MAIN INJECTOR BPM CABLE MEASUREMENTS

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Introduction

As a part of the Main Injector BPM system upgrade and to quantify system errors that can lead to reporting incorrect beam positions, signal transmission measurements were made on each of 208 pairs of Main Injector BPM cables[1]. The two cables from each BPM are generically labeled "A" and "B". Nominally equal signals were obtained from a power splitter and injected into the tunnel ends of each pair of RG-8 type BPM cables. The signals transmitted through cable pairs were received and observed on two channels of an oscilloscope connected via patch cables to the inside of the relay rack top-entry panel in the respective service building. Data was saved in two manners: 1) amplitude and phase values computed by the internal oscilloscope measurement function were manually recorded on paper and 2) scope trace data for each pair of signals was saved on floppy disk. Measurements were done with 2.5 MHz and with 52.8 MHz (referred to as 53 MHz hereafter) test signals. Results and analyses of the measurements are described and gain correction factors for use in beam position computations are presented.

Data Validation – Comparing Manually Recorded Data to Scope Trace Data

The manually recorded 53 MHz signal peak-to-peak amplitudes from all 208 "A" and "B" cables and the corresponding cable pair phase differences were transcribed into an EXCEL file, "3-13-06 MI BPM Tunnel Measurements.xls", by M. Olson. The oscilloscope trace data files for the same measurements were processed in a MathCad program written by B. Webber. The MathCad program fits each scope trace data set to a sinusoidal function with amplitude, frequency, phase, and offset as free parameters. The fits all show very small residual differences from the input data, as might be expected for a proper fit to a well-controlled input signal. The "A" cable and "B" cable signal amplitudes for both test frequencies and the phase of each signal for the 53 MHz test frequency are written to file "_outputfile.txt" listed in Appendix 1.

A first check of data validity compares the amplitude and phase values of the fitted data to the transcribed, manually recorded data. The normalized differences between manually recorded and fitted "A" cable signal amplitudes [$(A_{fitted} – A_{manual})/A_{fitted}$] are plotted in

[1] Ultimately 215 cable pairs were measured, including those for instrumenting both planes of the seven ExtraWide Aperture BPMs installed during the Spring 2006 shutdown. Only the original 208 cable pairs are presented in the body text and plots of this note. Data for all 215 cable pairs is included the appendices.

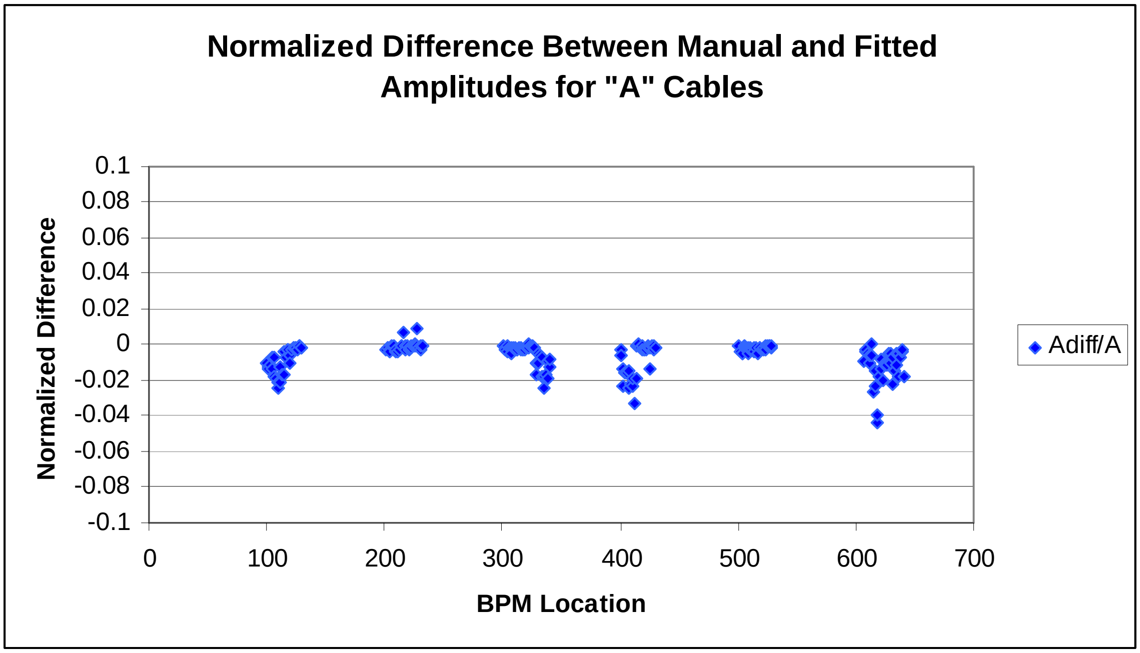

Figure 1. Normalized difference of manual and fitted 53MHz amplitudes for “A” cables, $(A_{fitted} - A_{manual})/A_{fitted}$

