May 2004 Measurements Of IF Non-linearities In The IF Rack And The DCR

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1 Introduction

During observing checkouts for GBT Proposal 1A4 it was discovered that the resulting data showed signs of non-linear gain in the system [1]. Follow-up observations were then done which isolated the source of the largest non-linearities to the IF Rack [2].

A special project, the GBT IF System Non-linearity Project, was then chartered to locate and correct the devices which exhibit non-linear gain in the GBT IF system. The project team members are Toney Minter, Steve White and Roger Norrod.

In this memo we report on the first measurements of the linearity of the IF Rack.

2 The Measurements

On May 26, 2004 Steve White and Roger Norrod made controlled measurements of the IF Rack gains. A noise source was used to inject power into the IF Rack and the DCR was used to take data. Two series of measurements were made for each Optical Driver Module (ODM). Before each series of measurements the IF Rack was balanced to a target level of 1 Volt IF Power. In the first series of measurements the input power was decreased in steps of 1 dB and in the second series of measurements the input power was increased in steps of 1 dB. In Tables 1, 2, and 3 we show the results of these measurements.

The HP 3304 programmable attenuator was used for the precision attenuator steps of the ΔP_{in}

ODM1		ODM2		ODM3	
DCR Counts (10^5)	ΔP_{in} (dB)	DCR Counts (10^5)	ΔP_{in} (dB)	DCR Counts (10^5)	ΔP_{in} (dB)
11.201	0.00	10.511	0.00	9.580	0.00
8.924	-1.02	8.317	-1.02	7.557	-1.02
7.111	-2.03	6.571	-2.03	6.134	-2.03
5.675	-3.04	5.193	-3.04	4.939	-3.04
4.549	-4.04	4.113	-4.04	4.006	-4.04
3.640	-5.04	3.242	-5.04	3.253	-5.04
2.917	-6.06	2.550	-6.06	2.656	-6.06
2.344	-7.06	2.000	-7.06	2.183	-7.06
1.912	-8.02	1.585	-8.02	1.826	-8.02
1.546	-9.02	1.236	-9.02	1.525	-9.02
1.255	-10.02	0.958	-10.02	1.286	-10.02
1.025	-11.02	0.737	-11.02	1.095	-11.02
9.307	0.00	10.183	0.00	9.708	0.00
11.681	1.00	12.853	1.00	12.081	1.00
14.673	2.00	16.227	2.00	15.038	2.00
18.427	3.00	20.462	3.00	18.709	3.00
23.042	3.96	25.680	3.96	23.158	3.96
28.931	4.96	32.352	4.96	28.719	4.96
36.330	5.98	40.761	5.98	35.535	5.98
45.576	6.98	51.300	6.98	43.805	6.98
56.432	7.98	63.724	7.98	53.140	7.98
70.653	8.99	80.092	8.99	64.960	8.99
88.432	10.00	100.680	10.00	79.161	10.00
				96.060	11.02

Table 1: DCR counts versus change in input power (ΔP_{in}) for ODM1, ODM2 and ODM3 on May 26, 2004.

[1] See http://www.gb.nrao.edu/ tminter/1A4/1A4obscheckout.shtml

[2] See http://www.gb.nrao.edu/ tminter/1A4/nonlinear/index.html

ODM4		ODM5		ODM6	
DCR Counts (10^5)	ΔP_{in} (dB)	DCR Counts (10^5)	ΔP_{in} (dB)	DCR Counts (10^5)	ΔP_{in} (dB)
9.496	0.00	9.624	0.00	9.517	0.00
7.563	-1.02	7.566	-1.02	7.548	-1.02
6.025	-2.03	5.952	-2.03	5.986	-2.03
4.805	-3.04	4.689	-3.04	4.751	-3.04
3.852	-4.04	3.714	-4.04	3.787	-4.04
3.081	-5.04	2.933	-5.04	3.009	-5.04
2.469	-6.06	2.320	-6.06	2.390	-6.06
1.983	-7.06	1.839	-7.06	1.901	-7.06
1.618	-8.02	1.479	-8.02	1.532	-8.02
1.308	-9.02	1.176	-9.02	1.220	-9.02
1.062	-10.02	0.937	-10.02	0.973	-10.02
0.867	-11.02	0.748	-11.02	0.777	-11.02
9.675	0.00	8.920	0.00	9.103	0.00
12.075	0.96	11.247	1.00	11.470	1.00
15.142	1.96	14.185	2.00	14.467	2.00
19.008	2.98	17.888	3.00	18.250	3.00
23.846	3.98	22.455	3.96	22.930	3.96
29.549	4.98	28.310	4.96	28.950	4.96
37.063	5.99	35.680	5.98	36.570	5.98
46.485	7.00	44.910	6.98	46.220	6.98
		55.740	7.98	57.660	7.98
		69.902	8.99	72.895	8.99
		87.405	10.00	92.201	10.00

Table 2: DCR counts versus change in input power (ΔP_{in}) for ODM4, ODM5 and ODM6 on May 26, 2004.

