ALMA Memo 436

Band 6 Receiver Noise Measurements using a Pre-Prototype YIG-Tunable LO

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Abstract

In this memo, we present measured receiver noise data of a 200-300 GHz SIS mixer driven by a pre-prototype of the YIG-tunable LO driver followed by a varistor tripler. After identifying and solving some signal-to-noise problems in the LO driver chain, measurements were taken from 220-270 GHz showing an average noise over a 4-12 GHz IF less than 5 K for the worst LO frequency over the identical mixer and varistor tripler being driven by a W-band Gunn oscillator. The average excess noise over all measured LO frequencies is 1.4 K. The optimum LO driver for which these measurements were taken includes a YIG-tuned filter (YTF). LO driver configuration options without the YTF are explored with encouraging initial results.

1 Introduction

This report describes the first sideband noise measurements of the ALMA baselineYIG-tunable LO using an ALMA prototype mixer over the full RF and IF bandwidths. Receiver noise is measured for LO frequencies from 220-270 GHz using prototype band 6 single-ended mixers with integrated 4-12 GHz IF amplifiers. Noise measurements are compared to the case in which the YTO (YIG Tuned Oscillator) plus WMA (Warm Multiplier Assembly) is replaced by a Gunn oscillator. The cold multiplier, operated at room temperature for these measurements, is either a Millitech FTT-04 tripler or a Virginia Diodes Inc. varistor tripler, a prototype of the ALMA band 6 cold tripler.

Initial measurements showed unacceptably high levels of excess noise extremely dependent on both LO and IF frequency. Through a series of measurements, problem areas, mostly involving signal-to-noise issues, were identified. This process led to an optimized LO configuration, measured over a 220-270 GHz frequency range, meeting the specifications for LO sideband noise [1].

2 Block Diagram Description

The initial configuration for the LO driver is shown in Fig. 1. The active doubler block is an NRAO assembly using commercial MMICs. Eventually, this active doubler will become the AMC (Active Multiplier Chain), which will also include a W-band tripler, driver amplifier, and balanced mixer for phase locking. The active doubler here also includes a microstrip lowpass filter after the final amplifier to eliminate higher harmonics which were initially found to cause problems at the final tripler output. The active doubler is followed by a Pacific Millimeter W3 tripler (PM-W3).

The W-band power amplifier is also an NRAO assembly using a HRL InP MMIC designed by Samoska at JPL [2]. The same MMIC, or one very similar, will be used for the actual ALMA LO drivers.

The YTO is phase locked at its fundamental frequency using an EIP counter, though it was probably not necessary for these particular measurements.

The SIS mixer with integrated IF preamplifier is described in [3].

3 Measurements

Using this initial configuration, receiver noise was measured at 250 GHz from 4-12 GHz IF. The results are shown in Fig. 2. The extremely high excess noise, over 100K at some IF frequencies, below about 6.5 GHz IF obviously caused great concern. After checking power levels in the chain it was found that the 8 dB attenuator needed to be removed and amplifier biases changed to improve signal-to-noise ratios. This gave a significant improvement to the measurements, also shown in Fig. 2.

After trying several LO frequencies with this configuration, it was found that 245 GHz seemed to be a worst case; effort was then spent optimizing for lowest excess noise at this point. It should be noted that even at this early stage of optimization, the excess noise at lower LO frequencies such as 230 GHz was almost zero. It was noticed that the output power from the W-band tripler (PM-W3) was lower than expected. There also appeared to be a very bad matching problem between the active doubler and W-band tripler.

Based on a measured noise temperature of the W-band power amplifier of approximately 2000 K, the measured input power to the amplifier of 500μW would give a sideband noise ratio of 4 K/μW. Harmonic balance simulations indicate that varistor triplers degrade the signal-to-noise by about 20log(n) where n is the multiplication ratio [4]. This gives a sideband noise ratio of about 36 K/μW at the SIS mixer, almost four times greater than the specified level of 10 K/μW. Based on a calculated SIS junction LO power of about 0.5μW, this gives excess noise of about 18K. This will be highly dependent on matching and phasing of sidebands, seemingly indicated by the large ripple in noise shown in the plots.

