Academia Sinica, Institute of Astronomy & Astroph

AMiBA Project

Subject: Correlator Module SNR Tests	**Date:** May 1, 2007 2007-DK003	**From:** Derek Kubo
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References: Memos 2003-DK001, 2007-DK001, 2007-DK002

Introduction

We have been working under the assumption that the optimum drive level into the correlator module is approximately -12 dBm (0.063 mW). This number was initially derived from characterizing the input 1 dB compression point (P1dBc) using a CW tone at 10 GHz to be approximately -5 dBm. That is, two 100% correlated input signals fed to the correlator module at -5 dBm produces an output signal which is compressed by 1 dB, or a normalized output of 0.79 V instead of 1 V[1]. The general rule to preserve the Gaussian amplitude characteristics of noise is to operate approximately 10 dB away from the P1dBc point. Following this rule would put the input signal levels at -15 dBm, however, we found that the correlated output signal would be only be about five times larger than the backend Johnson plus readout noise. We compromised at -12 dBm.

As a separate test, Chao-Te characterized the overall system SNR at different correlator input drive levels using the W-band noise source mounted on a translation stage. This test confirmed that -12 dBm was near the optimum drive level (see *Figure 1*).

With the 7-element AMiBA system completed, we are in the process of refinement for improved stability and sensitivity (see memos 2007-DK001, DK002 for details). During this process we have seen some limited evidence that increasing the IF power (from the nominal -12 dBm) to the correlator modules produces improved SNR performance. As a result I am now questioning whether the conditions of the original tests to determine the drive level were valid. For example the CW test described above bares little resemblance to the actual signals seen during observation which is dominated by uncorrelated noise. The SNR tests performed by Chao-Te, however, does resemble an astronomical observation with the exception that the W-band noise source emits a signal which is ~15 times the strength of Jupiter, our strongest calibration source. This memo describes the results of recent SNR tests performed in the lab.

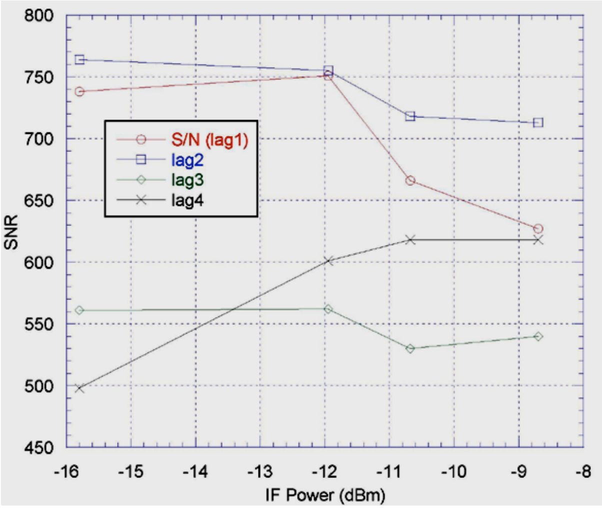

Figure 1 Overall system SNR using W-band noise source on translation stage.

Summary

A correlator module was recently characterized in the lab using a combination of uncorrelated noise and a weak correlated CW tone to attempt to determine the optimal input operating point. The uncorrelated noise and CW tone represent the independent receiver noise and astronomical signal, respectively. The results of these tests show that the small signal (-27 to -33 dB below the noise) correlated response does not show any significant compression even when driving the correlator module at an input level of -1 dBm. The large signal noise, however, does show an input 1dBc of approximately -7 dBm. The module responsivity varies with noise loading and approaches its maximum value of 274 $\mathrm{kV_{RMS}}$/W when driven below -10 dBm. Driving at -6.5 dBm (99.8% noise) still produces a responsivity of 262 $\mathrm{kV_{RMS}}$/W. These tests indicate that operating at input levels of -7 dBm may produce improved overall SNR without compromising the linearity of the desired signal. Follow-up astronomical tests are recommend to validate (or invalidate) these lab results.

