Lab Measurements of the Optical Drive Module Linearities with the New NRAO Built Amplifiers

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1 Introduction

The commercially bought amplifiers initially used in the GBT Optical Drive Modules (ODMs) proved to have undesired non-linear responses (see GBT Memo 235 [1]). In order to replace these non-linear amplifiers so that the GBT had a better overall linear response to astronomical signals, NRAO built amplifiers of its own design in 2005. The NRAO amplifiers were used to replace the commercially bought amplifiers in the ODMs. As each ODM was upgraded to the new amplifiers each module's linearity was remeasured in the lab. In this memo we report on the results of these measurements using the new NRAO manufactured amplifiers.

2 The Measurements

The measurements were done with the same equipment, setup and procedures as described in GBT Memo 235[1] and the reader is referred there for details on the measurements.

It is currently believed that the current limitation in measuring the linearity of the ODMs is due to the temperature response of the attenuators used to change the input power to the ODMs.

3 Optical Drive Modules

The results of the measurements for the linearity of the ODMs are presented in Tables 2–7. The first column is the amount by which the input power was changed during the measurements. The second column is the IF center frequency. The third through fifth columns in each table give the error in the output power as compared to the expected linear response (*i.e.* these columns are $\Delta P_{in} - \Delta P_{out}$) for the Optical Drive Modules. The attenuator levels were determined by inserting a known input power level into the attenuators and then using a power meter to determine the output power level. The results are also plotted in Figures 1–8.

IF Channel	serial number
1	9
2	6
3	3
4	4
5	7
6	5
7	8
8	1
spare	2

Table 1: Relationship between IF Channel number and Optical Driver Serial Number on February 17, 2006. These pairings are subject to change without notice.

3.1 ODM sn001

The results for ODM sn001 are shown in Figure 1. ODM sn001 does not differ from linearity by more than 0.012 dB (0.28%) from −11 dB to 11 dB. This

[1] GBT Memo 235 is available at http://wiki.gb.nrao.edu/pub/Knowledge/GBTMemos/GBTmemo235.pdf

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn001 (dB)	sn002 (dB)	sn003 (dB)
10.991 ± 0.016	3	-0.007	0.022	-0.020
9.981 ± 0.014	3	-0.009	0.020	-0.014
8.973 ± 0.012	3	-0.005	0.014	-0.011
7.966 ± 0.011	3	-0.005	0.013	-0.010
7.018 ± 0.010	3	-0.004	0.009	-0.005
6.013 ± 0.010	3	-0.006	0.008	-0.004
5.008 ± 0.008	3	-0.003	0.006	-0.003
4.004 ± 0.008	3	-0.006	0.004	-0.004
3.019 ± 0.006	3	-0.003	0.002	-0.001
2.014 ± 0.005	3	-0.001	0.002	-0.002
1.007 ± 0.003	3	-0.001	-0.001	0.000
-1.017 ± 0.003	3	0.003	0.001	-0.002
-2.033 ± 0.004	3	0.003	-0.003	0.003
-3.046 ± 0.008	3	0.000	-0.003	0.005
-4.037 ± 0.007	3	-0.002	-0.007	0.010
-5.044 ± 0.008	3	-0.004	-0.007	0.010
-6.050 ± 0.011	3	-0.005	-0.010	0.016
-7.056 ± 0.011	3	-0.004	-0.010	0.012
-8.003 ± 0.011	3	-0.004	-0.013	0.017
-9.007 ± 0.011	3	-0.003	-0.014	0.015
-10.010 ± 0.012	3	-0.003	-0.018	0.015
-11.014 ± 0.013	3	-0.004	-0.020	0.017

