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To: UVLBI Group/SMA
From: Shep Doeleman and John Test
Subject: Tests of SMA LO System for VLBI

The SMA LO to be used for planned 230GHz VLBI observations is shown in Figure 1. A 10 MHz reference (a Hydrogen maser in the case of VLBI) is buffered and then multiplied up to the 6 - 8 GHz range, where the signal locks a tunable YIG oscillator. This YIG output is sent to each antenna on optical fiber where a second YIG is locked, which provides the reference for the Gunn phased lock loop. For VLBI, the purity and stability of the LO signal is critical, and the quality of the first YIG PLL output is of particular importance since it represents a multiplication factor of ~80 from the 10MHz reference.

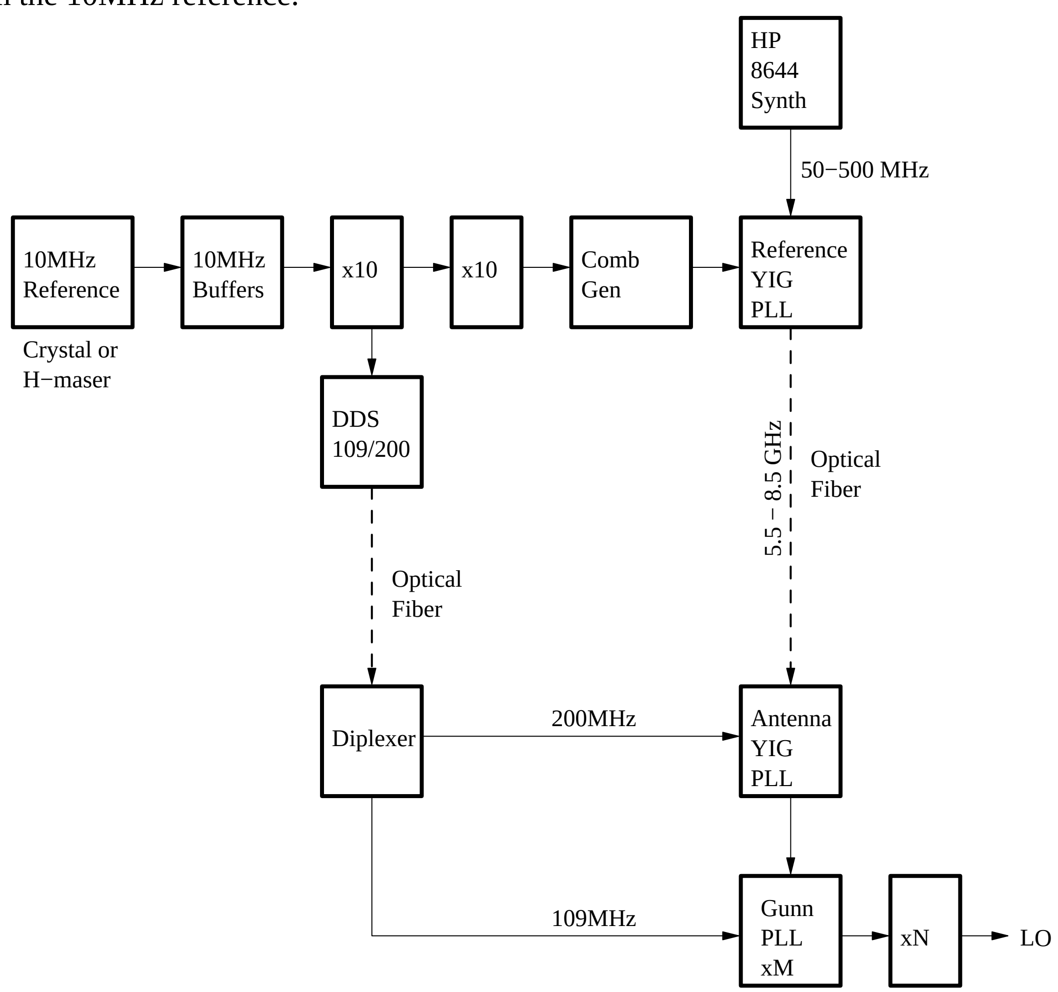


Figure 1: Block schematic of SMA LO elements that are most critical for VLBI.

The SMA MRG (Master Reference Generator) includes the LO signal path from the 10MHz reference to the Reference YIG output. On 7 Oct 2005, two completely independent MRG systems were compared with each other and the phase noise for the combination of the two systems was calculated using resolution bandwidths down to ~73mHz. The tests and results are described in this memo.