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[1] These original tests are described in detail in the referenced memo 2003-DK001.

Test Setup

Figure 2 describes the test setup. An IF noise source (2 to 18 GHz) was split using a power divider and decorrelated using two unequal cable lengths (3 feet disparity ~4.39 nsec). These two noise signals represent the noise output from a pair of receivers. The maximum input noise available to the correlator module was approximately -1 dBm (0.79 mW). A 10 GHz CW signal was generated by an HP synthesizer and split using a power divider. The right half signal was fed to the correlator module through the coupled port of a directional coupler. The left half CW signal was bi-phase modulated using a mixer and 1 kHz sine wave tone with the result being a double sideband tone centered around 10 GHz (see spectral representation in *Figure 2*). I would have preferred to generate a single sideband tone but the setup would have been a bit too complicated for this experiment. The SNR was controlled by selecting pad values for AT4 and AT5. The input drive level to the correlator module was controlled by selecting pad values for AT1 and AT2.

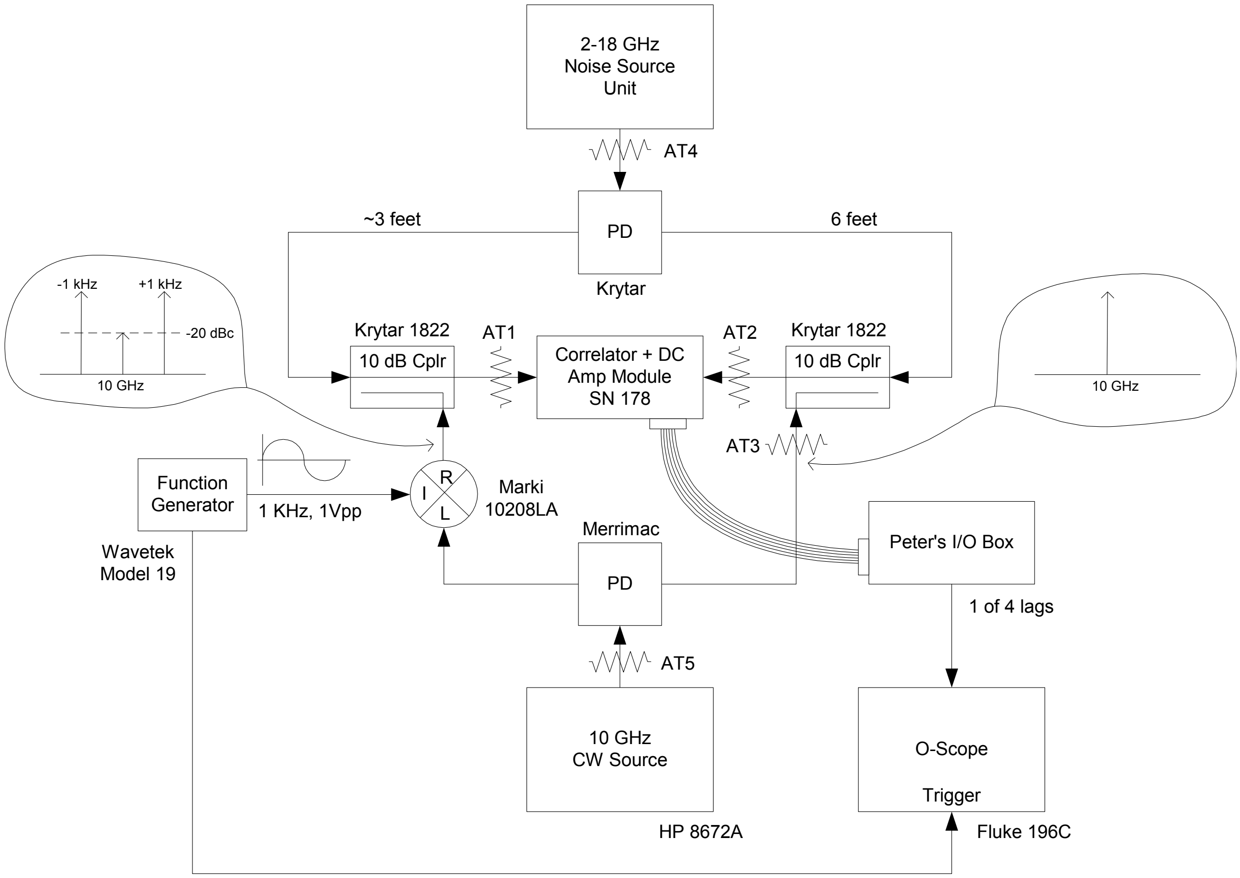

Figure 2 SNR Test Setup

The upper left plot of *Figure 3* represents a signal input level condition of -26.5 and -27.0 dBm for left and right inputs, respectively, and no noise. The red and blue traces represent the correlated output and input trigger signals, respectively. The module + DC amplifier responsivity spec is 80 kV$_{RMS}$/W[2], and using this value I calculate a minimum expected output level of 0.51 Vpp. The actual measured output level is 1.5 Vpp and exceeds the spec value by almost a factor of three. The remaining five plots represent the same input signal conditions but with progressively more noise added (left to right, top to bottom). Input signal SNRs are: infinity (no noise), -9.3, -14.4, -19.8, -23.9, and -25.9 dB. Note that the total power to the correlator module is dominated by the noise for all but the first plot. It is clear from these plots that the correlated signal output is diminishing with larger input noise power, however, it's difficult to separate the effect of lower SNR from the larger input power because both parameters are changing simultaneously.

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[2] The Marki module spec is 80V$_{RMS}$/W and is followed a DC amplifier with a gain of 1000V/V