Table 2: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn004 (dB)	sn005 (dB)	sn006 (dB)
10.991 ± 0.016	3	——	-0.002	-0.020
9.981 ± 0.014	3	——	-0.003	-0.021
8.973 ± 0.012	3	——	-0.006	-0.018
7.966 ± 0.011	3	——	-0.006	-0.017
7.018 ± 0.010	3	——	-0.004	-0.019
6.013 ± 0.010	3	——	-0.003	-0.017
5.008 ± 0.008	3	——	-0.003	-0.014
4.004 ± 0.008	3	——	-0.004	-0.013
3.019 ± 0.006	3	——	0.000	-0.012
2.014 ± 0.005	3	——	0.000	-0.009
1.007 ± 0.003	3	——	0.001	-0.005
-1.017 ± 0.003	3	——	0.000	0.006
-2.033 ± 0.004	3	——	0.002	0.005
-3.046 ± 0.008	3	——	0.004	0.007
-4.037 ± 0.007	3	——	0.004	0.007
-5.044 ± 0.008	3	——	0.005	0.009
-6.050 ± 0.011	3	——	0.004	0.010
-7.056 ± 0.011	3	——	0.003	0.014
-8.003 ± 0.011	3	——	0.002	0.009
-9.007 ± 0.011	3	——	0.003	0.010
-10.010 ± 0.012	3	——	0.002	0.011
-11.014 ± 0.013	3	——	0.002	0.014

Table 3: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the ODM sn001 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{0.9998 \pm 0.0003} \quad (1)$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

3.2 ODM sn002

The results for ODM sn002 are shown in Figure 2. ODM sn002 does not differ from linearity by more than 0.047 dB (1.09%) from -11 dB to 11 dB. This corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the ODM sn002 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{1.019 \pm 0.0003} \quad (2)$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn007 (dB)	sn008 (dB)	sn009 (dB)
10.991 ± 0.016	3	0.017	0.000	0.012
9.981 ± 0.014	3	0.014	0.001	0.011
8.973 ± 0.012	3	0.014	0.000	0.010
7.966 ± 0.011	3	0.014	0.001	0.010
7.018 ± 0.010	3	0.011	0.000	0.012
6.013 ± 0.010	3	0.010	0.001	0.011
5.008 ± 0.008	3	0.009	-0.003	0.010
4.004 ± 0.008	3	0.007	0.006	0.009
3.019 ± 0.006	3	0.002	0.005	0.009
2.014 ± 0.005	3	0.000	0.003	0.007
1.007 ± 0.003	3	-0.001	0.001	0.004
-1.017 ± 0.003	3	0.001	-0.003	-0.003
-2.033 ± 0.004	3	0.003	-0.004	-0.007
-3.046 ± 0.008	3	0.007	-0.008	-0.014
-4.037 ± 0.007	3	0.005	-0.010	-0.003
-5.044 ± 0.008	3	0.005	-0.010	-0.006
-6.050 ± 0.011	3	0.006	-0.013	-0.010
-7.056 ± 0.011	3	0.010	-0.012	-0.014
-8.003 ± 0.011	3	0.008	-0.012	-0.007
-9.007 ± 0.011	3	0.009	-0.010	-0.013
-10.010 ± 0.012	3	0.009	-0.013	0.000
-11.014 ± 0.013	3	0.011	-0.012	-0.006

Table 4: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn001 (dB)	sn002 (dB)	sn003 (dB)
10.953 ± 0.018	6	-0.014	0.022	-0.023
10.036 ± 0.015	6	-0.005	0.021	-0.018
8.955 ± 0.013	6	-0.007	0.019	-0.016
8.041 ± 0.011	6	-0.006	0.017	-0.012
6.947 ± 0.011	6	-0.005	0.015	-0.007
6.036 ± 0.010	6	-0.007	0.013	-0.006
4.959 ± 0.009	6	-0.005	0.011	-0.007
4.048 ± 0.007	6	-0.006	0.009	-0.006
2.910 ± 0.008	6	-0.007	0.009	-0.002
1.999 ± 0.006	6	-0.006	0.007	-0.001
0.912 ± 0.003	6	-0.004	0.003	-0.001
-0.924 ± 0.006	6	-0.005	-0.004	0.008
-2.016 ± 0.011	6	-0.002	-0.009	0.011
-2.935 ± 0.015	6	-0.008	-0.010	0.015
-4.063 ± 0.015	6	-0.004	-0.010	0.020
-4.975 ± 0.017	6	-0.002	-0.011	0.021
-6.061 ± 0.019	6	-0.006	-0.012	0.020
-6.972 ± 0.021	6	-0.004	-0.014	0.022
-8.069 ± 0.020	6	-0.003	-0.018	0.022
-8.978 ± 0.022	6	-0.007	-0.019	0.024
-10.060 ± 0.024	6	-0.007	-0.022	0.023
-10.968 ± 0.026	6	-0.003	-0.025	0.023

Table 5: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

3.3 ODM sn003

The results for ODM sn003 are shown in Figure 3. ODM sn003 does not differ from linearity by more than 0.047 dB (1.09%) from −11 dB to 11 dB. This corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the ODM sn003 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{0.9982 \pm 0.0003} \quad (3)$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

3.4 ODM sn004

The linearity for ODM sn004 with the new NRAO manufactured amplifiers has not yet been measured.