I. Two MRG Systems

In the first setup, the MRGs were tuned to 8100MHz and 8110MHz using the HP8644 synthesizers, then mixed to 10MHz and input to an HP8563A spectrum analyzer (Figure 2). The 10MHz reference for both MRGs was a Wenzel 10MHz crystal.

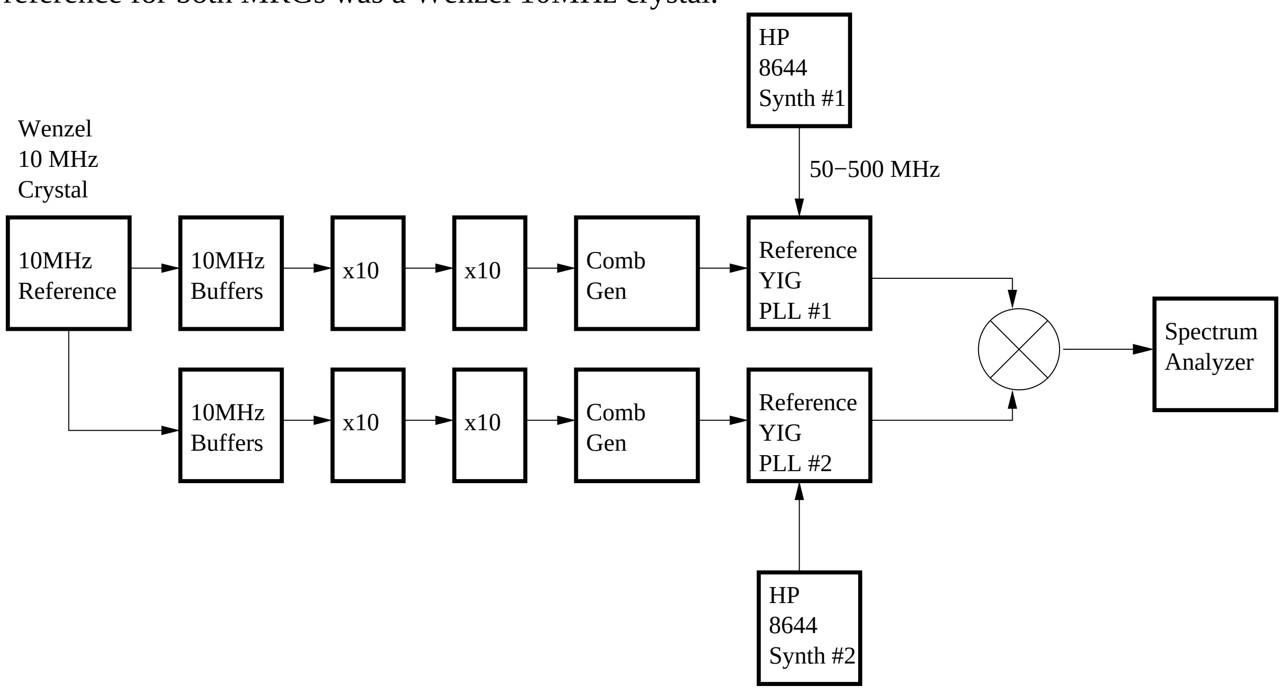


Figure 2: Phase test of two SMA MRG systems.

At spans of 10MHz, each YIG shows a phase noise pedestal of width ~5MHz and ~64dB weaker than the carrier (Figure 3a,b). The resolution BW was 100kHz, so for each MRG, the ratio of power in the carrier to power in these pedestals extrapolated to 230GHz is:

ratio = 64dB - 10log(5MHz/100kHz) - 20log(230GHz/8GHz) = 18dB

which represents about a 2% loss. As expected, a similar pedestal appears in the 10MHz mixed signal about 62dB down from the carrier peak (Figure 4). No new phase noise features appear from spans of 10MHz to 100kHz (Figures 5a,b). At spans from 10kHz to 3kHz, a triangular pedestal appears in the spectrum (Figure 6a,b,c), which contains ~ -15dB (3%) of the carrier power (see appendix for calculation of triangular pedestal power).

