

## 5.1.11.2 WAC FM LINEARITY CALIBRATION RESULTS

*As reported in Reference 5.1.11.2-1*

**Reference 5.1.11.2-1 - IOM 388-PAG-CCA97-6, "WAC FM Calibration Results: Linearity", C. Avis, September 24, 1997**

### 5.1.11.2.1 INTRODUCTION

The Wide-angle Flight Model thermal/vacuum testing included the acquisition of a set of images for determination of the system gain. The image data was taken at a temperature of +25° and +5° C. This data set is also applicable to the derivation of the system linearity. The term 'linearity' describes how closely the camera response to light fits a linear function.

### 5.1.11.2.2 METHOD

For this camera system, the DN resulting from an exposure may be described by the following equation.

$$DN = VL(T - t_0) + DC_T + DN_0$$

where

- DN is the measured pixel value
- V is the system sensitivity (in DN/radiance\_unit-milliseconds)
- L is the measured radiance (in arbitrary radiance\_units)
- T is the commanded exposure time (in milliseconds)
- t<sub>0</sub> is the known shutter-offset (a function of image sample number, in msec)
- DN<sub>0</sub> is the bias level (in DN)
- DC<sub>T</sub> is the dark-current level (a function of exposure time, in DN)

Analysis so far of DC<sub>T</sub> indicates that for the exposure used here (maximum of 1000 msec), this value should be less than one DN. Therefore, the above equation is simplified to

$$DN = VL(T - t_0) + DN_0$$

Because the shutter-offset was previously derived, only V and DN<sub>0</sub> need to be solved for. DN<sub>0</sub> could be measured by zero-exposure images, but it falls out of the least-squares fit anyway.

Images at the same signal level are combined to produce signal and energy values at 100 small (20 pixel by 20 pixel) areas at all available signal levels. Energy values come from the product of the exposure time (corrected for shutter-offset) and the radiance of the source. Values for Sensitivity and the Bias level are then derived at each of these small areas independently. This is done by solving the above equation using least-squares.

The 100 derived values are then compared and any areas giving values more than 2 sigma from the mean are flagged as bad. Global values for V and DN<sub>0</sub> are then derived by averaging the values at the remaining good areas.

Using these best-fit V and DN<sub>0</sub>, a calculated value DN can be determined for each exposure time. The absolute deviation from linearity

$$A(T) = DN(T) - DN(T)$$

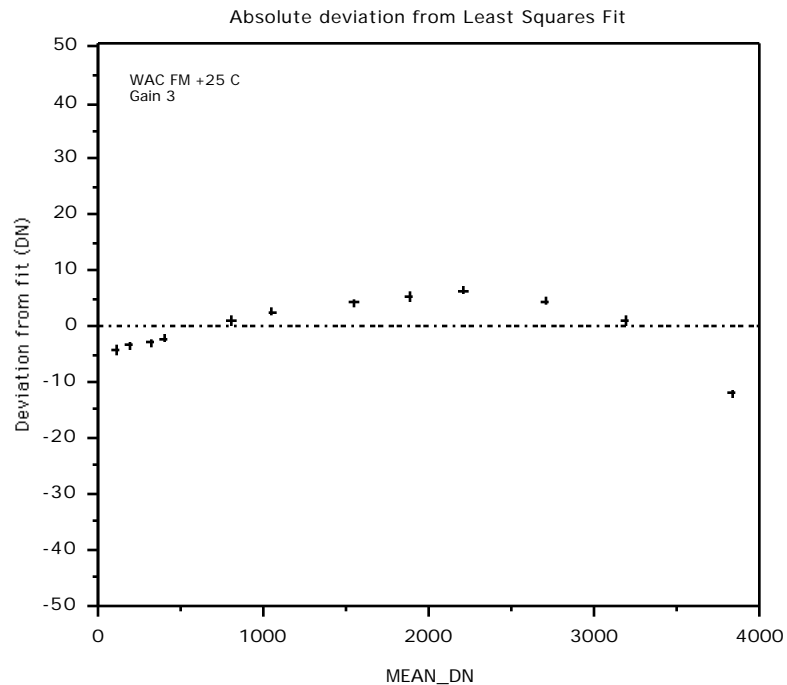
and the relative deviation from linearity

$$R(T) = (DN(T) - DN(T))/DN(T)$$

can be used as measures of linearity over the range of exposure times used.