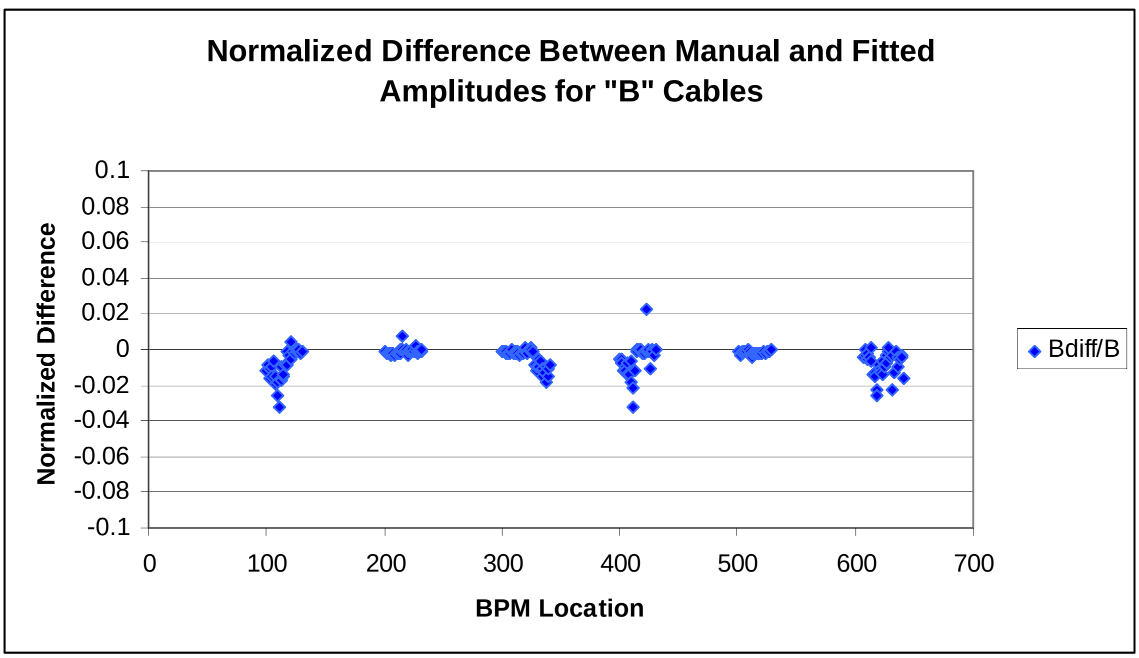

Figure 2. Normalized difference of manual and fitted 53MHz amplitudes for “B” cables, $(B_{fitted} - B_{manual})/B_{fitted}$