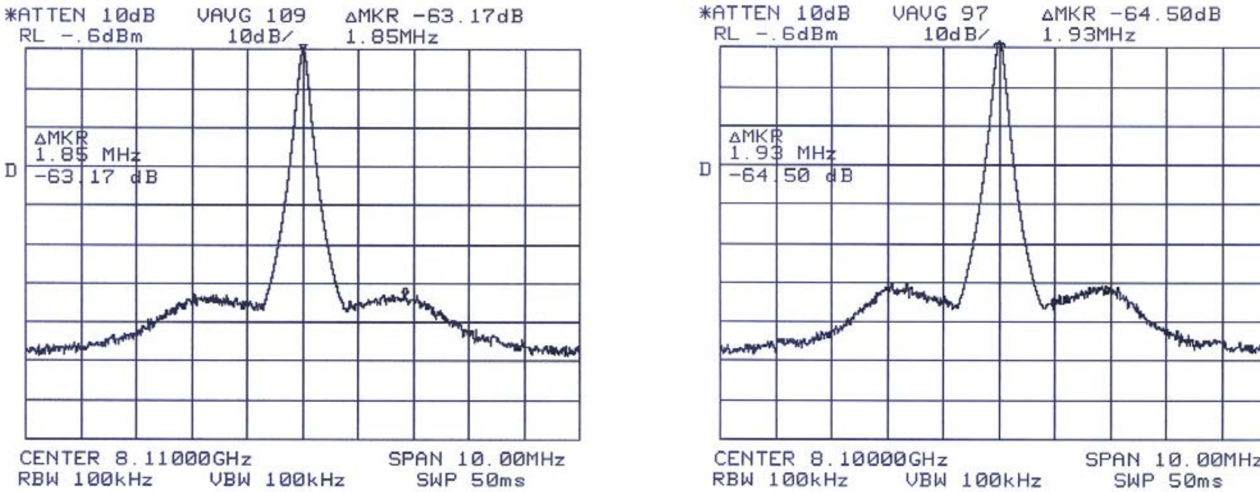


Figure 3 (above): a) Left figure shows YIG 1 tuned to 8110MHz; b) shows YIG 2 tuned to 8100MHz.

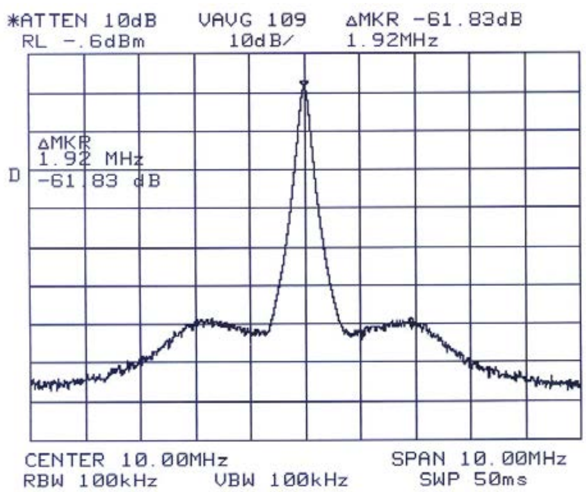


Figure 4 (left): 10MHz signal after YIG 1 mixed with YIG2.