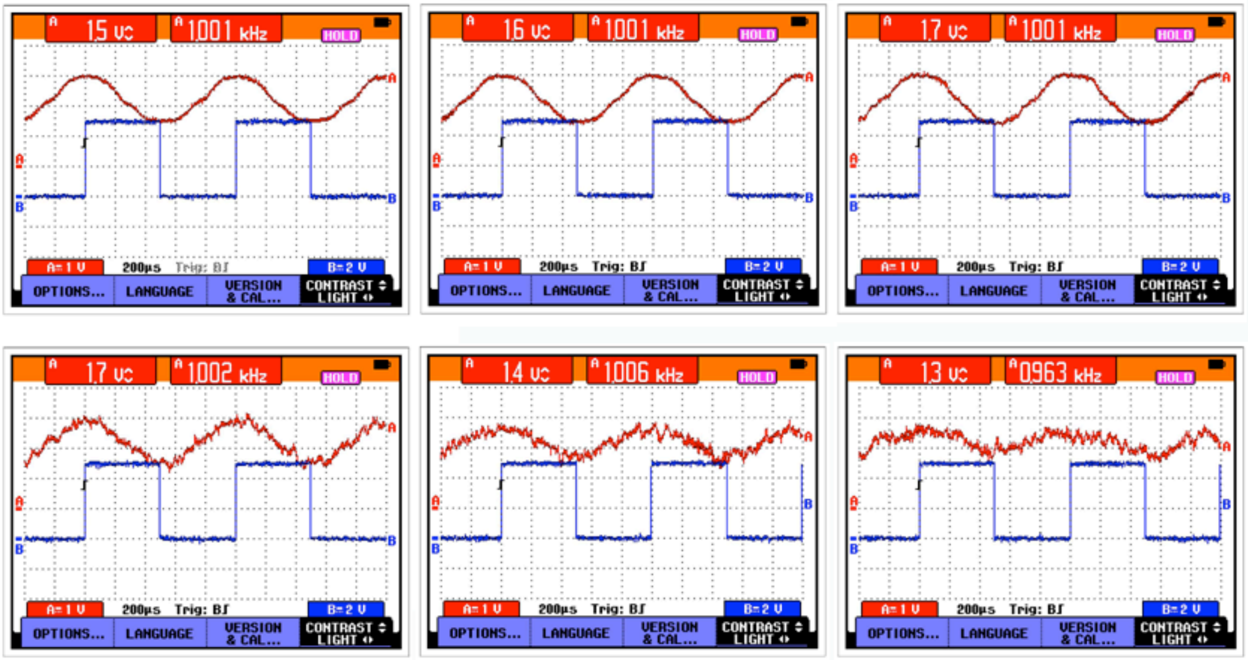

Figure 3 *Input signal held constant at -26.5 & -27.0 dBm for left & right inputs, respectively. Upper left – no noise; upper center - noise = -17.2 & -17.7 dBm; upper right – noise = -12.1 & -12.6 dBm; lower left – noise = -6.7 & -7.2 dBm; lower center – noise = -2.6 & -3.1 dBm; lower right – noise = -0.6 & -1.1 dBm.*

Detailed Characterization of Signal and Noise Response

A separate set of tests were performed to characterize the output SNR WRTo input SNR and power. *Table I* shows the results for the input power to the correlator module fixed at -0.75 dBm (0.84 mW) and varying input SNRs of -26.4, -29.4, and -32.4 dB. The input SNRs were controlled by adjusting the input signal levels in the second column. The forth column shows the signal output amplitude with the noise removed (similar to upper left plot of *Figure 3*). Note the fairly nice linear relationship of this output amplitude WRTo signal input power. E.g., starting from the third row the input power is approximately doubled for the second row, and doubled again for the first row. The forth column represents the measured output sinusoid amplitudes of 139, 274, and 552 mV RMS which are very close to the ideal doubled values of 139, 278, and 556 mV RMS. So for the noise off condition we can conclude that the relationship between the input power and the correlated output voltage is quite linear.