### 5.1.11.2.3 RESULTS

The following plot shows a typical fit. The absolute deviation is plotted to illustrate how the Least Squares solution distributed the deviations over the range of DN.

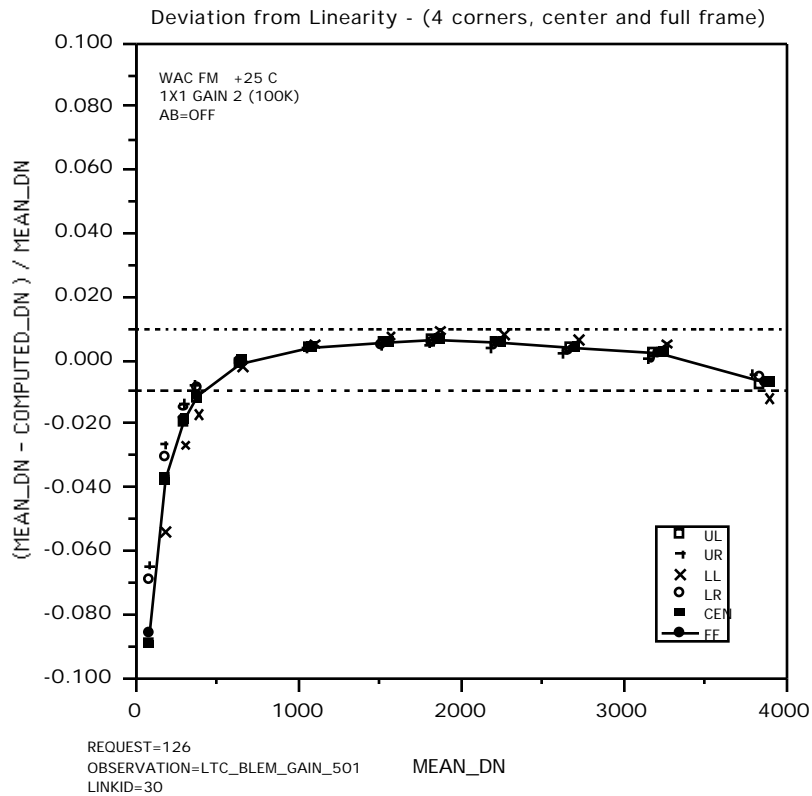
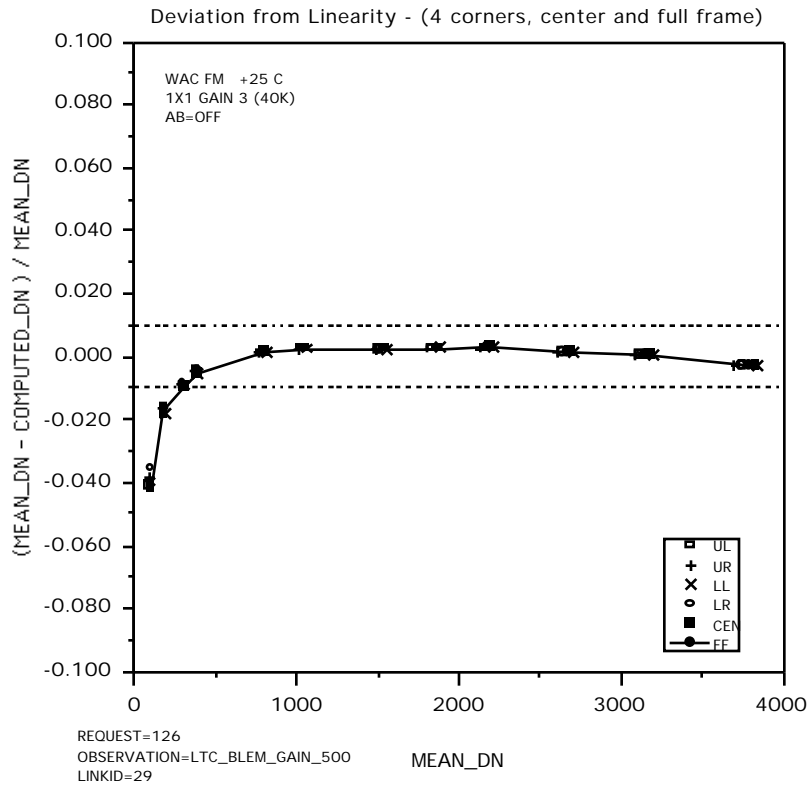