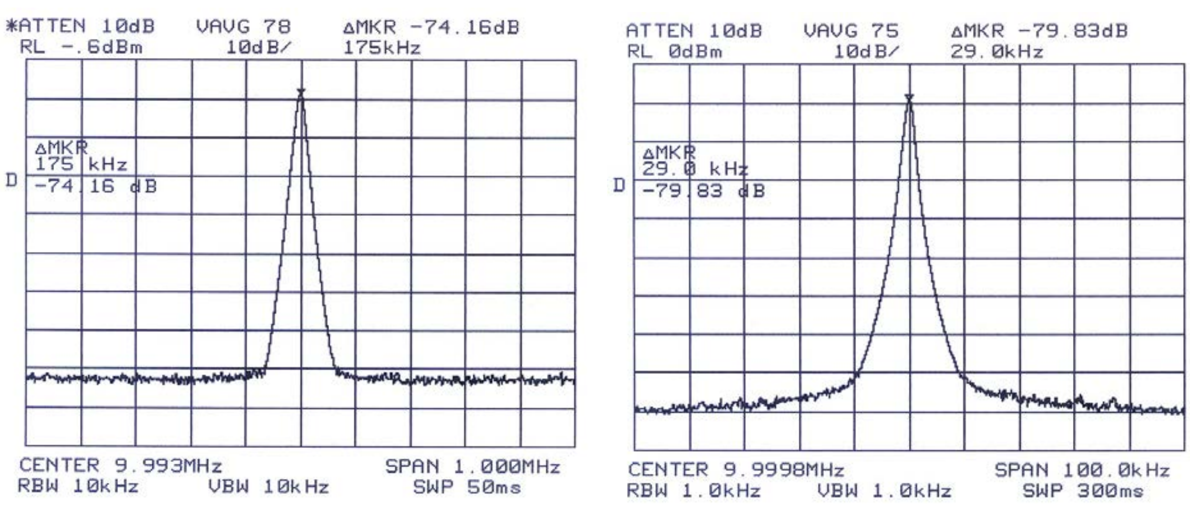
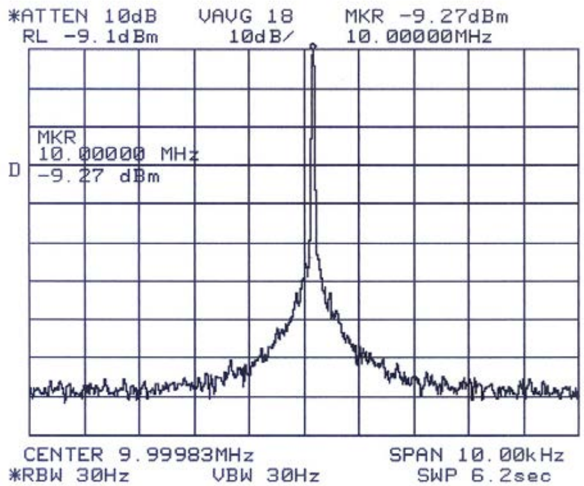
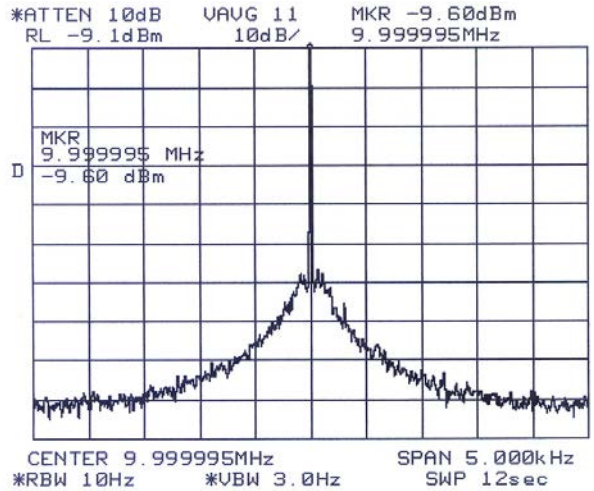


Figure 5 (above): 10MHz YIG1-YIG2 mixed signal at a) 1MHz (left) and b) 100kHz (right) spans.





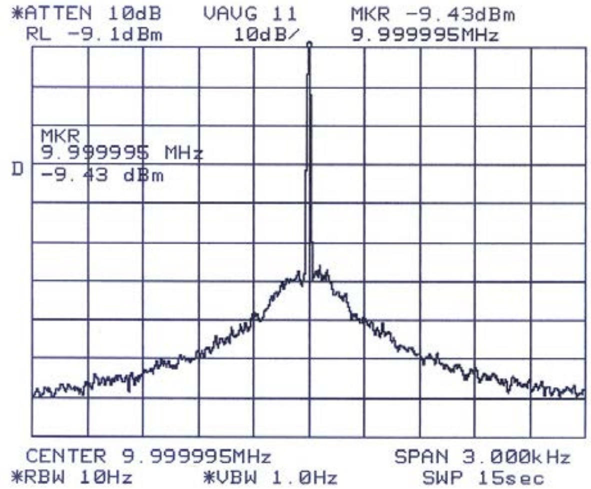


Figure 6: 10MHz YIG1-YIG2 mixed signal at a) 10kHz (left,above) and b) 5kHz (right,above) and c) 3kHz (left) spans.

To continue close in phase noise measurements the YIGs were tuned to 8000MHz and 8000.01MHz then mixed to 10kHz and input to the low frequency FFT signal analyzer (Figure 2). At a span of 250Hz, 60Hz sidebands appear that are ~ 63dB down from the carrier peak, and a new noise feature forms that can be approximated as a rectangular pedestal ~50Hz wide (RSBW = 3.63 Hz) and 58dB down from the carrier peak (Figure 7a,b).