ODM7		ODM8	
DCR Counts (10^5)	ΔP_{in} (dB)	DCR Counts (10^5)	ΔP_{in} (dB)
9.227	0.00	10.091	0.00
7.325	-1.02	7.909	-1.02
5.814	-2.03	6.208	-2.03
4.615	-3.04	4.885	-3.04
3.678	-4.04	3.865	-4.04
2.920	-5.04	3.053	-5.04
2.317	-6.06	2.416	-6.06
1.840	-7.06	1.918	-7.06
1.480	-8.02	1.545	-8.02
1.175	-9.02	1.232	-9.02
0.933	-10.02	0.986	-10.02
0.742	-11.02	0.791	-11.02
9.733	0.00	9.379	0.00
12.250	1.00	11.818	1.00
15.428	2.00	14.900	2.00
19.411	3.00	18.789	3.00
24.302	3.96	23.592	3.96
30.539	4.96	29.764	4.96
38.341	5.98	37.545	5.98
48.076	6.98	47.339	6.98
59.446	7.98	58.860	7.98
74.251	8.99	74.001	8.99
92.525	10.00	92.836	10.00

Table 3: DCR counts versus change in input power (ΔP_{in}) for ODM7, and ODM8 on May 26, 2004.

columns of Tables 1, 2, and 3. The programmable attenuator has a total of 11 dB attenuation in 1 dB steps. Before the IF Rack linearity measurement, each attenuator step was measured using an Agilent E4412A power head with a linearity specification of $\pm 3\%$ over the range of the power head. Fortunately, the input power level from the noise source is ~ -26 dBm, which was later determined to be in the most linear range of the power head ($\pm 1\%$). The bandwidth effects of the attenuator were not quantified during these measurements. The uncertainties of the HP attenuator bandwidth for each attenuator step and the non-linearity of the power head at the time of the measurement resulted in errors of a few percent. Thus the subsequent measurements should be considered coarse when considering the deviations from linearity on the order of $\geq 1\%$, but do give a good indication of the substantial differences between ODM's.

Another significant measurement was also made. The IF Rack inputs were set to unused inputs so that the input was essentially a floating ground that produces a very small input power – typically only a few milli-Volts. This then provides a means of measuring the DC offset of the DCR when the power input is zero Volts. In Table 5 the DC offsets for each DCR

IF Channel	Generic Name	serial number
1	ODM1	sn005
2	ODM2	sn006
3	ODM3	sn003
4	ODM4	sn008
5	ODM5	sn002
6	ODM6	sn004
7	ODM7	sn001
8	ODM8	sn007

Table 4: Relationship between IF Channel number and Optical Driver Serial Number on September 21, 2004. These pairing are subject to change without notice.

channel are listed.

Channel	Counts (10^5)
1	0.141
2	0.000
3	0.362
4	0.118
5	0.032
6	0.022
7	0.009
8	0.057

Table 5: DC offsets measured for the DCR on May 26, 2004.

3 Results

In Figures 1–8 we have plotted the results of the measurements. The pluses represent the raw measurements. As can be seen from Figures 1–8 nearly all ODMs show a non-linear behavior for decreasing input power such that there is more output power than is expected. This is due to the DC offsets not being compensated for in these measurements. Once we compensate for the DC offsets, represented by circles in Figures 1–8 we see that the ODMs responses are much more linear.

3.1 ODM 1

From Figure 1 we see that ODM 1 is within 0.1 dB (2.3%) of being linear from −11 dB (0.08 V) to +7 dB (5 V). However it is also apparent that ODM 1 is behaving non-linearly above +5 dB (3.2 V). ODM 1 does not vary from linearity by more than 0.2 dB (4.7%) from −11 dB (0.08 V) to +10 dB (10 V).