This same test was repeated with the input noise power turned on. Note the output voltage levels in the fifth column are diminished by a factor of 2.4 with the noise turned on. This decreased output is presumably caused by a reduction of the mixer responsivity in the presence of noise. The measured output sinusoid amplitudes are 59, 116, and 229 mV RMS (ideal doubling is 59, 118, and 236 mV RMS). It's quite interesting to note that the input to output relationship is still linear even with the noise turned on. The implication of this statement is quite significant. Up until now we've been concerned about linearity and how to calibrate out any non-linearity introduced into the system. We still have to be somewhat concerned about maintaining linearity in the IF system prior to the correlator module but this should be an easily managed issue.

Table I *Noise Input Set to -0.75 dBm, Varying SNR*

Input SNR (dB)	Signal In Pwr, (L/R)	Noise In Pwr, (L/R)	Signal Out w/o Noise	Signal Out w/ Noise	Noise Out (RMS)	Output SNR (linear)
-26.4 dB	-26.5/-27.4 dBm	-0.5/-1.0 dBm	552 mV RMS	229 mV RMS	152 mV RMS	1.5
-29.4 dB	-29.6/-30.4 dBm	-0.5/-1.0 dBm	274 mV RMS	116 mV RMS	152 mV RMS	0.8
-32.4 dB	-32.5/-33.4 dBm	-0.5/-1.0 dBm	139 mV RMS	59 mV RMS	152 mV RMS	0.4

Table II shows the results of a similar test but with the noise and signal input power levels reduced by approximately 6 dB. The signal outputs without noise (forth column) are 34.5, 70, and 146 mV RMS and are quite close to the ideal doubled values of 34.5, 69, and 138 mV RMS. With noise, the numbers reduce to 19.5, 61, and 131.5 mV RMS, with doubled values of 19.5, 39, and 78 mV RMS. These measured values unfortunately don't follow the doubled values and I don't know the reason for this (other than measurement error). The reduction in responsivity with noise on is a factor of ~1.1, or nearly the same responsivity as with the no noise condition.