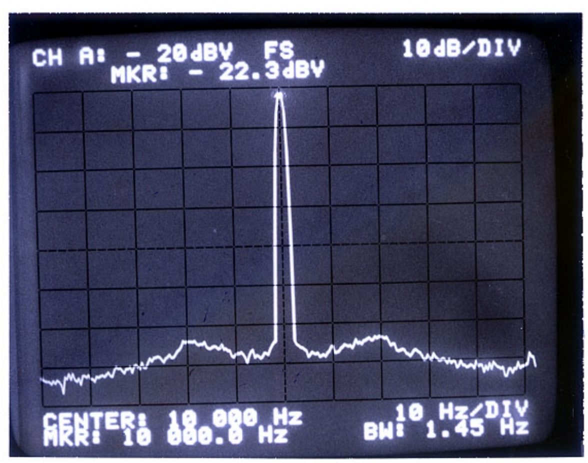


Figure 7: 10kHz YIG1-YIG2 mixed signal at a) 250 Hz (left,above) and b) 100 Hz (right,above) spans.

The ratio of carrier to pedestal power is ~ 17dB at 230GHz (1.7%). Finally, at a span of 10Hz (RSBW=145mHz), a small new noise feature is seen (Figure 8) that is ~2Hz wide. But this feature only represents ~1% of the carrier power at 230GHz.

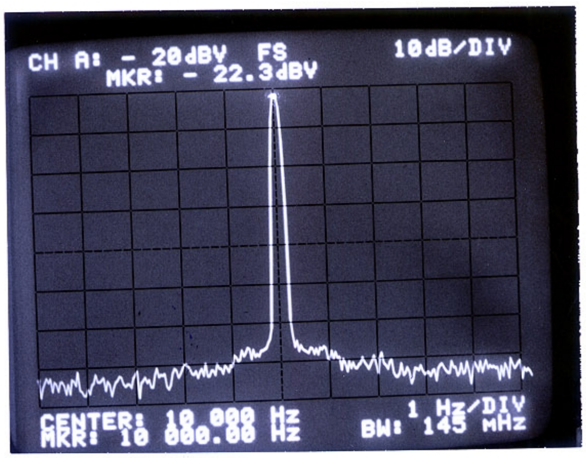


Figure 8 (left): 10kHz YIG1-YIG2 mixed signal at 10Hz span.

Summary: Total loss due to phase noise of two MRG systems at 230GHz < 2+3+1.7+1 = 7.7%. Assuming RMS phase adds in quadrature, the loss due to one MRG is ~ 4%.

<u>**II.** MRG comparison with CTI 8080MHz cavity tuned oscillator.</u>

In the second setup, an SMA MRG system was tuned near the 8080MHz output of a CTI cavity tuned oscillator, and the signals were mixed and fed to both spectrum analyzers. The CTI was locked to the 5MHz output of the Wenzel crystal as shown in Figure 9.

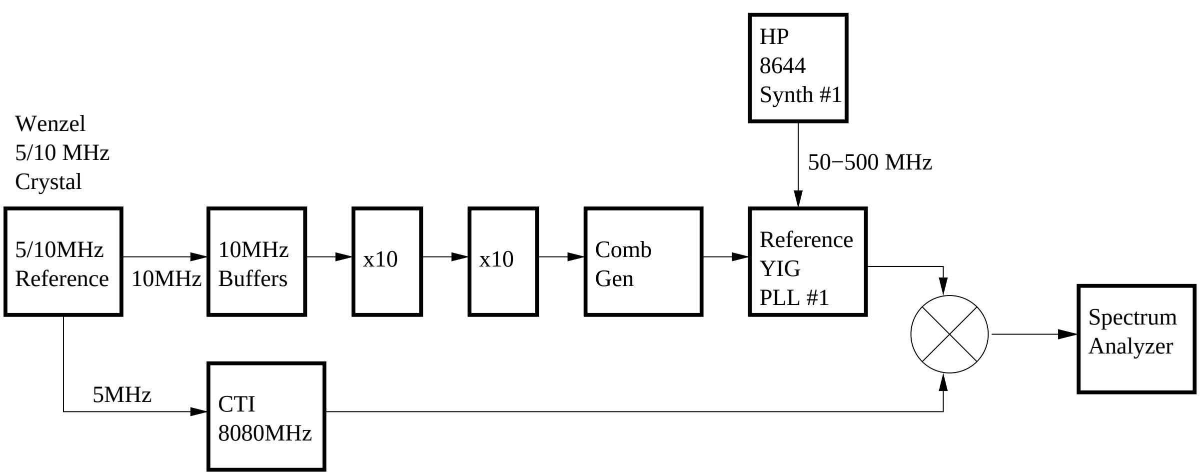


Figure 9: Setup for SMA MRG comparison with CTI 8080MHz oscillator.