To test the hypothesis that signal-to-noise issues at the W-band power amplifier input were a major contributor to the excess noise problems, the Gunn oscillator was used to feed the power amplifier through a variable attenuator, as shown in Fig. 3. The measured data is plotted in Fig. 4. The attenuator was set first for an input power to the amplifier of –3.7 dBm, giving the top trace, showing large amounts of excess noise with a ripple of almost 100 K peak-to-peak. Increasing the power input to the amplifier to –0.2 dBm gives the next trace, also with a smaller ripple. Adding an isolator after the amplifier gives the red triangle trace, removing the ripple but leaving a constant excess noise of about 10K. Although the data is not shown, increasing the input power to the amplifier reduces the excess noise to an eventual negligible level. Approximately 1 mW going into a 2000K amplifier gives a 2 K/μW sideband noise ratio, which is then degraded by the tripler to 18 K/μW. This ratio multiplied by the 0.5 μW needed to pump the mixer gives about 9K excess noise, close to what is measured. The result for the lower input power (-3.7 dBm) is much worse that what is calculated by this method, possibly indicating higher-order mixing of noise sideband products. This emphasizes the importance of maintaining a high signal-to-noise ratio throughout the entire chain. Amplifier gain saturation may also play a role in lowering the effective input noise temperature.

To improve the signal-to-noise ratio at the W-band amplifier input, the integrated active doubler was replaced by individual components. The HMMC-5040 NRAO assembly was replaced by a commercial (Miteq) amplifier. This amplifier has higher output power and a better match to the W-band tripler (PM-W3). The output power of the tripler (PM-W3) was greater than 3 dBm across the band using this Miteq amplifier. Using individual components also allowed the insertion of a YTF (YIG Tunable Filter) between the two Ka-band amplifiers, which was also found to reduce excess noise. The YTF could not be placed after the Miteq amplifier because the YTF limits at 10 dBm. This optimized driver, shown in Fig. 5, was used to drive the mixer at 220-270 GHz in 10 GHz steps. The results of these measurements are shown in Figs. 6-11. The results are also summarized below in Table 1.

LO Freq. (GHz)	Avg. [YTO Rx Noise – Gunn Rx Noise (K)]	Peak (YTO Rx Noise – Gunn Rx Noise (K))
220	0.5	9.5
230	1.1	7.4
240	2.1	19.8
250	4.4	20.1
260	2.6	19.8
270	-2.2	9.7

Table 1 Summary of receiver noise measurements for LO frequencies from 220-270 GHz showing average and peak excess noise of YTO LO versus Gunn LO. IF measured from 4-12 GHz every 200 MHz.

These results appear to meet specification with the possible exception of a few IF points at 240, 250, and 260 GHz with peaks over 15K. The average noise over the entire IF is acceptable for all these LO frequencies.

The addition of a 22-33 GHz YTF, implemented for ALMA, would add significant cost as well as thermal loading to the cartridge. Alternatives to this approach are being considered. First of all, the noise performance may be good enough without a YTF. A YTF was used for the 220-270 GHz sweep because it gave the best performance. Measurements at 245 GHz, plotted in Fig. 12, show that the additional nose incurred by not using a YTF is 1.8 K averaged over a 4-8 GHz IF. A second option is replacing the YTO plus the doubler and first amplifier by a YTO at twice the original frequency (23.4-29.4 GHz for ALMA band 6). This configuration was also tried at 245 GHz, giving the encouraging results shown in Fig. 11, actually decreasing the average noise from 4-8 GHz IF by 0.5 K compared to the YTF case . This was not the original proposed configuration because the YTOs were found to have much higher phase noise above 26 GHz [5]. For this particular band however, the phase noise of a 30-GHz YTO may still be acceptable, especially if a wider PLL bandwidth is used.

4 Conclusions

Sideband noise measurements were performed on a band 6 prototype SIS mixer pumped by a YIG-tunable LO, a pre-prototype of the ALMA band 6 LO driver. While initial results were disappointing, optimization of the driver chain improved results to within specification. This optimized chain included a YTF, a costly addition to the ALMA LO system. Alternatives were explored at a single frequency with encouraging results. More measurements are planned for the next month to explore these alternatives over the full

ALMA band 6 bandwidth. Also, the phase noise performance needs to be measured for the optimized configuration. The effect of power leveling using the W-band power amplifier gate and/or drain bias on sideband noise needs to be measured as well.