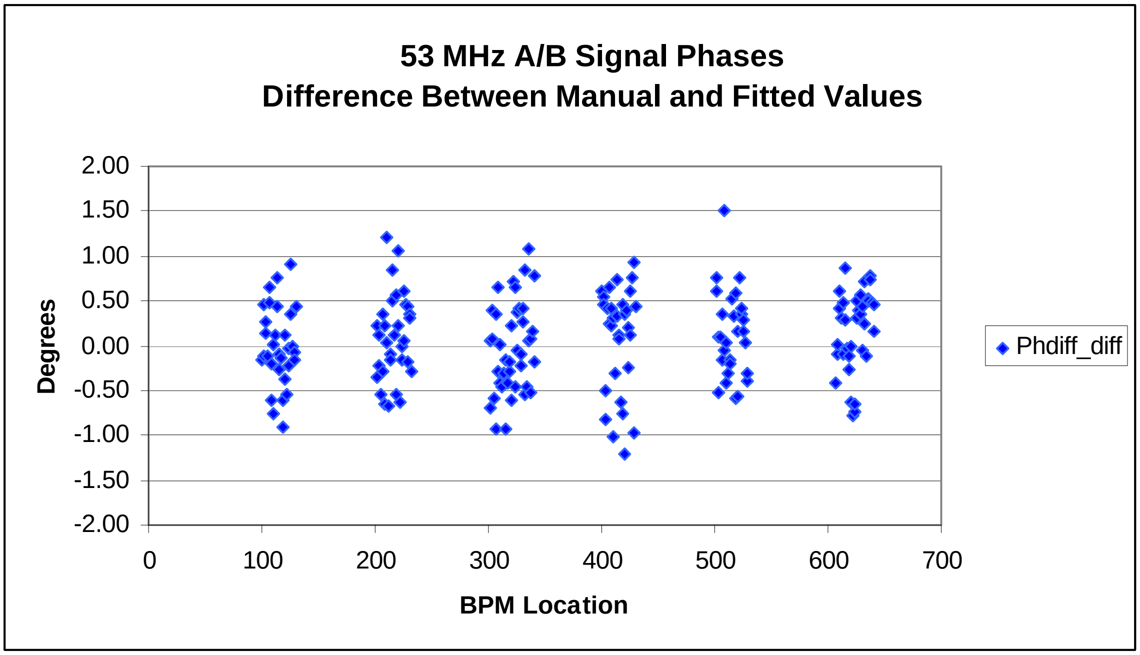

Figure 3. Difference between manual and fitted differential phase values for cable pairs at 53 MHz

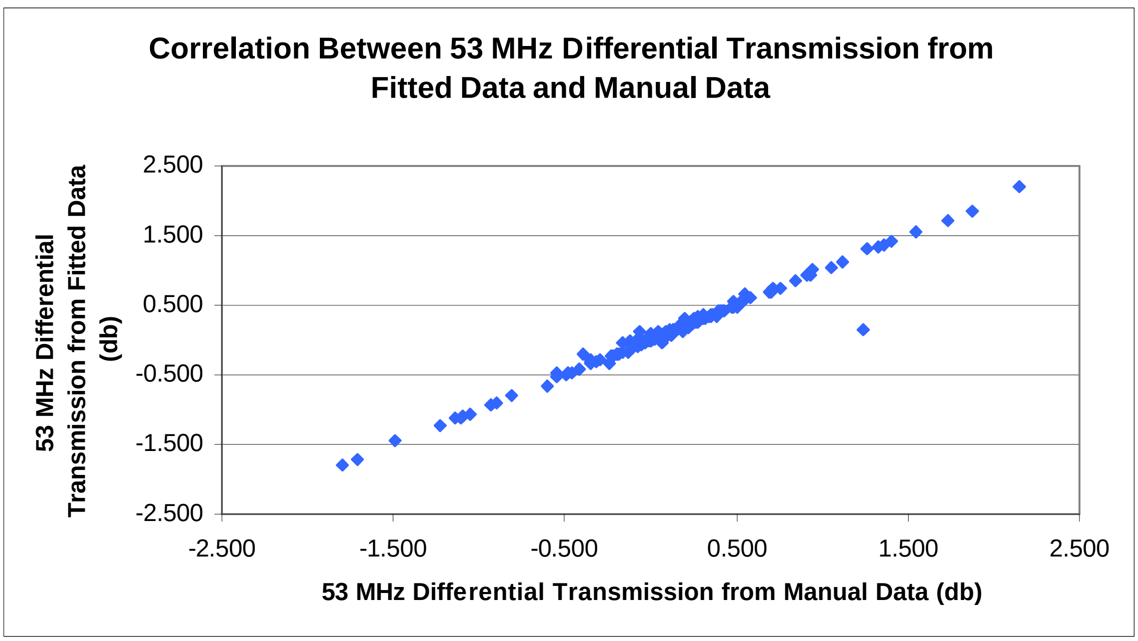

Figure 4. Correlation between fitted and manual 53MHz differential transmission values for cable pairs

Figure 1. Figure 2 is the equivalent plot for the “B” cables. Figure 3 shows the difference between fitted and manual pair phase-difference data. The differential transmission for each cable pair at 53 MHz was calculated from both the manual and fitted data. The correlation of those values from the manual and the fitted data is shown in Figure 4.

Figures 1 and 2 show consistency between the manual and the fitted amplitude data. The normalized differences are generally smaller than 2% and exhibit a bias toward negative values. The manually recorded values were obtained using the peak-to-peak measurement function of the scope. Although the scope was set-up for signal averaging, any residual noise would cause the peak-to-peak measurement to overestimate the signal magnitude. This is consistent with the negative bias observed in the plots.

Figure 3 shows ±1 degree agreement between manual and fitted cable pair differential phase values. The high of correlation between manual and fitted data is also evident in the differential transmission values plotted in Figure 4. The one outlying data point in that figure is believed to be due to a transposed or mistyped value in the manually transcribed data.

