5.1.11.4 WAC FM NONLINEAR RESPONSE TERMS

As reported in Reference 5.1.11.4-1

Reference 5.1.11.4-1 - IOM 388-PAG-CCA98-14, "WAC FM Calibration Results: Nonlinear Response Terms", Bob West and Charlie Avis, July 20, 1998

5.1.11.4.1 INTRODUCTION

Linearity tests made during thermal vac calibration revealed a nonlinear behavior (see Section 5.1.11.2). Departures from linearity (decreased sensitivity at high DN levels) were strongest for gain 0 with 4X4 summing. This behavior was thought to be caused by losses in the summing well on the CCD chip. There may also be some contribution to nonlinearity from the A/D converter at high signal levels. Both of these scenarios would imply that nonlinear behavior would be the same for all pixels, a function only of the charge in the summation well, but would differ for each gain state. They also imply that a nonlinearity correction can be made to the DN to compensate for nonlinear behavior. In this report we derive interpolation tables for each gain state to correct for nonlinear effects.

5.1.11.4.2 METHOD

Sequences of increasing exposures were used which were taken at temperatures of +25° C (1x1) and +5° C (2x2 and 4x4) using clear filters in both wheels. Gain 0 and 1 were taken in 4x4 and 2x2 mode respectively and Gain 2 and 3 in 1x1 mode. All data were taken with Antiblooming 'OFF'.

Multiple input files (usually 3) were combined at each exposure level to suppress data errors and improve the signal-to-noise ratio. In addition, bias and dark current values were subtracted from each of the 13-14 images in each exposure sequence.

The mean DN value for the central 100 by 100 region was tabulated. The IDL routine POLYFITW was used to find a best-fit value for the weighted dependent variable array DN/(exposure time) as a function of the independent variable exposure time. The first term in the derived coefficients gives the best-fit linear term (A). A correction factor is then tabulated as

$$C = At / DN(t)$$

where   t is the exposure time and
          DN(t) is the tabulated mean DN for that exposure time.

The problem is somewhat subtle because the lowest DN values should behave linearly but also have the greatest uncertainty because they are most sensitive to errors in dark subtraction. The

