used. Output power leveling in the ALMA LOs is performed by adjusting the drain bias of the final power amplifier. A directional coupler will be used to monitor the LO power while the noise measurements are performed, eliminating the need for a manual variable waveguide attenuator.

Acknowledgment

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References

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