The general agreement between manual and fitted measurement results does not guarantee the validity of any particular measurement, but it does suggest that some large set of possible manual recording and file naming errors were avoided. The remainder of this note will focus on the analysis of data obtained from the scope trace fit routine.

Cable Data and Analysis

Figures 5 and 6 show the amplitudes of the received signals (average of “A” and “B” pairs) as a function of cable length for the 2.5 MHz and 53 MHz tests respectively. The smooth trends and absence of points far from the mean suggest that no major cable identification mix-ups were made. The spread in signal transmission at 53 MHz for any narrow range of cable lengths is curious, but has not been investigated. It might be due to the use of different oscilloscope gain settings at different times during the several days of data taking.

Figures 7 and 8 are plots of the transmission differences between the cables of each pair; units are decibels. The sign of the difference is such that a positive value represents a larger signal observed on the “B” cable, i.e. higher transmission (less loss) in the “B” cable relative to the corresponding “A” cable. The mean differential transmission factor over all cable pairs and for both 2.5 and 53 MHz is clearly non-zero. The mean differential transmission factor is 0.051 db at 2.5 MHz and 0.102 db (~1%) at 53 MHz. In each case, the mean “B” cable signal is greater than the mean “A” cable signal. As there is no reason that the average “A” cable should be different from the average “B” cable, this bias suggests a systematic difference between the nominally equal input signals and/or the oscilloscope channel gains. All cable measurements were made in a completely consistent manner with the exception of scope gain settings for the 53 MHz signal measurements. Attenuation was sufficiently large in the long cables that scope gain settings were changed, in an undocumented way, to compensate on the scope display.