slopes derived from the POLYFITW routine are sensitive to the weighting functions. After several tries, a weighting scheme was settled on which favors the low DN part of the array but gives zero weight to the shortest non-zero exposure. The shortest non-zero exposures consistently produce higher DN values than would be expected from the fits to longer exposures. They are high by up to 16.1%. The linear fits are shown as straight lines in the plots that follow, and the observed DN values are plotted as + symbols.
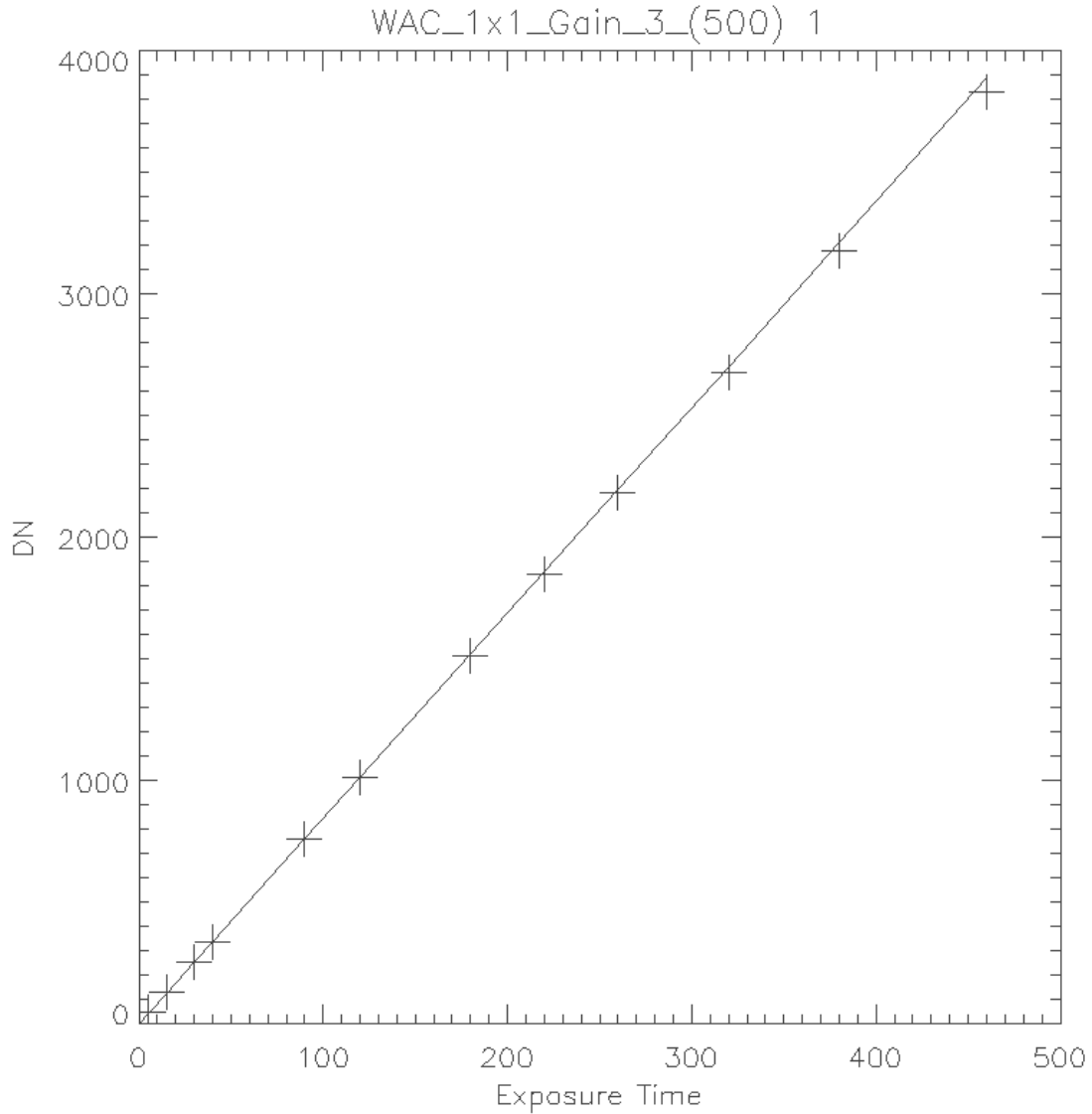
Figure 5.1.11.4-1 - Linear component of the fitted data (+) is plotted as the solid line. Summation is indicated in the title. Gain state is 3.
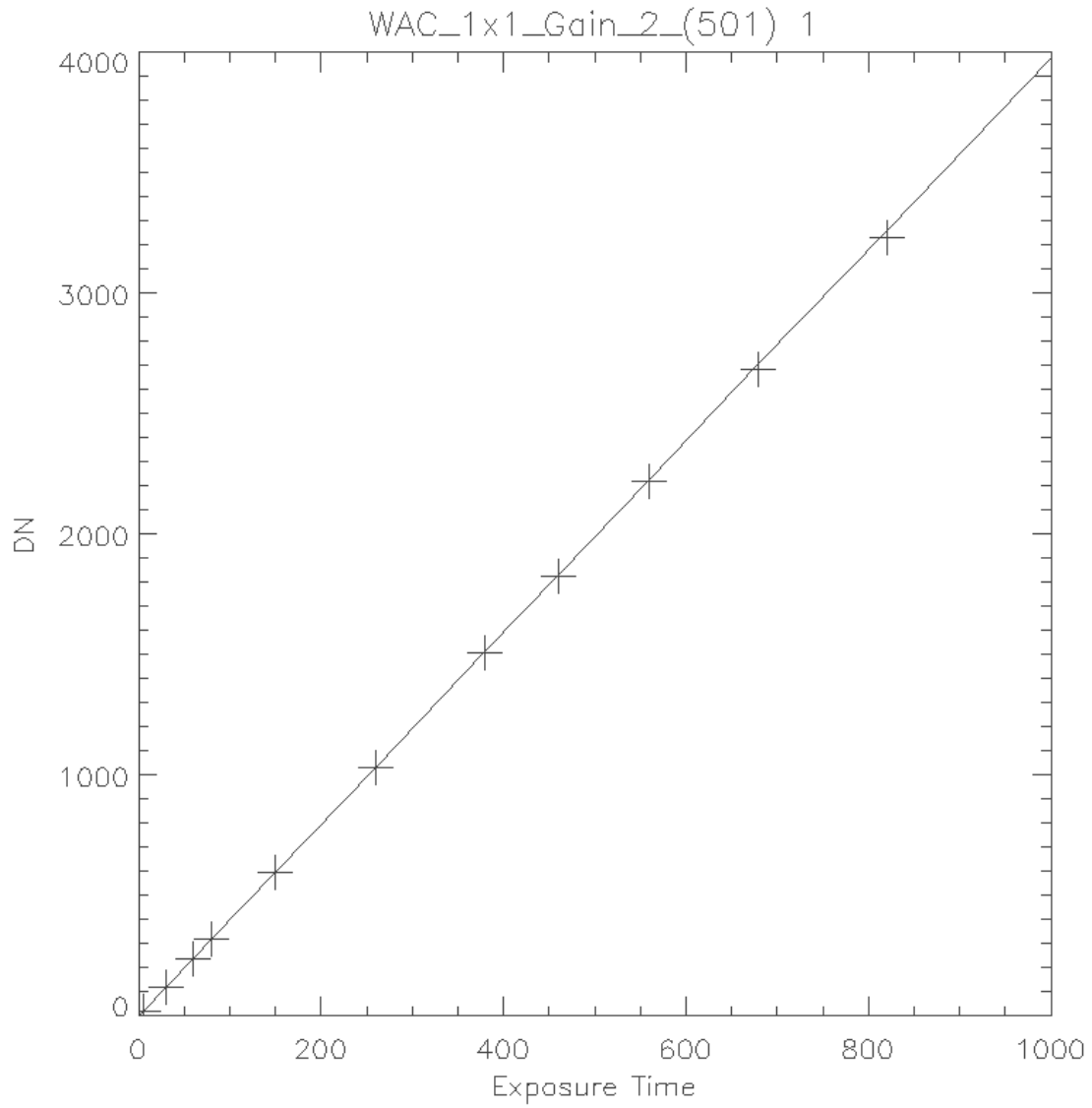