To check the far out phase noise, the HP8644 was set to 90.0 MHz, placing the YIG output at 8090.0 MHz with the mixer output at 10 MHz. As in setup **I**, the YIG spectrum showed a ~5MHz wide pedestal at 8080MHz, ~69 dB lower than the carrier, which was not apparent in the CTI spectrum (Figure 10). The loss due to this pedestal at 230GHz is ~0.5%. At a span of 500kHz (figure 11), a new triangular pedestal appears with base width ~300kHz, height ~17dB resulting in a loss at 230GHz of 0.5%.

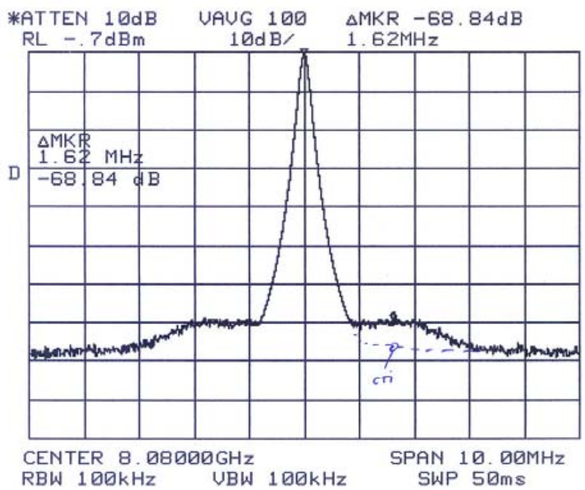


Figure 10: YIG 1 spectrum at 8080MHz. Dotted line indicates shape of corresponding CTI spectrum at 8080MHz.

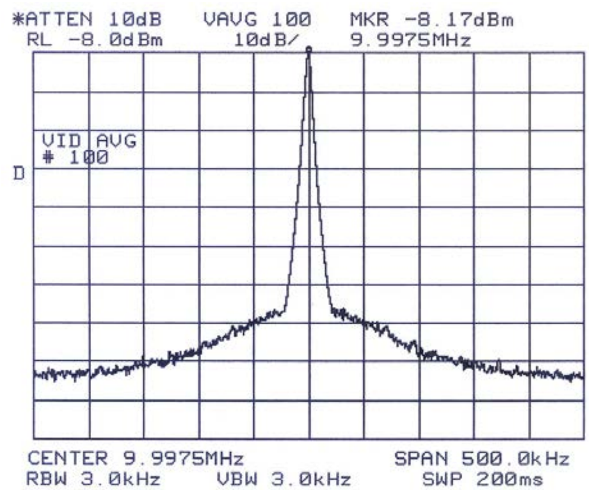


Figure 11: YIG 1 and CTI mixed down to 10MHz at a span of 500kHz.

At spans of 30kHz and 5kHz, a separate spectral feature emerges (figure 12a,b) representing ~8% loss at 230GHz. To examine the close in phase noise, the HP8644 was tuned to 80.02MHz and the mixer output at 20kHz was examined with the FFT analyzer.

