National Radio Astronomy Observatory
Charlottesville, Virginia 22903

ADDENDUM TO GBT MEMO NO. 115

S. Srikanth
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When the GBT tipping structure moves in elevation from the rigging angle of 43.8°, the components of the antenna, namely the main reflector, the subreflector and the feed, get displaced and tilted resulting in misalignment of the optics. In addition, there is deterioration of surface accuracy due to the effect of gravity on the reflector backup structure. The objective of GBT Memo #115 is to calculate the gain loss as a result of optics misalignment induced by gravity and its compensation by translation of the subreflector. The increased surface rms cannot be corrected by subreflector repositioning. An appropriate title for Memo #115 would be "Gain Reduction Due to Optics Misalignment of GBT Model 95, Version B, Induced by Gravity and Its Compensation by Subreflector Translation."

At the bottom of Table 2 of Memo #115, the surface rms values used at different frequencies are shown. The value 0.049" is the specified value to be met by the antenna contractor, while the other values (0.017", 0.0087") are the desired goals for high frequency operation. These values are used in calculating the aperture efficiency at the rigging angle as well as at horizon and at zenith. Hence, the effect of the surface rms changes on the aperture efficiency with change in elevation is eliminated in the memo. This has led to some confusion and, hence, tables of efficiencies are presented here assuming a surface error efficiency of unity at all frequencies and at the three elevation angles.

Table 3a which replaces Table 3 of Memo #115 gives the efficiency ($\eta_{spillover}$ * η_{taper} * $\eta_{phase\ error}$) at the rigging angle, horizon and zenith, before applying any correction. Referring to column 2 of Table 3a, the efficiency at 1.42 GHz is lower than that at 8 GHz (where -15 dB feed taper is used in both cases) because of higher diffraction and spillover losses at 1.42 GHz. The increase in efficiency going from 8 GHz to 20 GHz is largely due to higher illumination efficiency at 20 GHz where the feed taper is -13 dB. The small increase in efficiency at 50 GHz, compared to that at 20 GHz (-13 dB taper for both frequencies), is due to lower spillover loss at 50 GHz. The efficiency loss in columns 3 and 4, compared to column 2, is entirely due to misalignment of the optics. Table 4a replaces Table 4 of Memo #115 and presents efficiencies before and after correction. P. Napier suggested that a good starting point for positioning the subreflector would be to translate it so that one of its focii coincides with the focus of the deformed paraboloid. Columns 5 and 6 in Table 4a give the efficiency for this case. Losses in columns 5 and 6 of Table 4a are smaller compared to those in Table 4 of Memo #115, but still significant and, hence, need further correction. Columns 7 and 8 present the efficiency when the subreflector is translated for minimizing the phase error in the aperture. As seen from Table 4a, the gain loss due to misalignment of optics, as the tipping structure moves in elevation from the rigging angle, can be recovered by subreflector translation alone.

TABLE 3a. EFFICIENCY ($\eta_{spillover} * \eta_{taper} * \eta_{phase\ error}$) (%)
(Before Correction)

Freq. (GHz)	F = 60 m 43.8° Elev.	F = 60.0045 m (at horizon)	F = 60.0109 m (at zenith)
1.42	71.72	70.86	68.44
8	73.45	48.18	17.38
20	76.02	0.56	0.64
50	76.40	0.24	0.47
Feed Taper ≤ 8.2 GHz - −15 dB; > 8.2 GHz - −13 dB. Surface error efficiency = 1.			

As pointed out by D. Wells and P. Napier, the sentence at the bottom of page 2 of Memo #115, "Deflections of the elements of the telescope are linear functions of elevation . . . ." should read "Deflections of the elements of the telescope are sinusoidal functions of elevation and . . . .".

In order to present the effect of gravity-induced surface errors on the aperture efficiency, surface rms values from Table 7* (Surface RMS Error Budget) are used. For Phase 1 operation, when the main reflector surface actuators are fixed, the total surface rms (maximum wind) is 0.046" at horizon and at zenith. At the rigging angle, the gravity term on structure (0.041") is zero and surface rms is 0.021". In Phase 2 operation, when the surface actuators are used in an open loop, the surface rms has a maximum value of 0.014" and this value is assumed at all elevation angles. In Phase 3 operation, actuators operate in a closed loop and the expected rms is 0.009". Antenna Phase 1 operational conditions are assumed for 1 and 8 GHz, Phase 2 conditions for 20 GHz, and Phase 3 conditions for 50 GHz. The surface error efficiencies, using the above numbers, are presented in Table 8 at the four different frequencies considered. Table 4b presents aperture efficiency calculated using the surface error efficiency from Table 8 at the rigging angle and at horizon and zenith before correction and after correction. At 1.42 GHz and 8 GHz, correction is by subreflector translation alone. At 20 GHz and 50 GHz, in addition to subreflector translation, surface actuators are used to achieve the efficiencies listed.