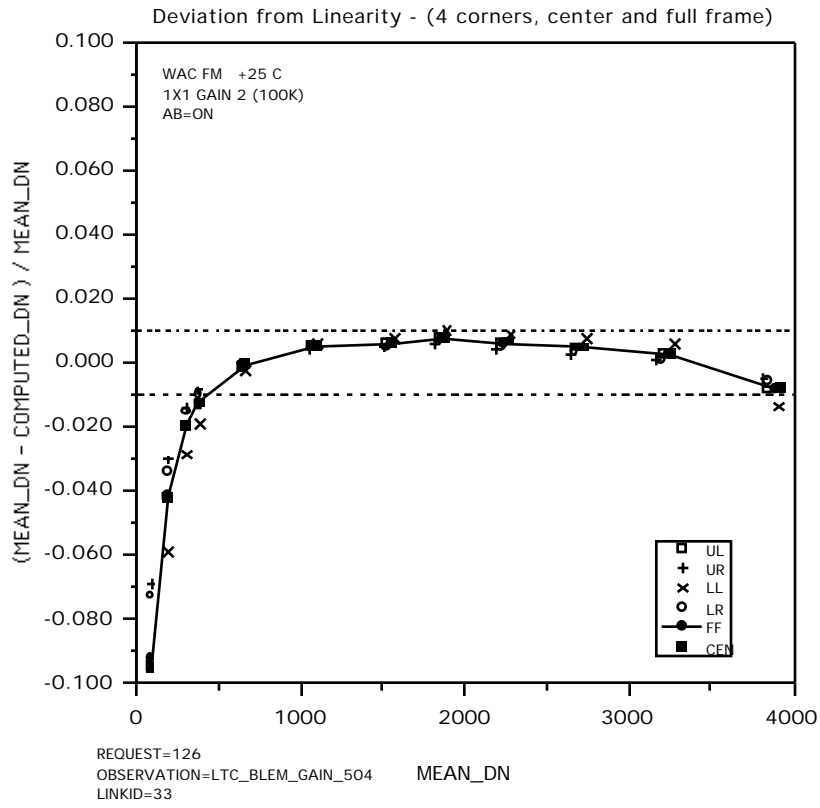
Generating the relative deviation from the absolute deviation distorts the symmetry of the absolute deviation curve by dividing by small mean DN numbers on one end and by large ones on the other. This typically yields a plot with worse relative deviations at the low DN range.