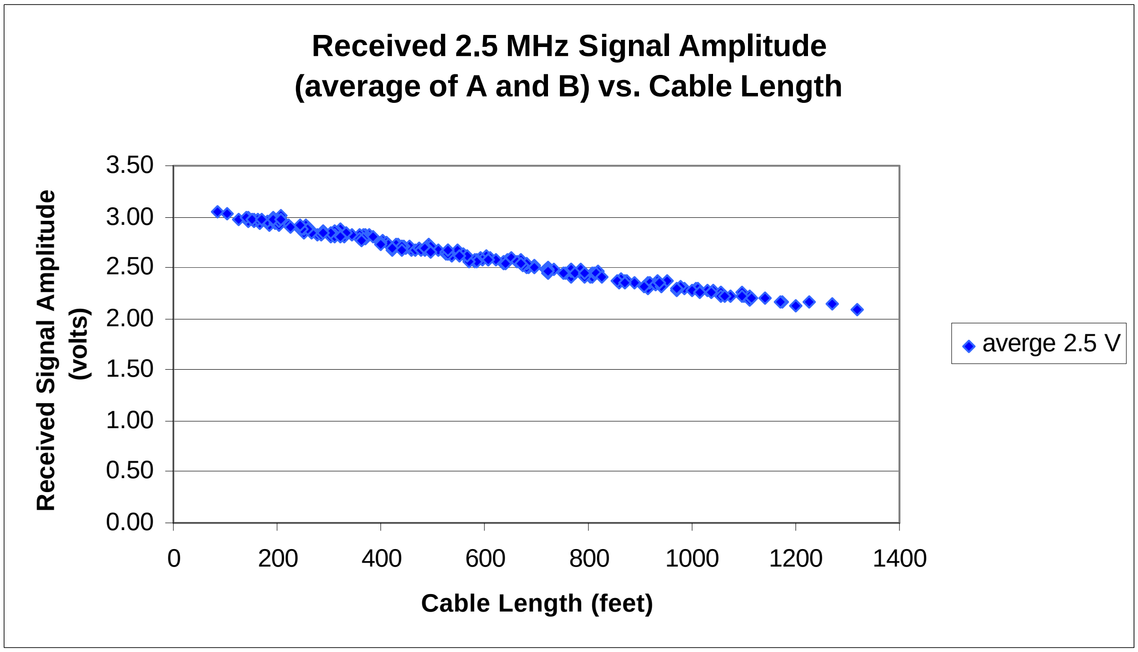

Figure 5. Average received signal through cable pairs at 2.5 MHz

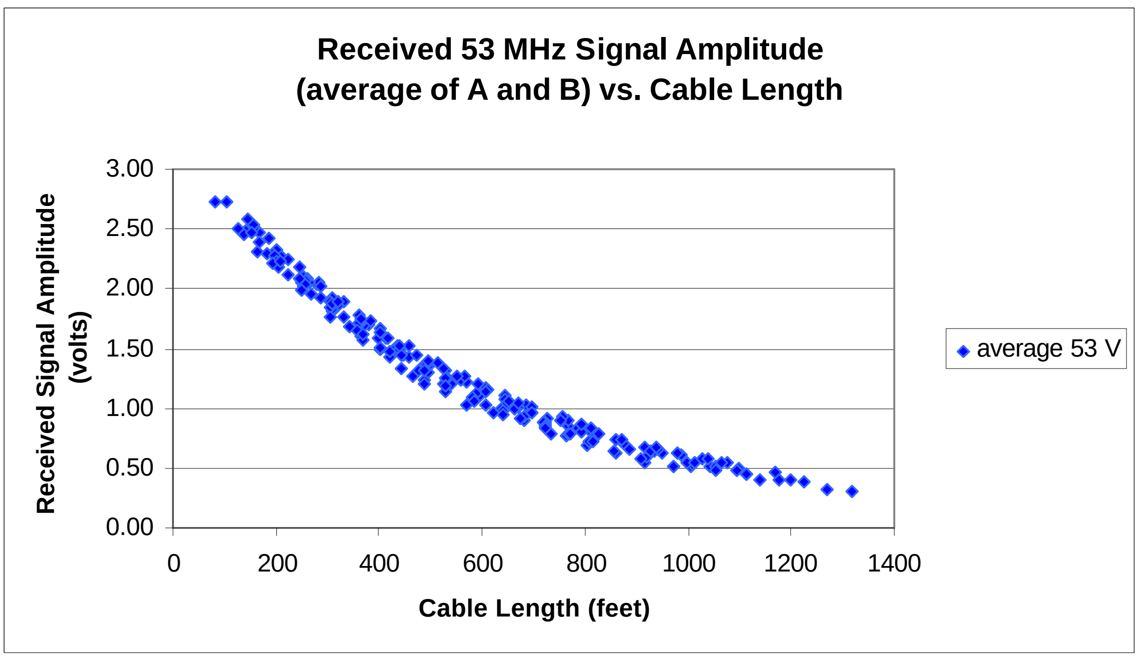

Figure 6. Average received signal through cable pairs at 53 MHz

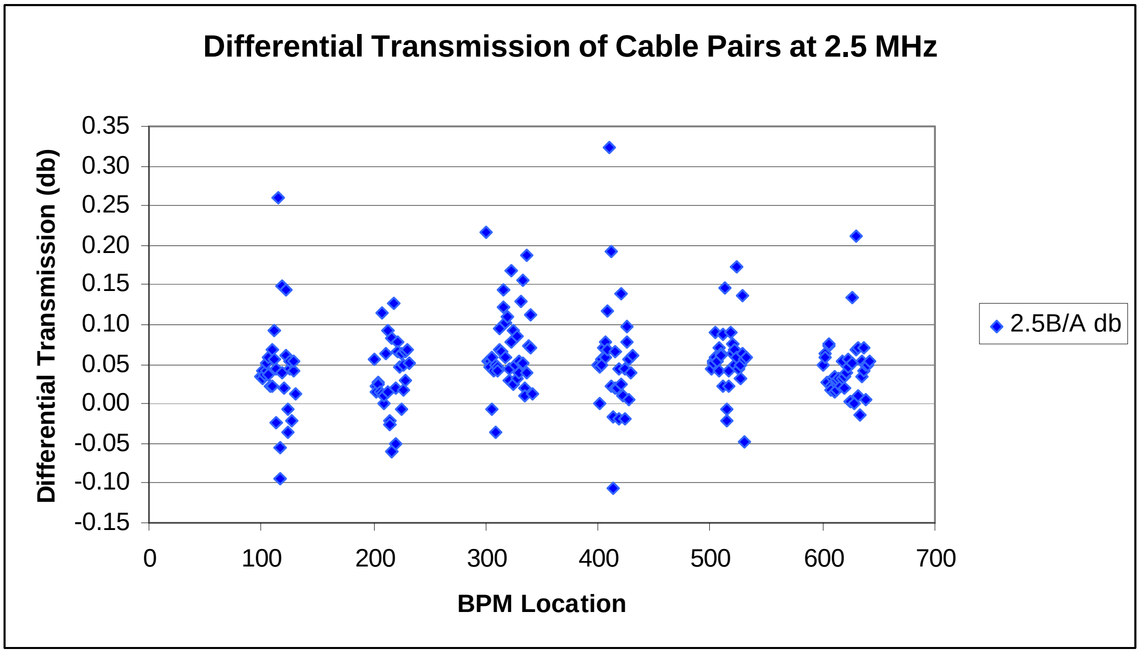

Figure 7. Differential transmission of cable pairs at 2.5 MHz

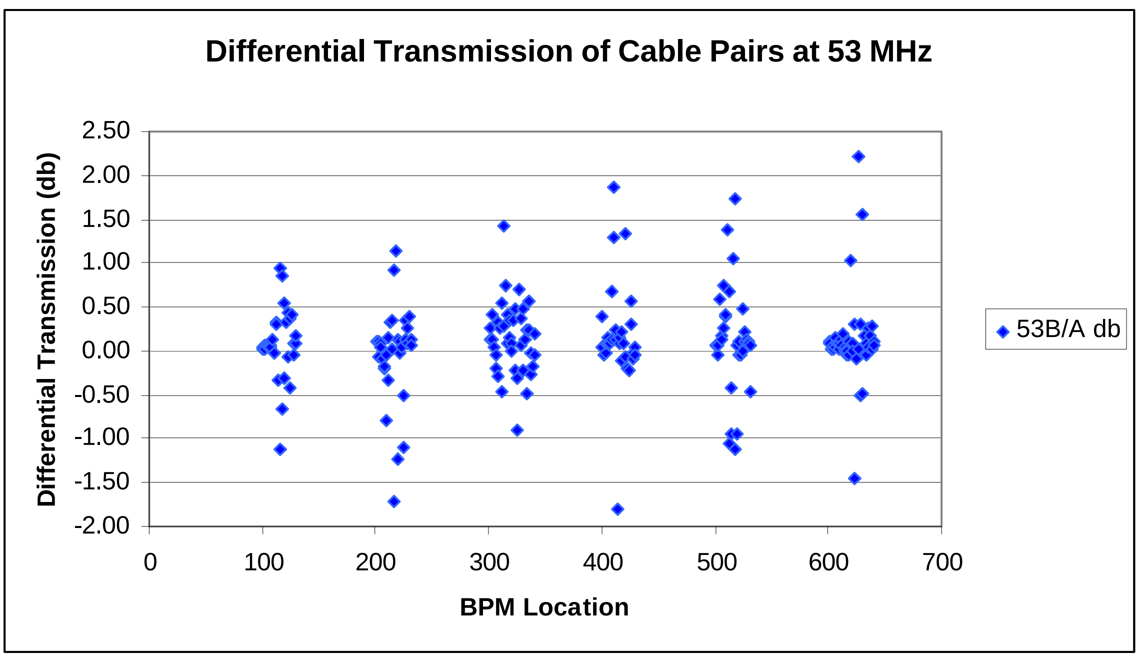

Figure 8. Differential transmission of cable pairs at 53 MHz

A check of the power splitter confirmed that it provided equal signals to better than 0.01db at all frequencies from 1 MHz to 100 MHz. The scope channel gain balance was not re-checked after measurements were completed. <u>It will be assumed that the mean differential transmission factor is a systematic measurement error that can be removed from each cable pair datum.</u>

The range of differential transmission factors is greater at 53 MHz than at 2.5 MHz. This might be expected since the absolute signal attenuation in any cable is larger at a higher frequency. The 2.5 MHz differential transmission values exhibit a range of 0.43 db with a standard deviation of 0.054 db. At 53 MHz the transmission differences have a range of 4.0 db with a standard deviation of 0.516 db. The near-center position sensitivity of standard MI BPMs is 1.67 mm/db in the vertical plane and 1.13 mm/db in the horizontal. The measured cable pair transmission differences are therefore quite significant for millimeter accuracy beam position determination.

Figure 9 displays the correlation between differential transmission values for cable pairs at 53 MHz and 2.5 MHz. Data in these plots have had the mean bias subtracted for both frequencies and thus center around the (0, 0) point. Larger differences at 2.5 MHz are generally accompanied by larger differences at 53 MHz as might be expected, but the spread is large. No further conclusion is suggested.

Figures 10 and 11 are plots of the zero-biased differential transmission magnitudes as a function of cable length at 2.5 MHz and 53 MHz respectively. The 2.5 MHz data show only a weak tendency to larger differentials for longer cable lengths; the 53 MHz data show a more significant probability of large differential attenuation for longer cables.