The most significant observation with this measurement is the noise output level of 110 mV RMS. The previous set had ~6 dB more noise power and produced an output of 152 mV RMS. If the relationship were linear I would expect a factor of 4 increase or 440 mV RMS. The intermediate conclusion is that the noise output has been compressed.

Table II Noise Input Set to -6.5 dBm, Varying SNR

Input SNR (dB)	Signal In Pwr, (L/R)	Noise In Pwr, (L/R)	Signal Out w/o Noise	Signal Out w/ Noise	Noise Out (RMS)	Output SNR (linear)
-26.7 dB	-32.7/-33.3 dBm	-6.5/-6.6 dBm	146 mV RMS	131.5 mV RMS	110 mV RMS	1.2
-29.8 dB	-35.7/-36.4 dBm	-6.5/-6.6 dBm	70 mV RMS	61 mV RMS	110 mV RMS	0.6
-32.8 dB	-38.6/-39.4 dBm	-6.5/-6.6 dBm	34.5 mV RMS	19.5 mV RMS	110 mV RMS	0.2

Table III shows the results of the last test with the noise and signal input power levels reduced again by another ~4 dB. I didn't reduce by 6 dB because the output signal level on the oscilloscope would have been too small to see. The signal outputs without noise (forth column) are 14, 27, and 54 mV RMS and are quite close to the ideal doubled values of 14, 28, and 56 mV RMS. With noise, the numbers change to 15, 28, and 58 mV RMS, with doubled values of 15, 30, and 60 mV RMS. There is no reduction in responsivity for this noise input level.

The measured output noise amplitude is 50 mV RMS. A 4 dB increase should result in 126 mV RMS noise yet we saw 110 mV RMS in the previous test. Close to linear but not quite.

Table III Noise Input Set to -10.2 dBm, Varying SNR

Input SNR (dB)	Signal In Pwr, (L/R)	Noise In Pwr, (L/R)	Signal Out w/o Noise	Signal Out w/ Noise	Noise Out (RMS)	Output SNR (linear)
-26.8 dB	-36.2/-37.3 dBm	-9.9/-10.5 dBm	54 mV RMS	58 mV RMS	50 mV RMS	0.5
-29.9 dB	-39.2/-40.4 dBm	-9.9/-10.5 dBm	27 mV RMS	28 mV RMS	50 mV RMS	0.25
-32.8 dB	-42.1/-43.3 dBm	-9.9/-10.5 dBm	14 mV RMS	15 mV RMS	50 mV RMS	0.1

A separate test was conducted to characterize the relationship between input noise power and output voltage. *Table IV* shows the results. The input power was measured using a power meter and the output voltage using the RMS measurement utility of the oscilloscope. The average input power was calculated and plotted against the output voltage in *Figure 4*. Note the nonlinear relationship, especially for input signal levels exceeding ~0.2 mW (-7 dBm).

Table IV Noise Input Verses Noise Output (no signal)

Left Input		Right Input		Average		Output
(dBm)	(mW)	(dBm)	(mW)	(dBm)	(mW)	(mV)
-0.25	0.94	-0.69	0.85	-0.46	0.90	152
-3.17	0.48	-3.59	0.44	-3.37	0.46	133
-6.34	0.23	-6.80	0.21	-6.56	0.22	102
-9.29	0.12	-9.77	0.11	-9.52	0.11	61
-12.45	0.06	-12.91	0.05	-12.67	0.05	24