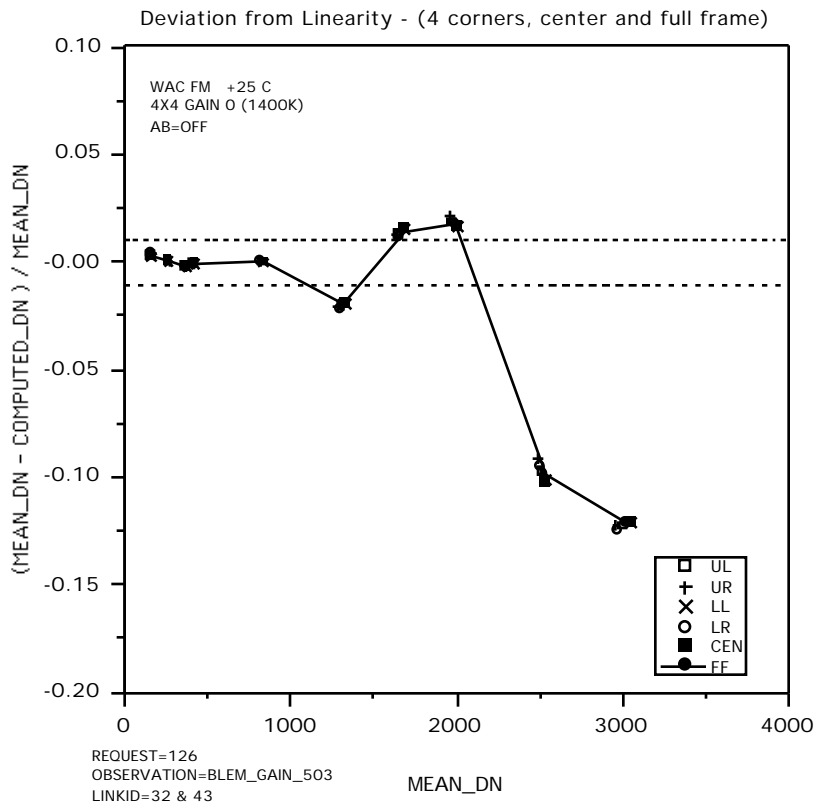
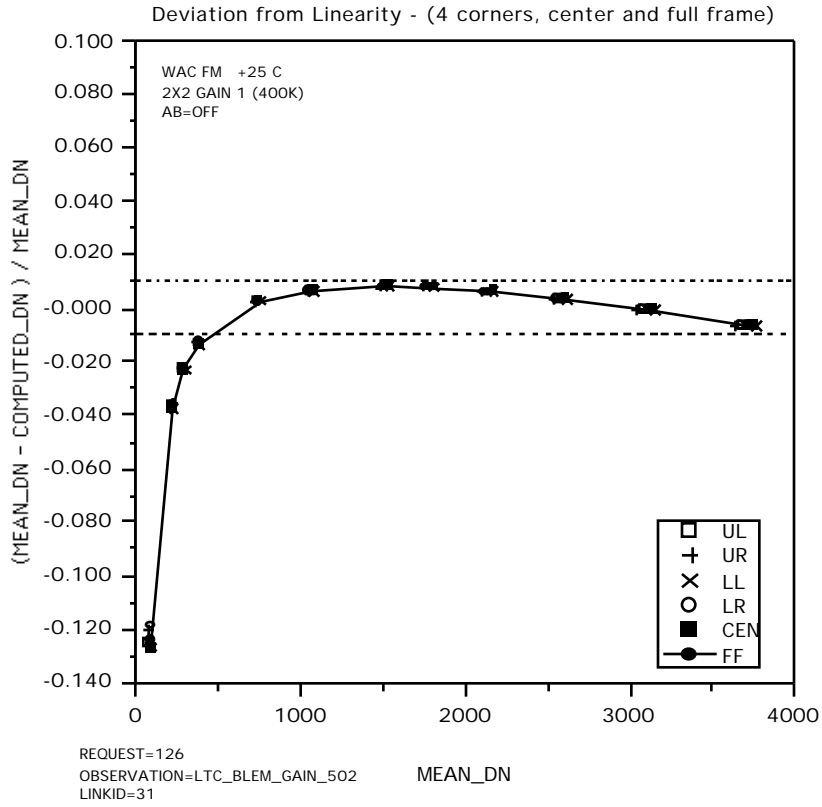
The plots which follow show the deviation from linearity for each Gain state. The deviation is shown as a function of signal level for the corner regions, the center and for the whole frame. Points for each region are plotted and the line connects the points for the entire frame. The dashed lines indicate  $\pm 1\%$  deviation.