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*Private communication, L. King and R. Norrod. GBT Memo No. 119, "GBT Surface Accuracy," R. Norrod.

TABLE 4a. EFFICIENCY ($\eta_{spillover} * \eta_{taper} * \eta_{phase\ error}$) (%)
(Before and After Correction)

Freq. (GHz)	43.8° Elev.	Before Correction		Subrefl. Focus at Focus of Deformed Paraboloid		Subrefl. Translated for Minimizing Phase Error	
		Horizon	Zenith	Horizon	Zenith	Horizon	Zenith
1.42	71.72	70.86	68.44	71.72	71.69 (0.05)	71.72	71.72
8.00	73.45	48.18	17.38	73.39 (0.08)	73.37 (0.10)	73.45	73.45
20.00	76.02	0.56	0.64	73.09 (3.86)	74.05 (2.58)	76.02	75.45 (0.75)
50.00	76.40	0.24	0.47	56.68 (25.81)	67.53 (11.61)	76.40	75.80 (0.79)

Numbers in parentheses are losses in efficiency as a percentage of column 2.
Surface error efficiency = 1.

TABLE 4b. APERTURE EFFICIENCY (%)
(Before and After Correction
With Surface Error Efficiency)

Freq. (GHz)	43.8° Elev.	Before Correction		Subrefl. Focus at Focus of Deformed Paraboloid		Subrefl. Translated for Minimizing Phase Error	
		Horizon	Zenith	Horizon	Zenith	Horizon	Zenith
1.42	71.65	70.52	68.11	71.37 (0.38)	71.34 (0.43)	71.37 (0.38)	71.37 (0.38)
8	71.13	41.32	14.91	62.95 (11.51)	62.93 (11.53)	62.99 (11.44)	62.99 (11.44)
20	69.55	0.51	0.59	66.87 (3.86)	67.76 (2.58)	69.55	69.03 (0.75)
50	60.74	0.19	0.37	45.06 (25.81)	53.68 (11.61)	60.74	60.26 (0.79)
Numbers in parentheses are losses in efficiency as a percentage of column 2							

TABLE 7. SURFACE RMS ERROR BUDGET

PHASE 1 OPERATION

	Inches
Surface Panel:	
Manufacturing	0.003
Gravity	0.003
Temperature	0.004
Wind	0.002
Measurement System	0.001
Antenna Structure:	
Gravity	0.041
Joint Rotation	0.002
Temperature	0.004
Wind	0.009
Measuring and Setting	0.018
Subreflector	0.004
Total Surface Accuracy:	
Maximum Temperature	0.046
Maximum Wind	0.046
Specified Surface Accuracy	0.049

PHASE 2 OPERATION

	Inches
Surface Panel:	
Manufacturing	0.003
Gravity	0.003
Temperature	0.004
Wind	0.001
Measurement System	0.001
Antenna Structure:	
Gravity	0.008
Joint Rotation	0.002
Temperature	0.002
Wind	0.005
Measuring and Setting	0.008
Subreflector	0.004
Total Surface Accuracy:	
Maximum Temperature	0.014
Maximum Wind	0.014

NOTE: Phase 1 – (i) Measuring and setting value reduced to 0.018 by NRAO from 0.040 as delivered.
(ii) Wind 6 m/s, gusting to 7 m/s.
(iii) Temperature 5°C across major dimensions of the antenna; 2°C front-to-back of surface panels.

Phase 2 – (i) Wind 3 m/s, gusting to 4 m/s.
(ii) Temperature 2°C across major dimensions of the antenna; 2°C front-to-back of surface panels.

TABLE 8. SURFACE ERROR EFFICIENCY (%)

Freq. (GHz)	43.8° Elevation		Horizon/Zenith	
	RMS (ins.)	Efficiency (%)	RMS (ins.)	Efficiency (%)
1.42 (Phase 1)	0.021	99.90	0.046	99.52
8 (Phase 1)	0.021	96.85	0.046	85.77
20 (Phase 2)	0.014	91.50	0.014	91.50
50 (Phase 3)	0.009	79.50	0.009	79.50