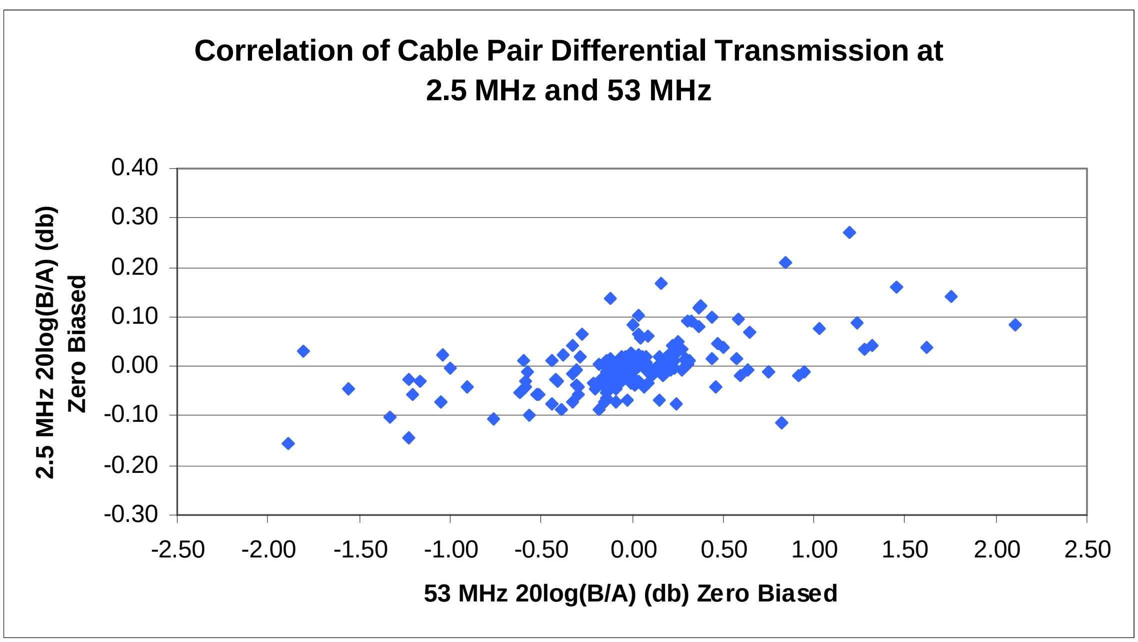

Figure 9. Correlation of 2.5 MHz and 53 MHz differential transmission for cable pairs