Figure 5.1.11.4-2 - Linear component of the fitted data (+) is plotted as the solid line. Summation is indicated in the title. Gain state is 2.
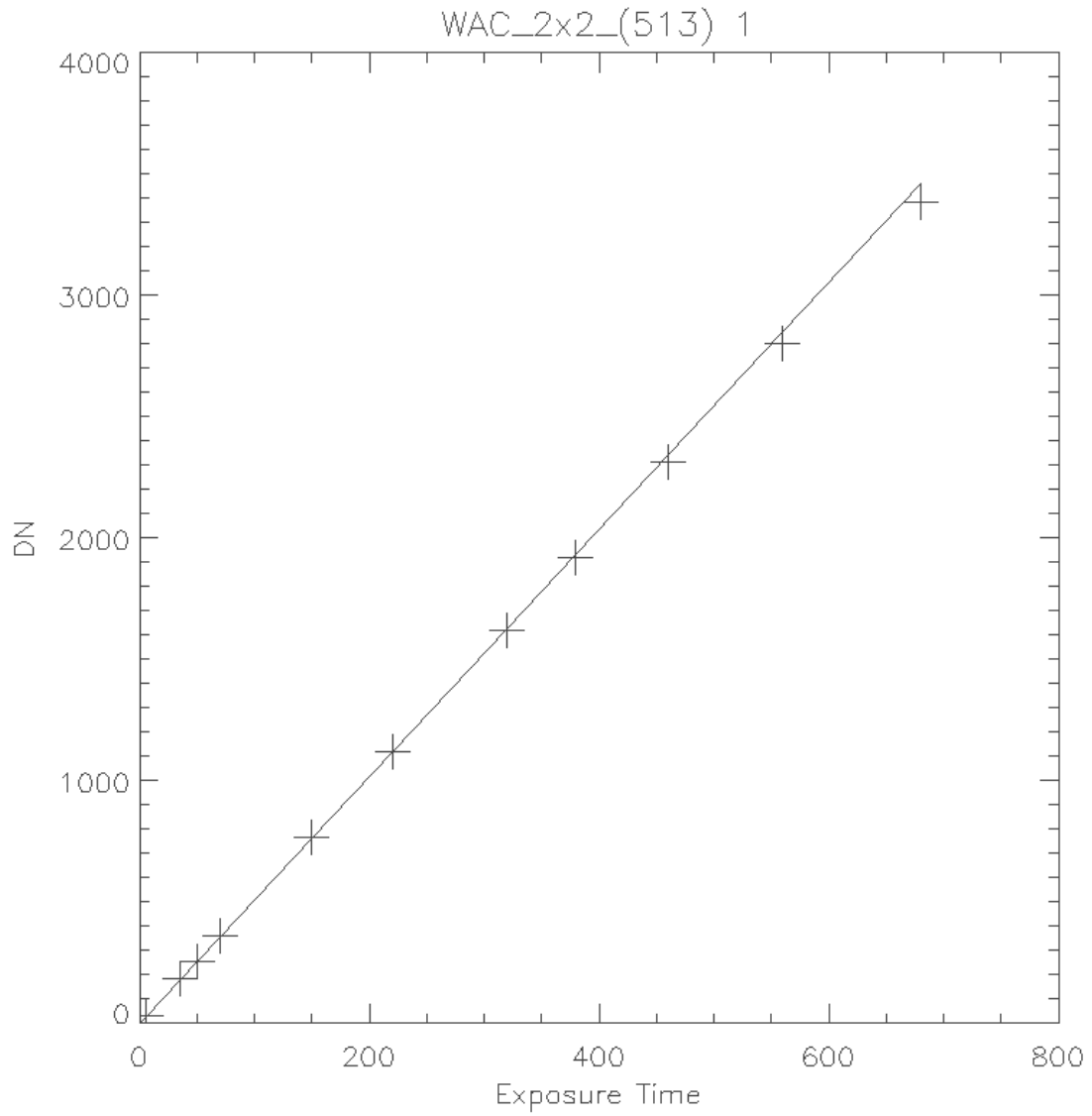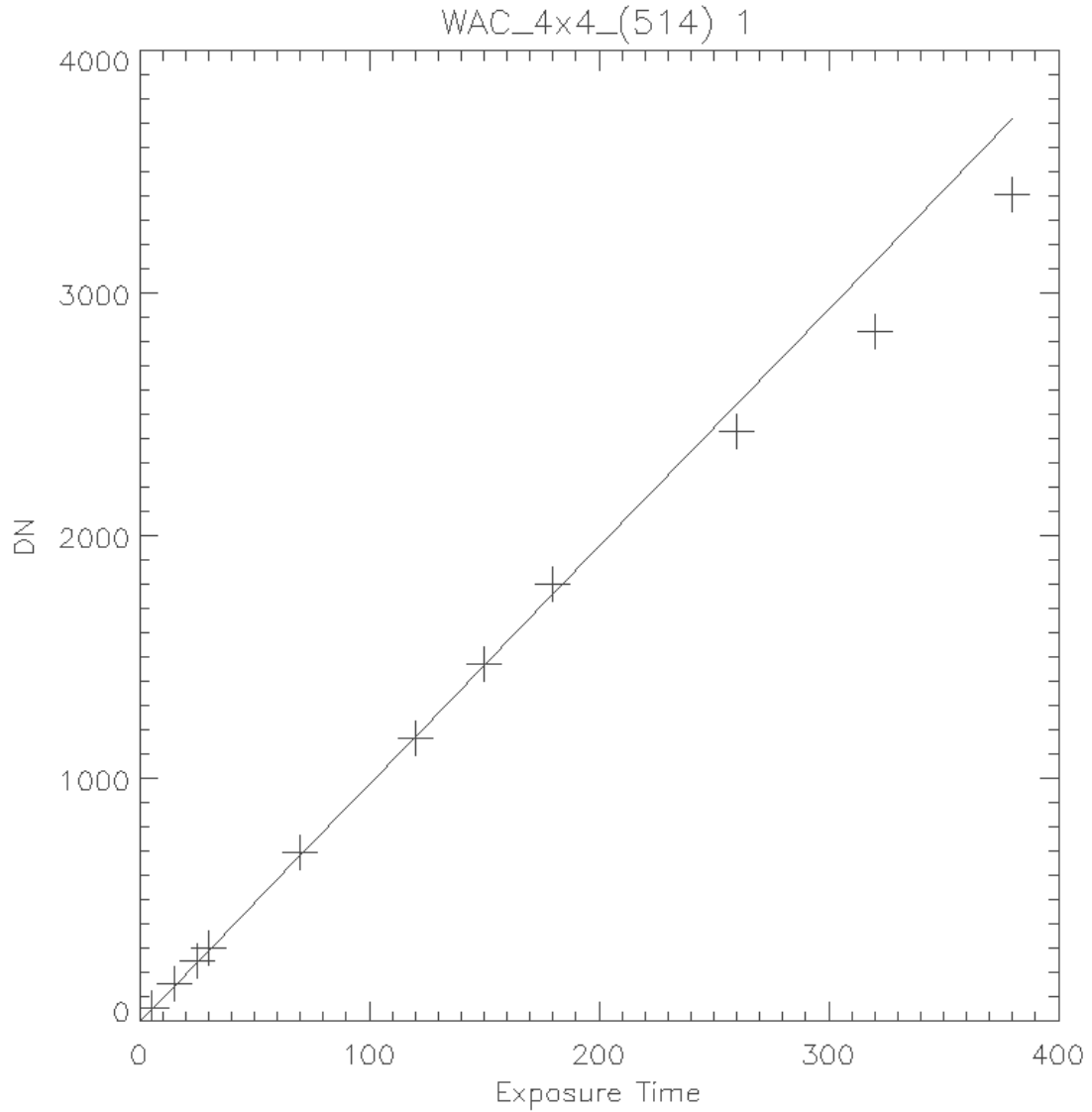
Figure 5.1.11.4-3 - Linear component of the fitted data (+) is plotted as the solid line. Summation is indicated in the title. Gain state is 1.