5 Acknowledgements

Thanks to Ralph Groves and John Effland for their assistance with the receiver noise measurements.

6 References

[1] ALMA Project Book, Chapter 7.

[2] L. Samoska and Y. C. Leong, "65-145 GHz InP MMIC HEMT medium power amplifiers," *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp.1805-1808, May 2001.

[3] E. Lauria, A. Kerr, M. Pospieszalski, S. K. Pan, J. Effland, and A. Lichtenberger, "A 200-300 GHz SIS mixer-preamplifier with 8 GHz IF bandwidth," ALMA Memo 378, June 2001.

[4] K. Saini, private communication

[5] E. Bryerton, D. Thacker, K. Saini, and R. Bradley, "Noise Measurements of YIG-tuned Oscillator Sources for the ALMA LO," ALMA Memo 311, August 2000.

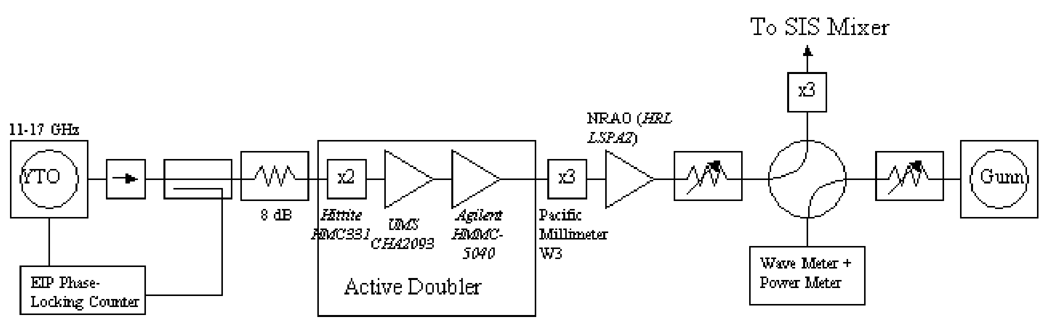

Figure 1 Block diagram of initial receiver noise measurement setup used to measure excess sideband noise of YTO LO over Gunn oscillator LO.