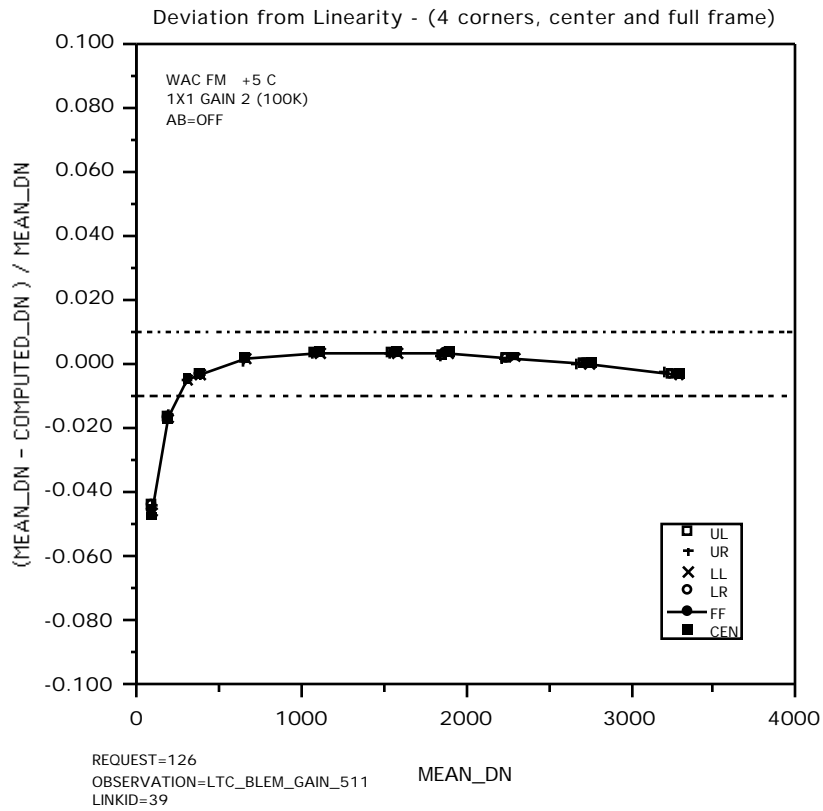
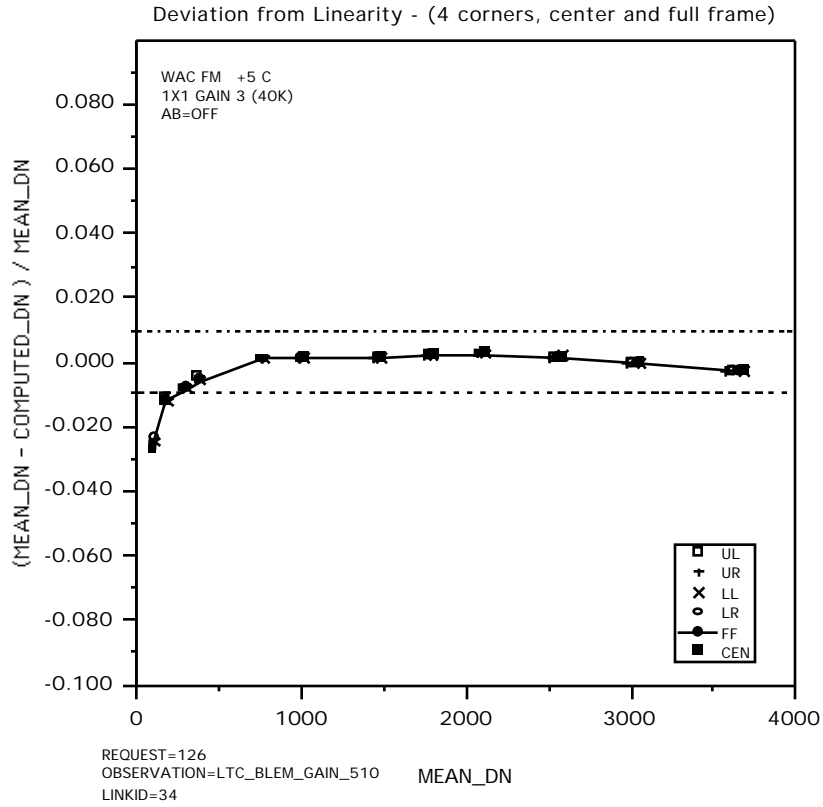
Notes:

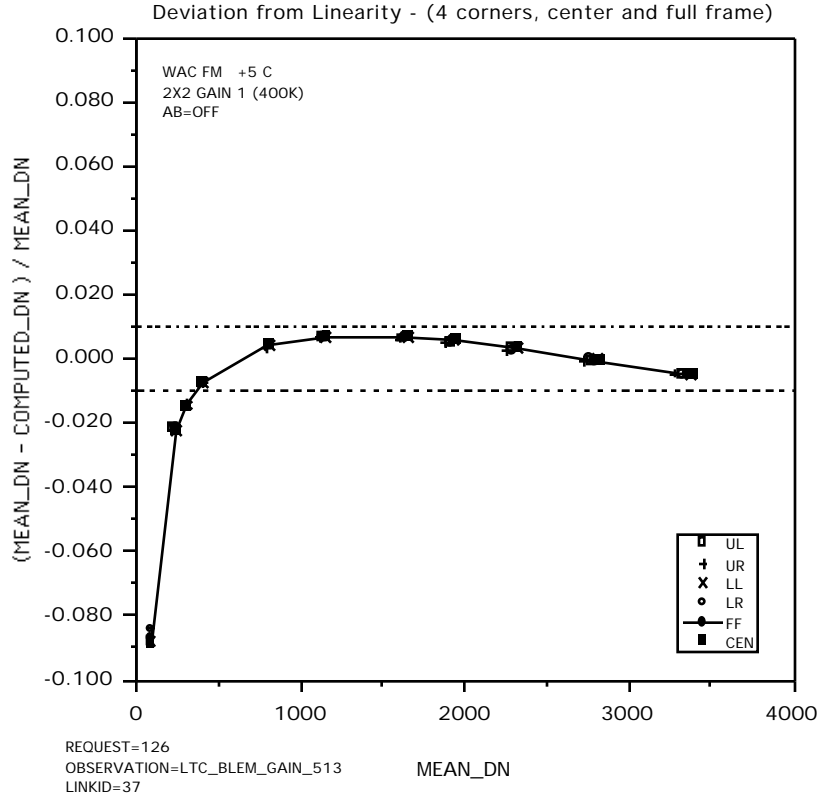
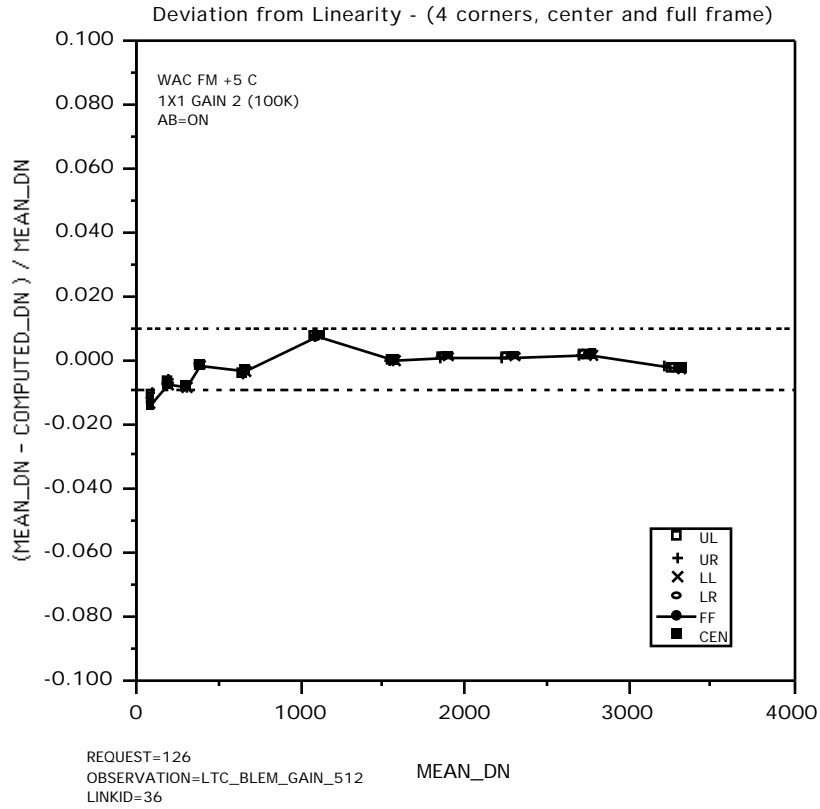
1. Due to linearity problems, the best-fit  $V$  and  $DN_0$  for Gain 0 were calculated using exposure times of 0 to 70 milliseconds.