Figure 5.1.11.4-4 - Linear component of the fitted data (+) is plotted as the solid line. Summation is indicated in the title. Gain state is 0.

5.1.11.4.3 RESULTS

The correction factors tabulated below correct for nonlinearity by

$$DN' = DN*C$$

where   C is the correction factor,
        DN is the observed DN (after dark-count and bias subtraction), and
        DN' is the desired DN.

A correction algorithm can interpolate to get C as a function of observed DN for each pixel. This procedure should occur after the uneven bit weighting correction during the radiometric correction of each image. Note that DN' values greater than 4095 will result in some cases even though the data were not actually saturated. This fact will have an effect on the design of the radiometric correction software.

Correction factors for the four gain states are listed in the following table.

Gain 0		Gain 1		Gain 2		Gain 3	
DN	C	DN	C	DN	C	DN	C
55.3	0.885	30.3	0.839	21.8	0.915	47.2	0.895
153.5	0.957	182.4	0.977	121.2	0.985	131.4	0.965
250.7	0.976	257.6	0.988	240.3	0.994	256.5	0.989
300.5	0.977	359.6	0.991	320.1	0.995	340.8	0.992
694.9	0.986	765.0	0.998	598.8	0.997	760.7	1.000
1167.7	1.006	1118.5	1.001	1034.9	1.000	1012.1	1.002
1472.7	0.997	1619.2	1.006	1509.9	1.002	1514.2	1.005
1805.8	0.976	1917.9	1.009	1827.8	1.002	1848.6	1.006
2430.6	1.047	2312.8	1.012	2219.6	1.004	2183.0	1.007
2844.5	1.101	2803.6	1.017	2687.7	1.007	2681.0	1.009
3405.9	1.092	3384.3	1.023	3231.7	1.010	3177.4	1.011
4096.0	1.168	4096.0	1.029	3902.4	1.020	3830.6	1.015
				4096.0	1.020	4096.0	1.016