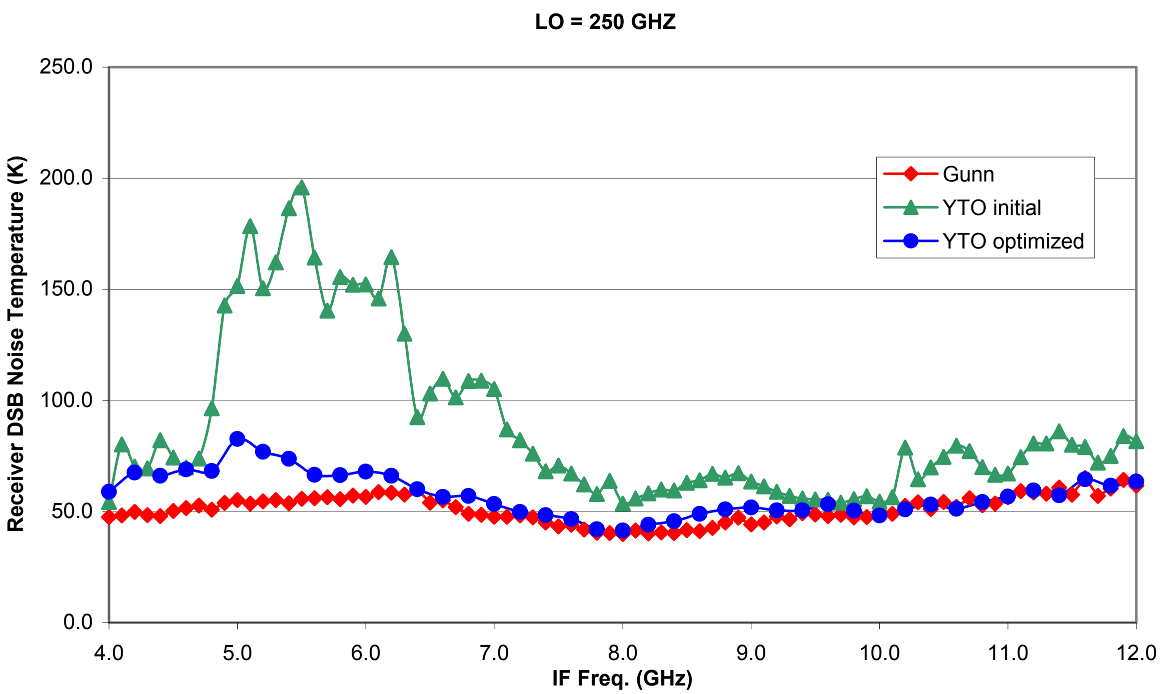

Figure 2 Measured receiver noise for Gunn oscillator LO (red diamond trace), initial YTO LO (green triangle trace), and YTO LO after attenuators were removed and biases optimized (blue circle trace).

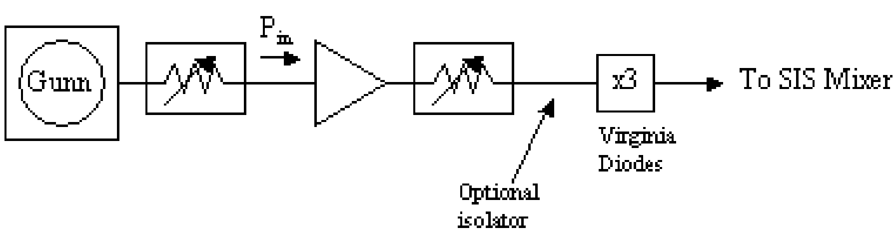

Figure 3 Block diagram of receiver noise measurement setup to measure effect of varying input power to W-band power amplifier.

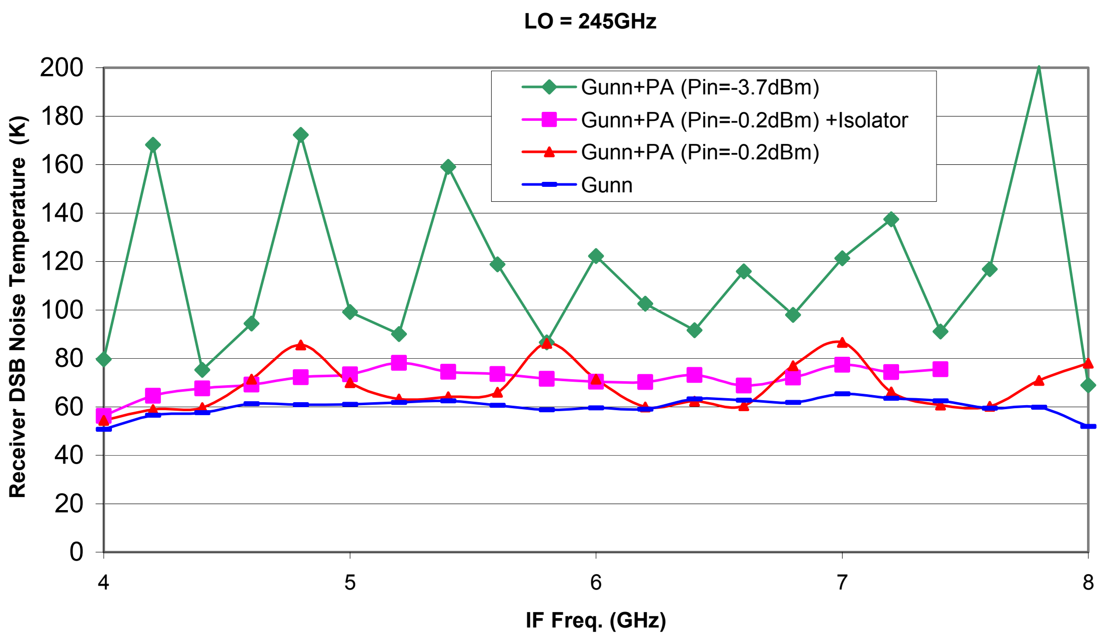

Figure 4 Measured receiver noise for Gunn oscillator LO alone (blue rectangle trace), plus amplifier with -3.7dBm input power (green diamond trace), plus amplifier with -0.2 dBm input power (red triangle trace), and plus amplifier with -0.2 dBm input power plus isolator (purple square trace).