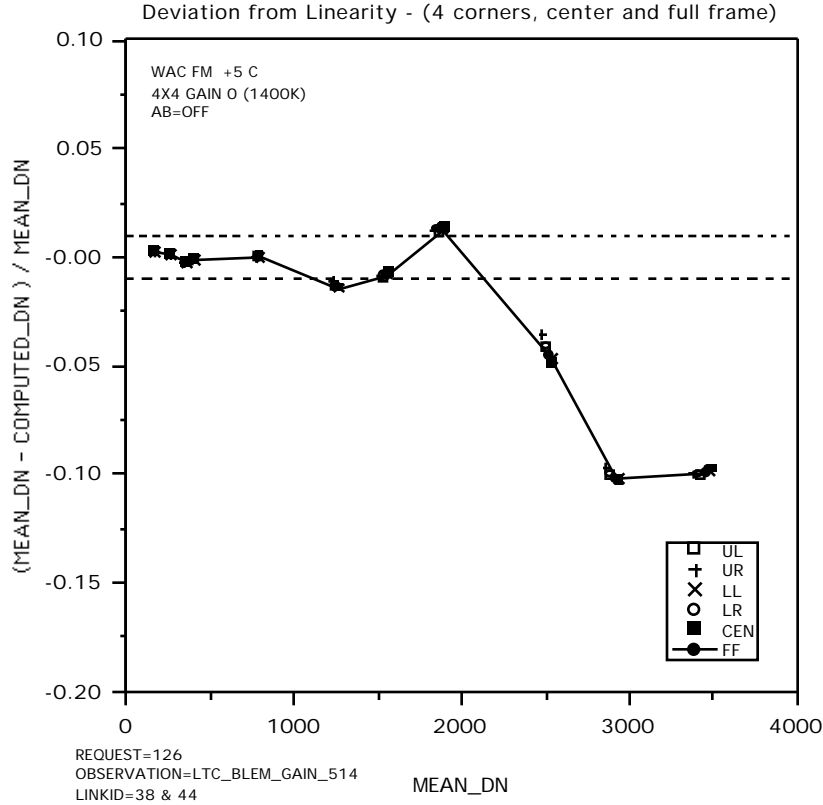












5.1.11.2.4 CONCLUSIONS

1. Except for 4x4 Gain=0, all gains and summation modes remained linear (within ±1 percent) over the entire dynamic range (excluding deviations at the extreme low end).
2. In 4x4 Gain=0, linearity breaks down at about 1000 DN at both temperatures.
3. Temperatures had no significant effect on the linearity results.
4. Antiblooming had no significant effect on the linearity results.

5.1.11.2.5 IMAGES USED IN LINEARITY ANALYSIS

image	day	time	observation	gain	mode	expos	radiance								
126933	180	4:47:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5	45.20	126956	180	5:20:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220	45.20
126934	180	4:49:9.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5	45.20	126957	180	5:21:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260	45.20
126935	180	4:50:38.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	5	45.20	126958	180	5:23:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260	45.20
126936	180	4:51:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15	45.20	126959	180	5:24:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	260	45.20
126937	180	4:53:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15	45.20	126960	180	5:25:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320	45.20
126938	180	4:54:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	15	45.20	126961	180	5:27:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320	45.20
126939	180	4:56:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30	45.20	126962	180	5:28:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	320	45.20
126940	180	4:57:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30	45.20	126963	180	5:30:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380	45.20
126941	180	4:59:9.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	30	45.20	126964	180	5:31:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380	45.20
126942	180	5:0:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40	45.20	126965	180	5:33:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	380	45.20
126943	180	5:1:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40	45.20	126966	180	5:34:19.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460	45.20
126944	180	5:3:13.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	40	45.20	126967	180	5:35:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460	45.20
126945	180	5:4:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90	45.20	126968	180	5:37:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	460	45.20
126946	180	5:6:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90	45.20	126840	180	1:17:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5	50.20
126947	180	5:7:40.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	90	45.20	126841	180	1:19:0.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5	50.20
126948	180	5:8:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120	45.20	126875	180	2:11:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	5	50.20
126949	180	5:10:15.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120	45.20	126842	180	1:20:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30	50.20
126950	180	5:11:44.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	120	45.20	126843	180	1:21:35.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30	50.20
126952	180	5:14:42.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180	45.20	126844	180	1:23:4.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	30	50.20
126953	180	5:16:11.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180	45.20	126845	180	1:24:33.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60	50.20
126969	180	6:11:48.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	180	45.20	126846	180	1:26:2.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60	50.20
126954	180	5:17:17.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220	45.20	126847	180	1:27:31.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	60	50.20
126955	180	5:18:46.0	LTC_BLEM_GAIN_500	3 (40K)	FULL	220	45.20	126849	180	1:30:6.0	LTC_BLEM_GAIN_501	2 (100K)	FULL	80	50.20





130245	195	12:38:12.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	70	58.80
130246	195	12:39:3.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	70	58.80
130247	195	12:39:54.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	70	58.80
130248	195	12:40:23.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	120	58.80
130249	195	12:41:14.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	120	58.80
130250	195	12:42:5.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	120	58.80
130251	195	12:42:57.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	150	58.80
130252	195	12:43:48.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	150	58.80
130253	195	12:44:39.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	150	58.80
130254	195	12:45:6.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	180	58.80
130255	195	12:45:57.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	180	58.80
130256	195	12:46:48.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	180	58.80
130257	195	12:47:40.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	260	58.80
130258	195	12:48:31.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	260	58.80
130259	195	12:49:22.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	260	58.80
130260	195	12:49:49.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	320	58.80
130261	195	12:50:40.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	320	58.80
130262	195	12:51:31.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	320	58.80
130263	195	12:52:23.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	380	58.80
130264	195	12:53:14.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	380	58.80
130265	195	12:54:5.0	LTC_BLEM_GAIN_514	0	(1400K)	SUM4	380	58.80