3.5 ODM sn005

The results for ODM sn005 are shown in Figure 4. ODM sn005 does not differ from linearity by more than 0.026 dB (0.60%) from −11 dB to 11 dB. This corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn004 (dB)	sn005 (dB)	sn006 (dB)
10.953 ± 0.018	6	——	0.021	-0.023
10.036 ± 0.015	6	——	0.012	-0.022
8.955 ± 0.013	6	——	0.000	-0.018
8.041 ± 0.011	6	——	-0.002	-0.014
6.947 ± 0.011	6	——	-0.001	-0.019
6.036 ± 0.010	6	——	-0.002	-0.016
4.959 ± 0.009	6	——	-0.005	-0.012
4.048 ± 0.007	6	——	-0.004	-0.010
2.910 ± 0.008	6	——	-0.002	-0.012
1.999 ± 0.006	6	——	-0.001	-0.009
0.912 ± 0.003	6	——	-0.002	-0.004
-0.924 ± 0.006	6	——	0.006	0.004
-2.016 ± 0.011	6	——	0.003	0.008
-2.935 ± 0.015	6	——	0.006	0.018
-4.063 ± 0.015	6	——	0.007	0.014
-4.975 ± 0.017	6	——	0.007	0.020
-6.061 ± 0.019	6	——	0.006	0.023
-6.972 ± 0.021	6	——	0.006	0.026
-8.069 ± 0.020	6	——	0.008	0.024
-8.978 ± 0.022	6	——	0.010	0.031
-10.060 ± 0.024	6	——	0.007	0.036
-10.968 ± 0.026	6	——	0.006	0.038

Table 6: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

ΔP_{in} (dB)	$\nu_{\rm IF}$ GHz	sn007 (dB)	sn008 (dB)	sn009 (dB)
10.953 ± 0.018	6	0.006	0.003	0.009
10.036 ± 0.015	6	0.002	0.005	0.007
8.955 ± 0.013	6	0.008	0.006	0.007
8.041 ± 0.011	6	0.007	0.007	0.005
6.947 ± 0.011	6	-0.001	0.007	0.014
6.036 ± 0.010	6	0.000	0.009	0.012
4.959 ± 0.009	6	0.003	0.007	0.011
4.048 ± 0.007	6	0.002	0.006	0.006
2.910 ± 0.008	6	-0.001	0.007	0.010
1.999 ± 0.006	6	-0.001	0.006	0.006
0.912 ± 0.003	6	0.001	0.002	0.004
-0.924 ± 0.006	6	0.004	-0.006	-0.009
-2.016 ± 0.011	6	0.016	-0.012	-0.015
-2.935 ± 0.015	6	0.013	-0.014	-0.023
-4.063 ± 0.015	6	0.012	-0.015	-0.022
-4.975 ± 0.017	6	0.009	-0.015	-0.028
-6.061 ± 0.019	6	0.013	-0.017	-0.030
-6.972 ± 0.021	6	0.014	-0.017	-0.033
-8.069 ± 0.020	6	0.010	-0.018	-0.028
-8.978 ± 0.022	6	0.013	-0.016	-0.032
-10.060 ± 0.024	6	0.015	-0.019	-0.033
-10.968 ± 0.026	6	0.020	-0.020	-0.038

Table 7: Optical Driver Module linearity measurements. The first column is the amount by which the input power was changed. The second column is the IF center frequency (the bandwidth was 1280 MHz). The fourth through sixth columns give the error in the output power as compared to a linear response (*i.e.* $\Delta \mathrm{P_{in}} - \Delta \mathrm{P_{out}}$) for the Optical Drive Modules.