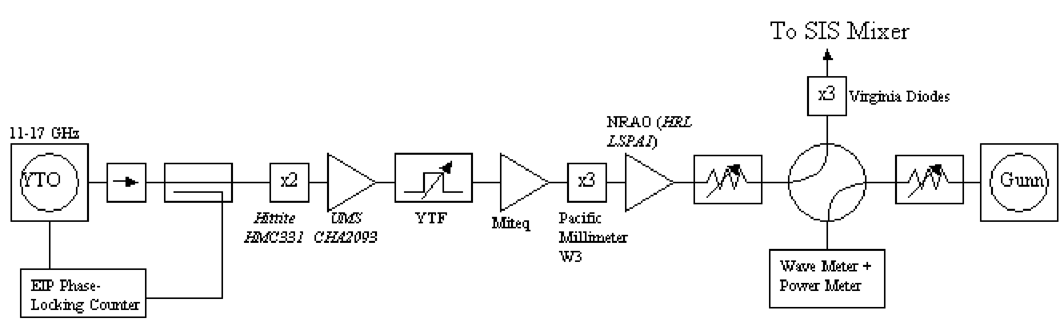

Figure 5 Block diagram of optimized YTO LO used for measurements of receiver noise from 220-270 GHz.

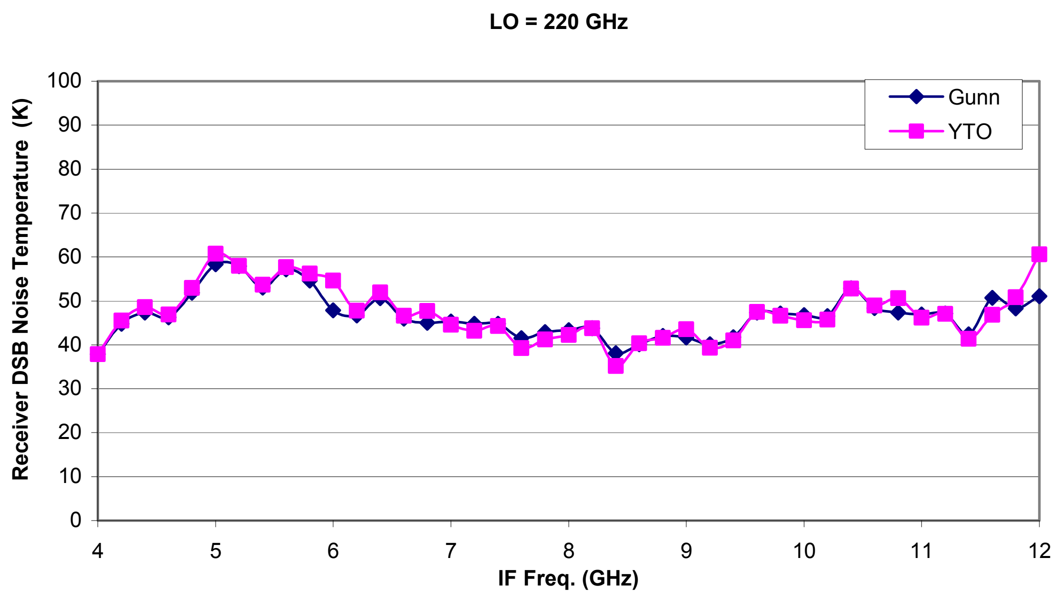

Figure 6 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

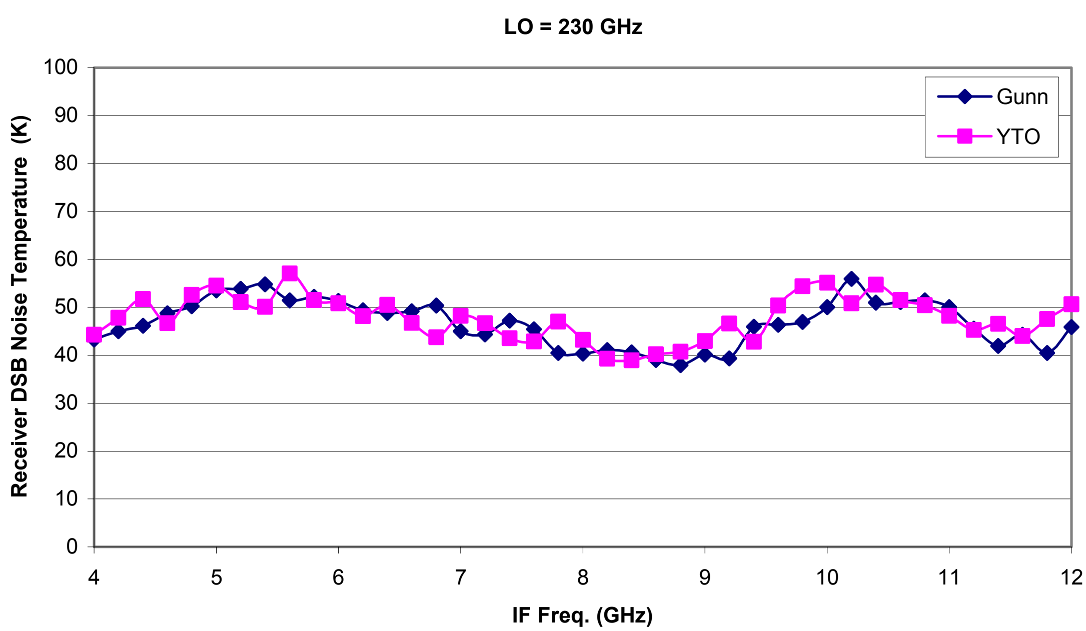