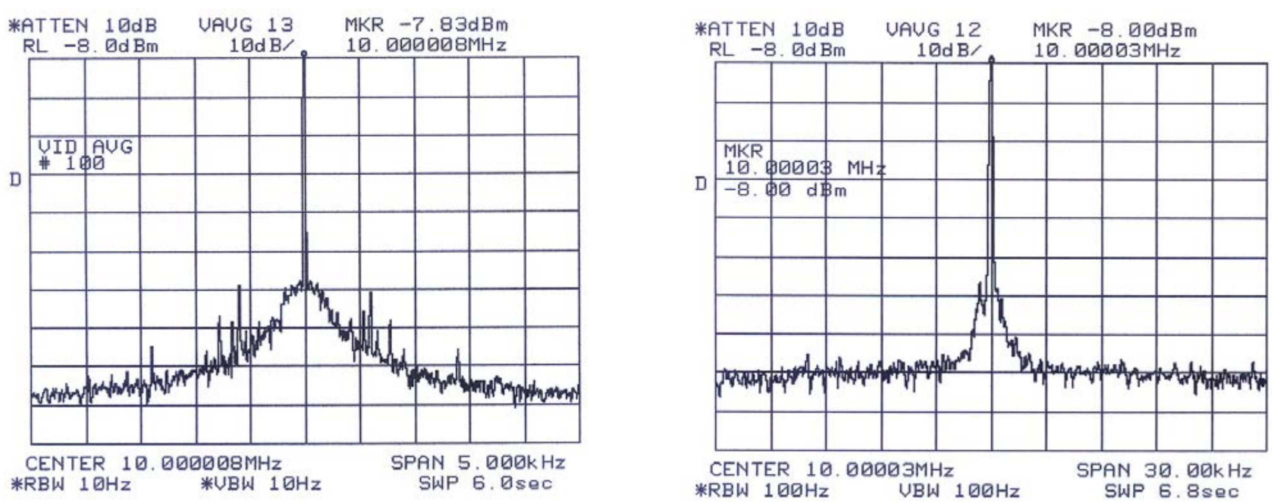


Figure 12: YIG 1 and CTI mixed down to 10MHz at spans of a) (left) 30kHz and b) (right) 5kHz.

The noise floor of the FFT analyzer is higher than that of the HP8563A, but at a span of 1kHz, 60Hz harmonics are evident, though they do not represent much more than an aggregate loss of ~1% at 230GHz (Figure 13). The 60Hz may be due to the power supply used for the CTI oscillator. The triangular pedestal seen in the 250Hz span plot represents a loss of less than 0.5%

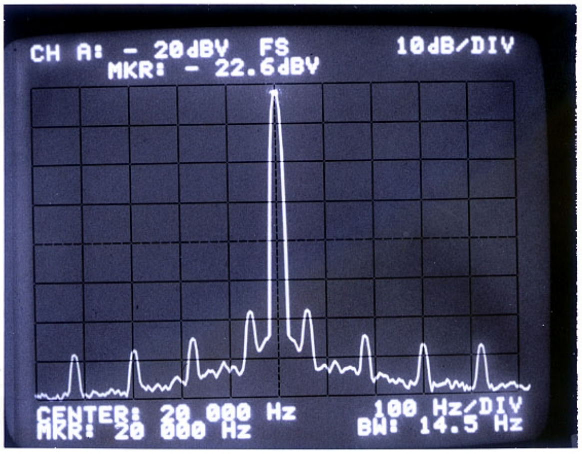


Figure 13: 60 Hz harmonics seen in 20kHz mixed signal from YIG 1 and CTI. Spans of 1kHz,

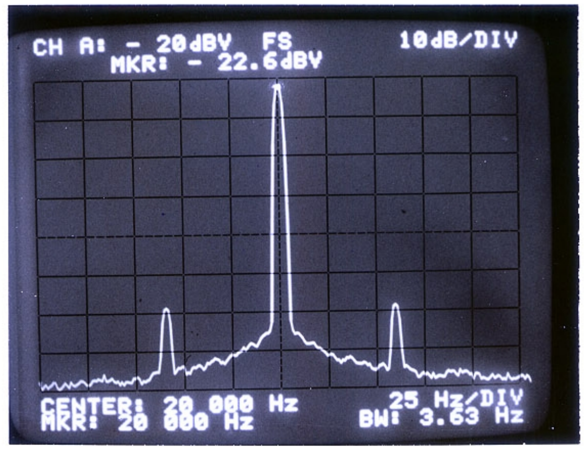


Figure 14: 60 Hz sidebands in 20kHz mixed signal from YIG 1 and CTI. Small triangular noise pedestal seen at span of 250Hz.

(Figure 14). Very close in, two spurious tones at +/- 1.8Hz appear, contributing ~1.5% loss at 230GHz (Figures 15a,b).