5.1.11.4.4 IMAGES USED IN NON-LINEARITY ANALYSIS

image	day	eventtime	observation	gain	mode	exp
+25°C						
126930	180	4:43:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	0
126931	180	4:44:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	0
126932	180	4:46:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	0
126933	180	4:47:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5
126934	180	4:49:9.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5
126935	180	4:50:38.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5
126936	180	4:51:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15
126937	180	4:53:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15
126938	180	4:54:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15
126939	180	4:56:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30
126940	180	4:57:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30
126941	180	4:59:9.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30
126942	180	5:0:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40
126943	180	5:1:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40
126944	180	5:3:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40
126945	180	5:4:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90
126946	180	5:6:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90
126947	180	5:7:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90
126948	180	5:8:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120
126949	180	5:10:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120
126950	180	5:11:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120
126952	180	5:14:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180
126953	180	5:16:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180
126969	180	6:11:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180
126954	180	5:17:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220
126955	180	5:18:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220
126956	180	5:20:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220
126957	180	5:21:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260
126958	180	5:23:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260
126959	180	5:24:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260
126960	180	5:25:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320
126961	180	5:27:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320
126962	180	5:28:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320
126963	180	5:30:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380
126964	180	5:31:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380
126965	180	5:33:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380
126966	180	5:34:19.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460
126967	180	5:35:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460
126968	180	5:37:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460
126836	180	1:11:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	0
126837	180	1:13:4.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	0
126838	180	1:14:33.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	0
126840	180	1:17:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5
126841	180	1:19:0.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5
126875	180	2:11:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5
126842	180	1:20:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30
126843	180	1:21:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30
126844	180	1:23:4.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30
126845	180	1:24:33.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60
126846	180	1:26:2.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60
126847	180	1:27:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60
126849	180	1:30:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	80
126850	180	1:31:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	80
126876	180	2:12:37.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	80
126852	180	1:34:33.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	150
126853	180	1:36:2.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	150
126877	180	2:14:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	150
126854	180	1:37:8.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	260
126855	180	1:38:37.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	260
126856	180	1:40:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	260
126857	180	1:41:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	380
126858	180	1:43:4.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	380
126859	180	1:44:33.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	380
126861	180	1:47:8.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	460
126862	180	1:48:37.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	460
126878	180	2:15:12.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	460
126863	180	1:50:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	560
126864	180	1:51:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	560
126865	180	1:53:4.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	560
126866	180	1:54:10.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	680
126867	180	1:55:39.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	680
126868	180	1:57:8.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	680
126869	180	1:58:37.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	820
126871	180	2:1:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	820
126879	180	2:16:18.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	820
126872	180	2:2:41.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
126873	180	2:4:10.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
126874	180	2:5:39.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
126880	180	2:17:24.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
126881	180	2:18:53.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
126882	180	2:20:22.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	1000
+5°C						
130191	195	10:38:4.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	0
130192	195	10:39:8.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	0
130193	195	10:40:13.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	0
130194	195	10:41:17.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	5
130195	195	10:42:21.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	5
130196	195	10:43:25.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	5
130197	195	10:44:3.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	35
130198	195	10:45:7.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	35
130199	195	10:46:11.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	35
130200	195	10:47:16.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	50
130201	195	10:48:20.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	50
130202	195	10:49:24.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	50
130203	195	10:50:6.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	70
130204	195	10:51:10.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	70
130205	195	10:52:14.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	70
130206	195	10:53:19.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	150
130207	195	10:54:23.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	150
130208	195	10:55:27.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	150
130209	195	10:56:5.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	220
130210	195	10:57:9.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	220
130211	195	10:58:13.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	220
130212	195	10:59:18.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	320
130213	195	11:0:22.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	320
130214	195	11:1:26.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	320
130215	195	11:2:8.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	380
130216	195	11:3:12.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	380
130217	195	11:4:16.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	380
130218	195	11:5:21.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	460
130219	195	11:6:25.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	460
130220	195	11:7:29.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	460
130221	195	11:8:11.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	560
130222	195	11:9:15.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	560
130223	195	11:10:19.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	560
130224	195	11:11:24.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	680
130225	195	11:12:28.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	680
130226	195	11:13:32.0	LTC_BLEM_GAIN_513	1 (400K)	SUM2	680
130230	195	12:26:10.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	0
130231	195	12:27:1.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	0
130232	195	12:27:52.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	0
130233	195	12:28:44.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	5
130234	195	12:29:35.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	5
130235	195	12:30:26.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	5
130236	195	12:30:53.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	15
130237	195	12:31:44.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	15
130238	195	12:32:35.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	15
130239	195	12:33:27.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	25
130240	195	12:34:18.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	25
130241	195	12:35:9.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	25
130242	195	12:35:38.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	30
130243	195	12:36:29.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	30
130244	195	12:37:20.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	30
130245	195	12:38:12.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	70
130246	195	12:39:3.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	70
130247	195	12:39:54.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	70
130248	195	12:40:23.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	120
130249	195	12:41:14.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	120
130250	195	12:42:5.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	120
130251	195	12:42:57.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	150
130252	195	12:43:48.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	150
130253	195	12:44:39.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	150
130254	195	12:45:6.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	180
130255	195	12:45:57.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	180
130256	195	12:46:48.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	180
130257	195	12:47:40.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	260
130258	195	12:48:31.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	260
130259	195	12:49:22.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	260
130260	195	12:49:49.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	320
130261	195	12:50:40.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	320
130262	195	12:51:31.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	320
130263	195	12:52:23.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	380
130264	195	12:53:14.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	380
130265	195	12:54:5.0	LTC_BLEM_GAIN_514	0 (1400K)	SUM4	380