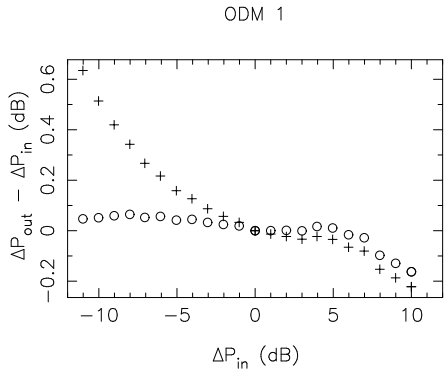

Figure 1: Difference in output power relative to the expected linear behavior as the input power is changed for ODM 1. The pluses are for the DCR raw counts uncorrected for the measured DC offsets while the circles are for DCR raw counts that have been corrected for the DC offsets.

3.2 ODM 2

From Figure 2 we see that ODM 2 is within 0.1 dB (2.3%) of being linear from −6 dB (0.25 V) to +10 dB (10 V). ODM 2 behaves non-linearly below −6 dB (0.25 V). ODM 2 does not vary from linearity by more than 0.2 dB (4.7%) from −7 dB (0.2 V) to +10 dB (10 V).

3.3 ODM 3

From Figure 3 we see that ODM 3 is within 0.1 dB (2.3%) of being linear from −11 dB (0.08 V) to +4 dB (2.5 V). ODM 3 behaves non-linearly above +3 dB (2.0 V). ODM 3 does not vary from linearity by more

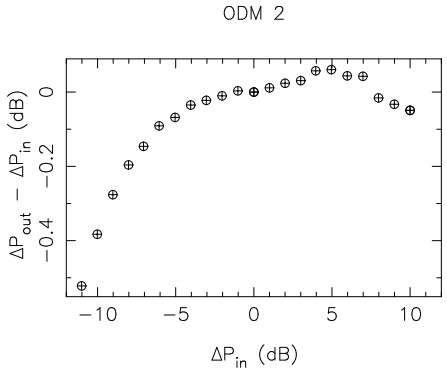

Figure 2: Same as Figure 1 but for ODM 2.

than 0.2 dB (4.7%) from −11 dB (0.08 V) to +6 dB (4 V).

ODM 3 shows significant gain expansion for large input power levels.

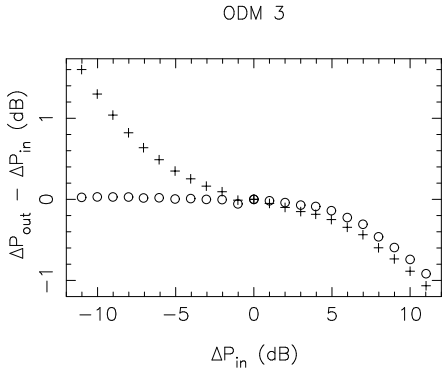

Figure 3: Same as Figure 1 but for ODM 3.

3.4 ODM 4

From Figure 4 we see that ODM 4 is within 0.1 dB (2.3%) of being linear from −11 dB (0.08 V) to +4 dB (2.5 V). ODM 4 behaves non-linearly above +4 dB (2.5 V). ODM 4 does not vary from linearity by more than 0.2 dB (4.7%) from −11 dB (0.08 V) to +7 dB (5 V).

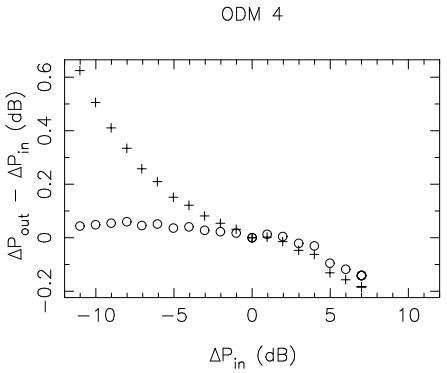

Figure 4: Same as Figure 1 but for ODM 4.

3.5 ODM 5

From Figure 5 we see that ODM 5 is within 0.1 dB (2.3%) of being linear from −3 dB (0.5 V) to +10 dB (10 V). ODM 5 behaves non-linearly below +4 dB (2.5 V) and above +7 dB (5 V. ODM 5 does not vary from linearity by more than 0.2 dB (4.7%) from −8 dB (0.16 V) to +10 dB (10 V).

ODM 5 shows gain compression for input power levels below 3 V.