ODM sn005 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{0.9996 \pm 0.0003} \tag{4}$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

3.6 ODM sn006

The results for ODM sn006 are shown in Figure 5. ODM sn006 does not differ from linearity by more than 0.061 dB (1.4%) from −11 dB to +11 dB. This corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the ODM sn006 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{0.9976 \pm 0.0003} \tag{5}$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

3.7 ODM sn007

The results for ODM sn007 are shown in Figure 6. ODM sn007 does not differ from linearity by more than 0.021 dB (0.48%) from −11 dB to +11 dB. This

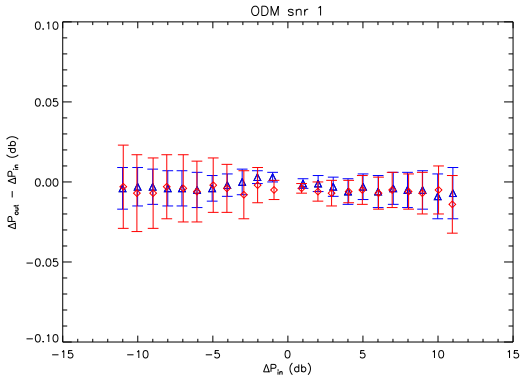

Figure 1: Difference in output power relative to the expected linear behavior as the input power is changed for ODM sn001. The data represented by the triangles (blue) had an input signal with a center frequency of 3000 MHz while the data represented by the diamonds (red) had an input signal with a center frequency of 6000 MHz. The bandwidth for both sets of data was 1280 MHz.

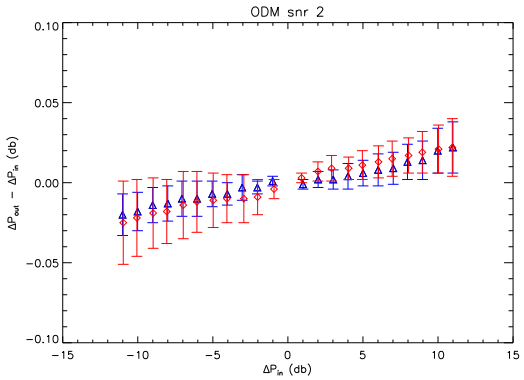

Figure 2: Same as Figure 1 but for ODM sn002.

corresponds to a range from $\sim$ 0.08 V to $\sim$ 12.6 V for the IF Rack power level. A linear fit to the

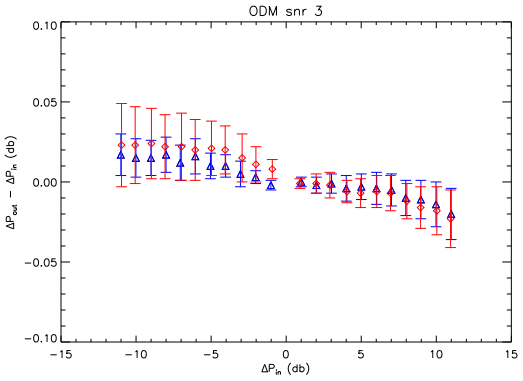

Figure 3: Same as Figure 1 but for ODM sn003.

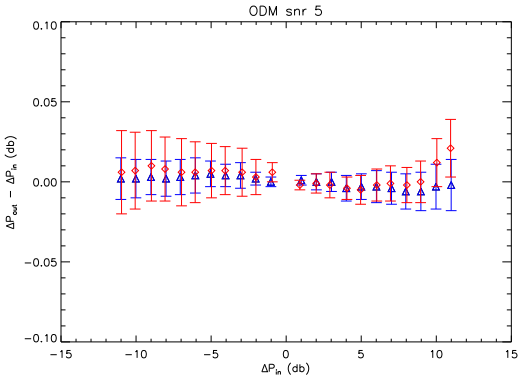

Figure 4: Same as Figure 1 but for ODM sn005.