Figure 7 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

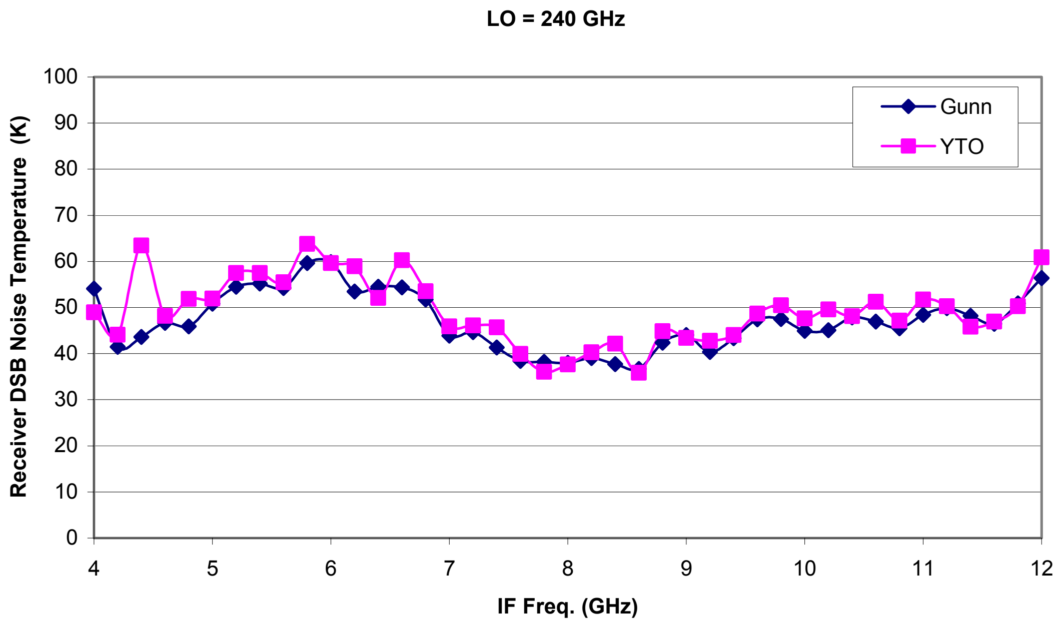

Figure 8 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

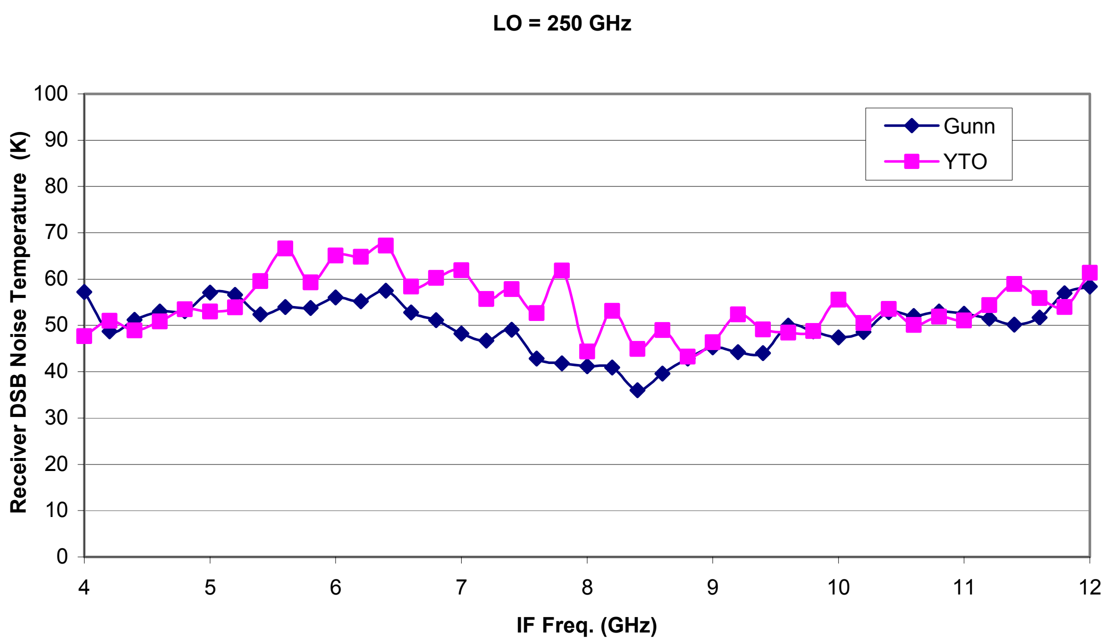

Figure 9 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

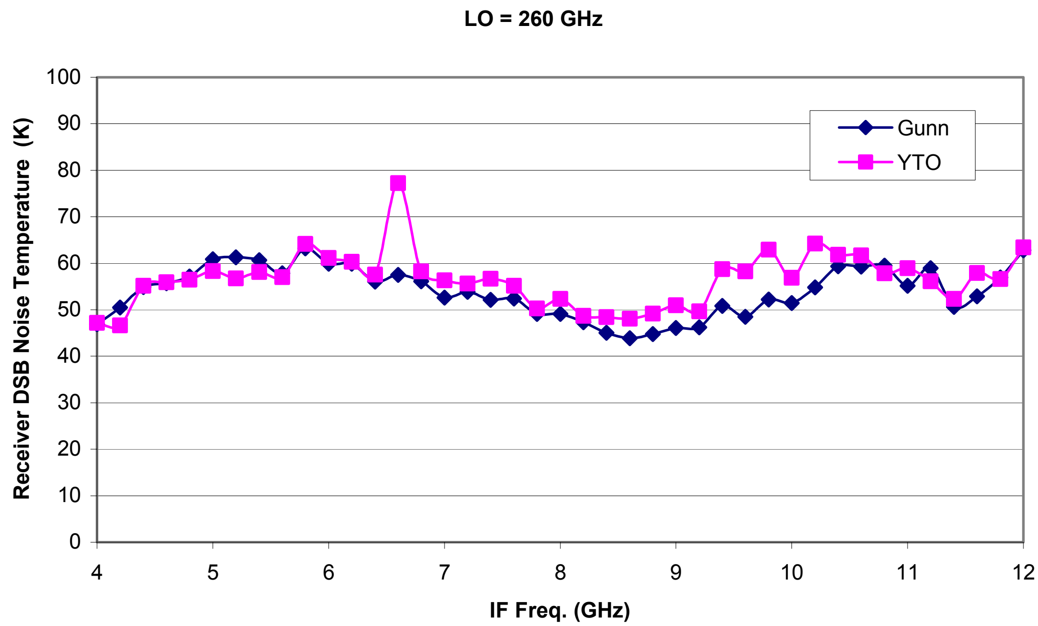