3.6 ODM 6

From Figure 6 we see that ODM 6 is within 0.1 dB (2.3%) of being linear from −11 dB (0.08 V) to +10 dB (10 V).

3.7 ODM 7

From Figure 7 we see that ODM 7 is within 0.1 dB (2.3%) of being linear from −11 dB (0.08 V) to +7 dB (5 V). ODM 7 behaves non-linearly above +5 dB (3 V). ODM 7 does not vary from linearity by more than 0.2 dB (4.7%) from −11 dB (0.08 V) to +9 dB (7.9 V).

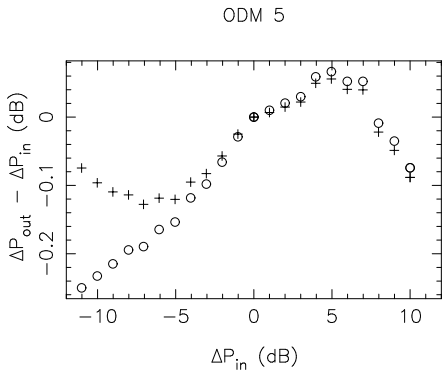

Figure 5: Same as Figure 1 but for ODM 5.

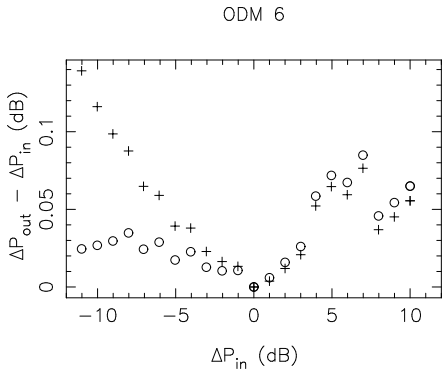

Figure 6: Same as Figure 1 but for ODM 6.

3.8 ODM 8

From Figure 8 we see that ODM 8 is within 0.1 dB (2.3%) of being linear from −2 dB (0.63 V) to +10 dB (10 V). ODM 8 behaves non-linearly below 0 dB (1.0 V). ODM 8 does not vary from linearity by more than 0.2 dB (4.7%) from −4 dB (0.4 V) to +10 dB (10 V).

ODM 8 shows gain compression for input power levels below 3 V.

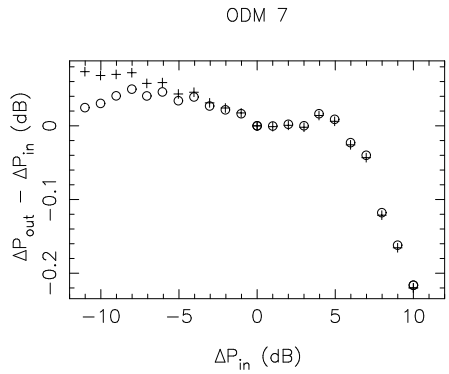

Figure 7: Same as Figure 1 but for ODM 7.

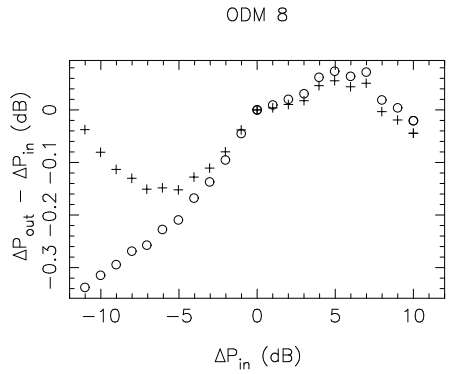

Figure 8: Same as Figure 1 but for ODM 8.

4 Conclusions

These measurements indicate that some of the non-linearities found during the checkout for GBT Proposal 1A4 are indeed due to unaccounted for DC offsets. Since the DC offsets are likely time variable, these will have to be measured and compensated for during observations which require good calibration. This will be addressed in a future memo.

There are some significant non-linearities in the IF Rack Optical Driver Modules. As a result, ODMs 3, 5 and 8 were removed from the IF system. These ODMs were cannibalized to produce one ODM that

exhibited a more linear behavior. Replacement of the remaining two ODMs must wait until new amplifiers are available.

The measurements presented in this memo are not of the high precision achievable. They were made do verify the suggested non-linearities reported from astronomical observations. By taking each ODM into the lab more precise measurements can be made. This will be done during the summer of 2004 and the results will be reported in another memo.