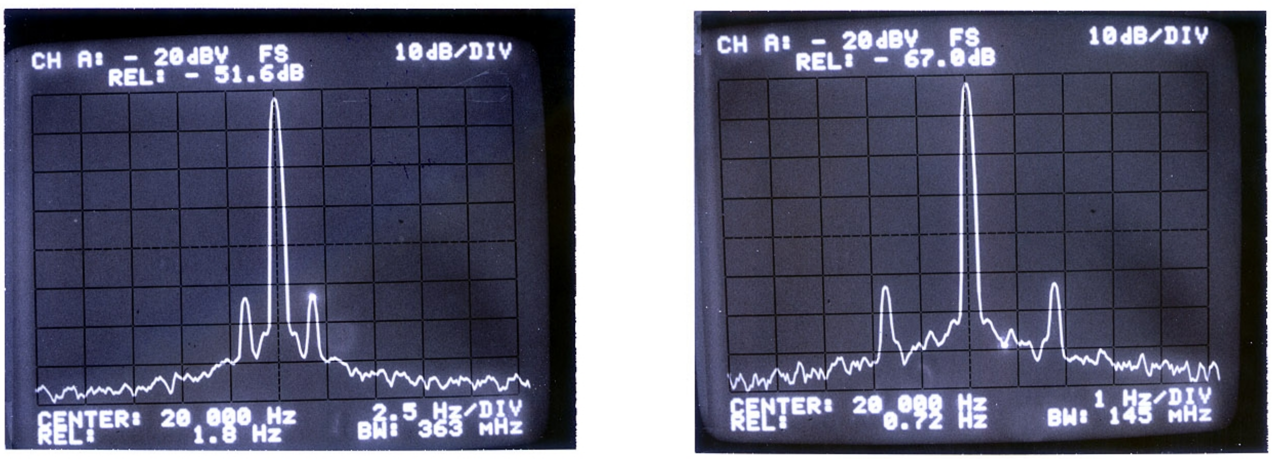
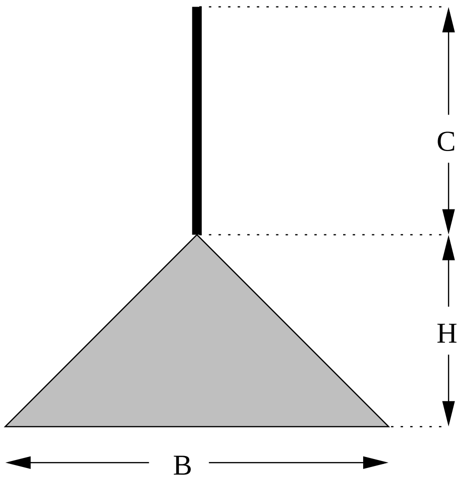


Figure 15: Spurious sidebands at +/- 1.8Hz in 20kHz signal from mix of YIG 1 and CTI outputs. Spans of a) (left) 25Hz and b) (right) 10Hz.

Summary: Total loss due to phase noise of an MRG and CTI system at 230GHz < 12%. So, the loss at 230GHz due to the CTI unit alone would be ~(1-0.88/0.96) = 8.5%.

Appendix A: Calculation of signal to noise power for a triangular phase noise pedestal.

Let a phase noise pedestal be triangular and the dimensions in the following figure made with a resolution bandwidth (RSBW) of R (in Hz):



Where:

C is the height of the carrier above the pedestal in dB.

H is the height of the pedestal in dB.

B is the width (base) of the pedestal in Hz.

And let **n = B/(2R)** (number of resolution elements across half of the pedestal)

For each frequency resolution element in the pedestal, we can write the ratio of phase noise power to power in the carrier as:

$$\frac{P_i}{P_c} = 10^{\frac{-\left(\frac{H\bullet i}{n}+C\right)}{10}} \qquad (1.1)$$

where P_i / P_c is this ratio for the ith frequency element ($0 \le i \le n$). Summing this ratio over all the frequency elements gives:

$$\begin{aligned}\frac{\sum P_i}{P_c} &= 10^{-\left(\frac{C}{10}\right)}\left(1+2\sum_{i=1}^{n}10^{-\left(\frac{H\bullet i}{10\bullet n}\right)}\right) \\ &= 10^{-\left(\frac{C}{10}\right)}\left(1+2\left(\frac{10^{-\left(\frac{H}{10\bullet n}\right)}-10^{-\left(\frac{H(n+1)}{10\bullet n}\right)}}{1-10^{-\left(\frac{H}{10\bullet n}\right)}}\right)\right)\end{aligned} \qquad (1.2)$$

So, if $n \gg 1$ then

$$\frac{\sum P_i}{P_c} \simeq 10^{-\left(\frac{C}{10}\right)}\left(\frac{1+10^{-\left(\frac{H}{10\bullet n}\right)}}{1-10^{-\left(\frac{H}{10\bullet n}\right)}}\right) \qquad (1.3)$$

And the ratio of pedestal power to carrier power in dB is:

$$\boxed{\frac{P_{pedestal}}{P_{carrier}}(in\ dB) = -C+10\log\left(1+10^{-\left(\frac{H}{10\bullet n}\right)}\right)-10\log\left(1-10^{-\left(\frac{H}{10\bullet n}\right)}\right)} \qquad (1.4)$$