Figure 10 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

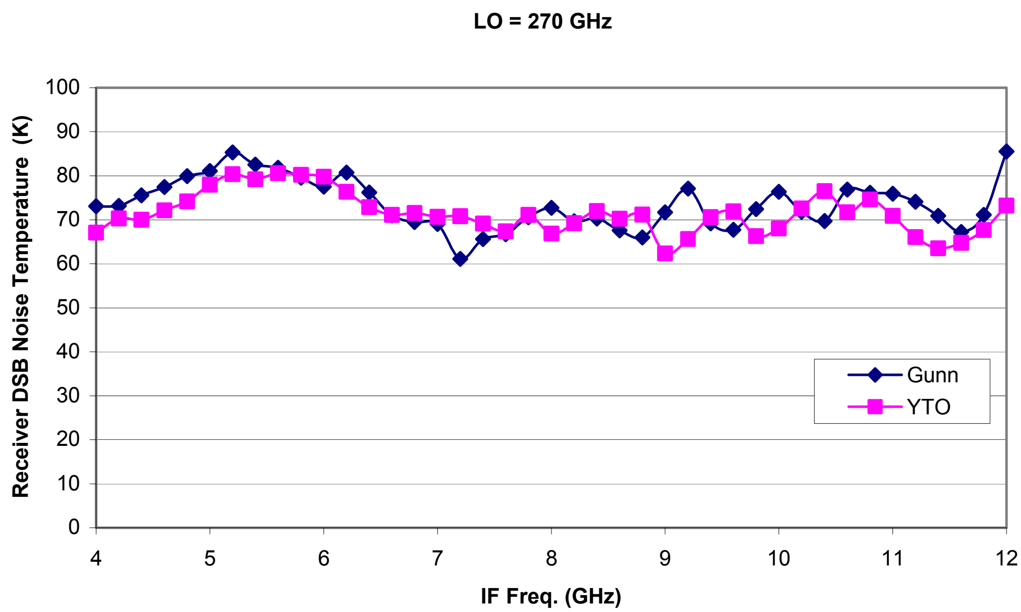

Figure 11 Measured receiver noise for Gunn oscillator LO (blue diamond trace) versus YTO LO (pink square trace). YTO LO also used YTF after first doubler and amplifier.

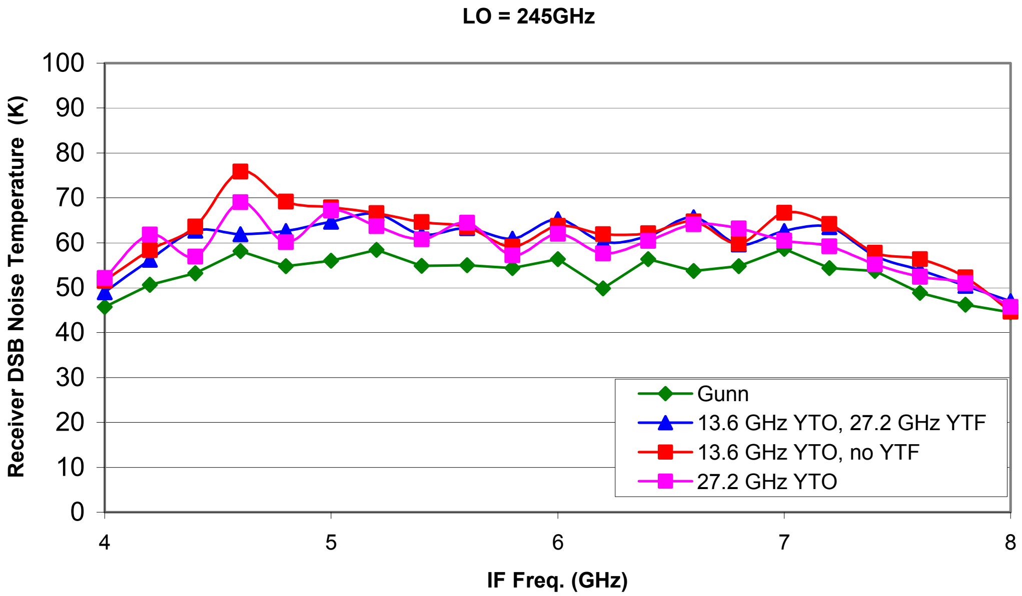

Figure 12 Measured receiver noise for the Gunn oscillator LO (green diamond trace), the 13.6 GHz YTO plus 27.2 GHz YTF LO used for 220-270 GHz measurements (blue diamond trace), the 13.6 GHz YTO with no YTF LO (red square trace) and the 27.2 GHz YTO without YTF LO (blue square trace).