ODM sn007 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}^{0.9998 \pm 0.0003}} \quad (6)$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

3.8 ODM sn008

The results for ODM sn008 are shown in Figure 7. ODM sn008 does not differ from linearity by more

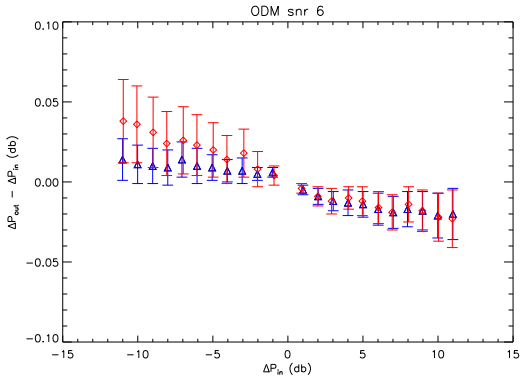

Figure 5: Same as Figure 1 but for ODM sn006.

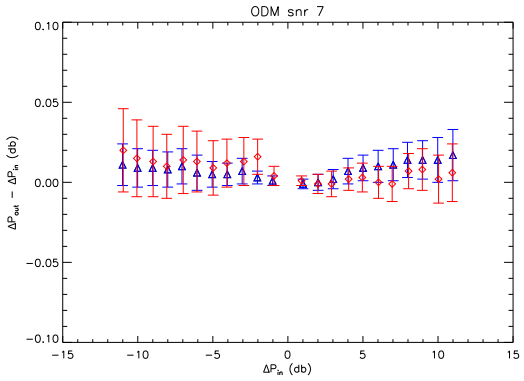

Figure 6: Same as Figure 1 but for ODM sn007.

than 0.029 dB (0.67%) from −11 dB to 11 dB. This corresponds to a range from ∼ 0.08 V to ∼ 12.6 V for the IF Rack power level. A linear fit to the ODM sn008 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{1.0014 \pm 0.0003} \tag{7}$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

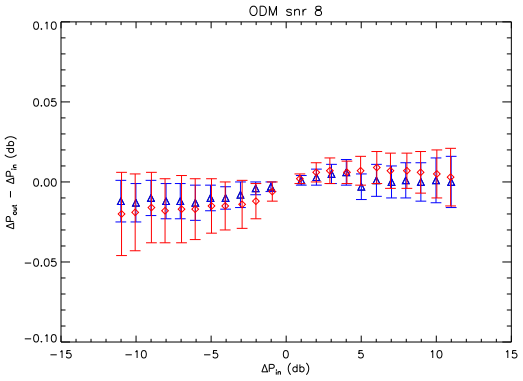

Figure 7: Same as Figure 1 but for ODM sn008.

3.9 ODM sn009

The results for ODM sn009 are shown in Figure 8. ODM sn009 does not differ from linearity by more than 0.052 dB (1.2%) from −11 dB to 11 dB. This corresponds to a range from ∼ 0.08 V to ∼ 12.6 V for the IF Rack power level. A linear fit to the ODM sn008 data results in

$$\Delta \mathrm{P_{out}} \propto \Delta \mathrm{P_{in}}^{1.0020 \pm 0.0003} \tag{8}$$

where ΔP_{in} is the change in the input power and ΔP_{out} is the change in the output power.

4 Square-Law Detectors

The Square-Law Detectors have not yet been modified. Their linearity responses are expected to be the same as in GBT Memo 235. For continuum observations, their non-linear responses will be the limiting factor.

5 Conclusions

The new NRAO manufactured amplifiers have linearized the response of the ODMs. All of the ODMs are now linear to within 1.4% over the entire IF Rack

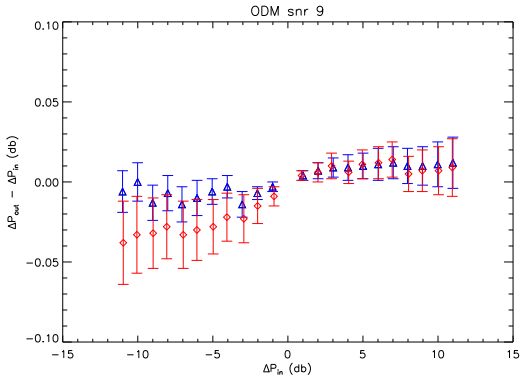

Figure 8: Same as Figure 1 but for ODM sn009.

voltage range. It is believed that this upper limit to the linearity of the ODMs is limited by the equipment used in the lab measurements and that the ODMs are actually much more linear.