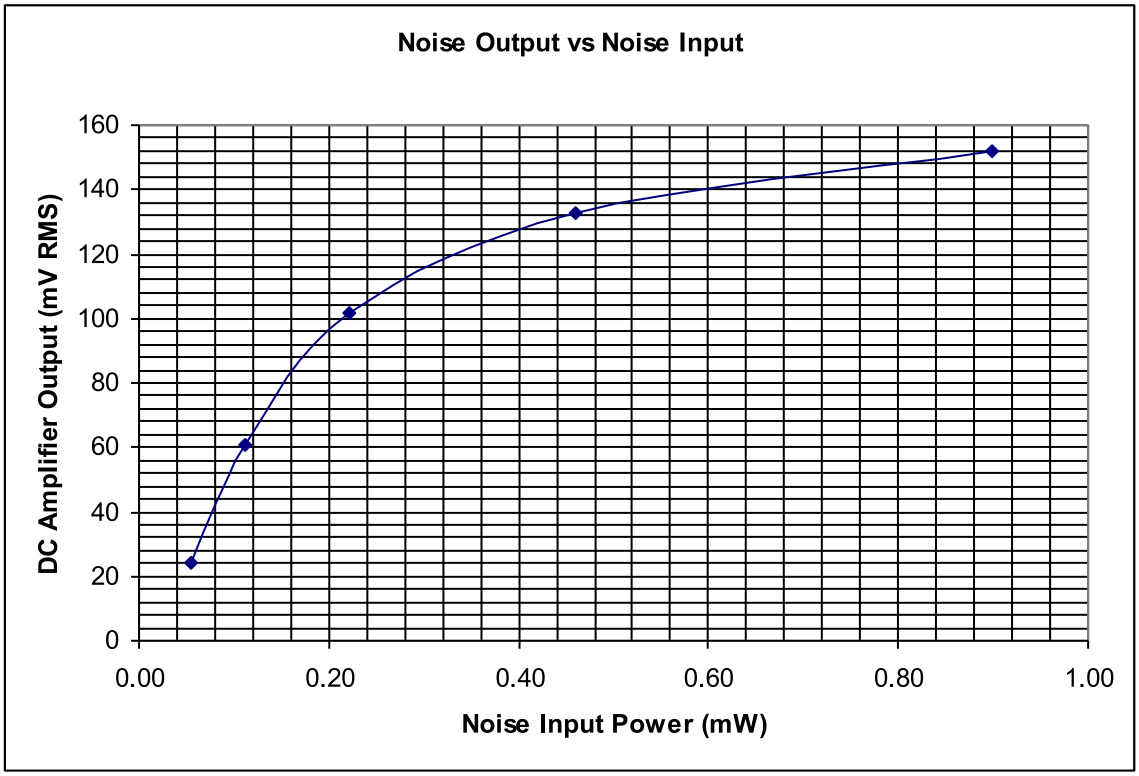

Figure 4 DC Amplifier Output Voltage Verses Noise Input Power

Conclusions and Recommendations

Based on the results of these tests it appears that improved SNR can be achieved by driving the correlator modules at a higher level than our current target of -12 dBm (0.063 mW). There are number of factors to consider in determining the optimal drive level which include:

1) Driving the correlator modules with more noise + signal results in more noise + signal output.
2) The larger noise output begins to compress much earlier than the desired small signal output resulting in an apparent improved SNR.
3) The readout chip can accept inputs of 2.2V +/-1V.
4) The responsivity of the correlator module reduces with more input power. $\mathcal{R}$= 113, 262, and 274 kV_{RMS}/W for inputs of -1.0, -6.5, and -10.0 dBm, respectively.

Driving at -1 dBm produces the largest noise + signal output but at the expense of reduced responsivity. The breakpoint to operate at maximum responsivity appears to be around -7 dBm. For item 2) above, one possible explanation for different linearity performances between the large signal noise and small signal sine wave signal is that the noise is uncorrelated where as the signal is 100% correlated. There may be two separate processes at play here. In any case, linear performance for the small signal input even in the presence of large amounts of noise is a fortuitous outcome for our application.

Even though this test more closely mimics the real input signals to the correlator module it is still not the same as an astronomical signal. The true correlated signal from an astronomical source will appear as broadband noise where as this test utilized a CW tone (so that I can see the results on an oscilloscope). We are presently attempting to measure the overall system SNR on Jupiter at various input power levels to the correlator.