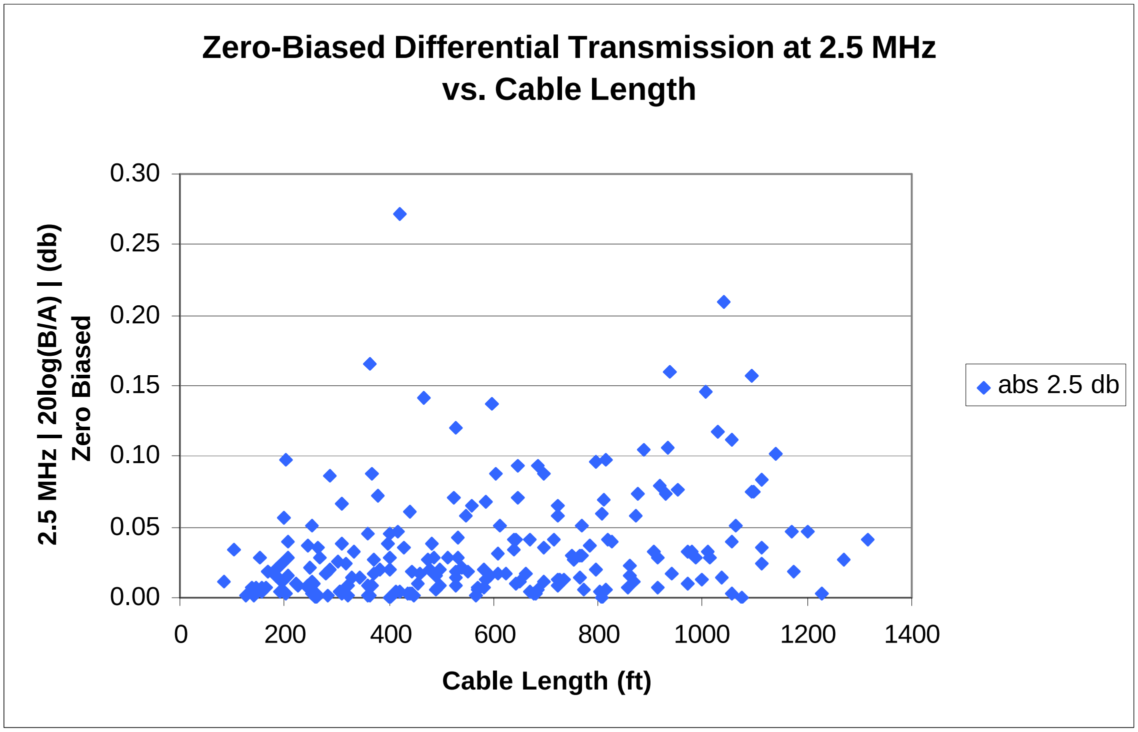

Figure 10. Differential transmission magnitudes at 2.5 MHz versus cable length

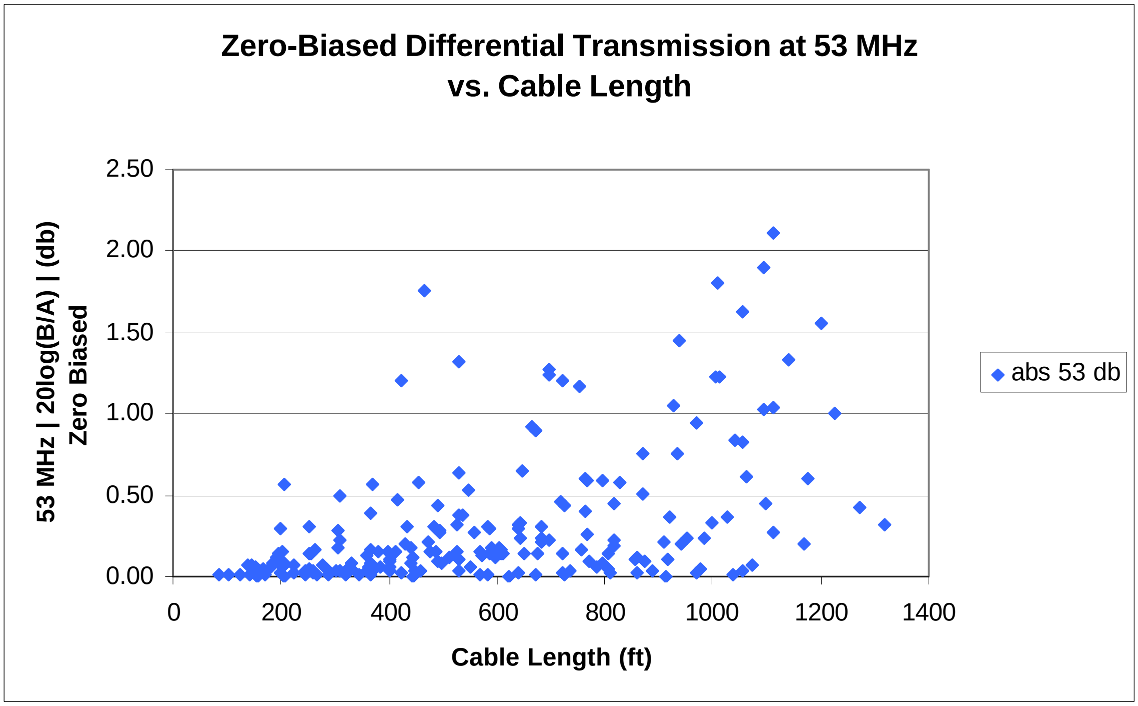

Figure 11. Differential transmission magnitudes at 53 MHz versus cable length

Figure 12 shows the phase differences of received signals from cable pairs at 53 MHz. Phase differences as large as -25 and +30 degrees were measured. This is somewhat surprising since the cables had purportedly been phase matched after installation. That matching was done using a TDR (time domain reflection) method. As a prelude to the transmission measurements described in this note, network analyzer S11 (frequency domain reflection) measurements were performed on several pairs of the BPM cables. The S11 results showed quite complicated features of the cables, probably due to variability of cable properties along the length. Unambiguous interpretation of the S11 data proved difficult. This suggests that the original TDR measurements might also have been ambiguous or inaccurate and might help explain the large phase mismatches.

Figures 13 and 14 are plots of phase differences for cable pairs, at 2.5 and 53 MHz respectively, as a function of cable length. The 2.5 MHz data show little trend, but at 53 MHz there is a clear indication that longer cable runs are more likely to exhibit larger phase differences. Appendix 2 lists file "_phases.txt" containing the measured phase values from fitted data for all cables.

Figure 15 shows the correlation of transmission phase differences at 2.5 MHz and 53 MHz. If simple physical length of the cables was the root of the phase differences, the 53 MHz phase should be just 21 times larger than that at 2.5 MHz. The figure indicates a trend along this line, but the large spread suggests a more complicated picture, consistent with significant cable inhomogeneities.

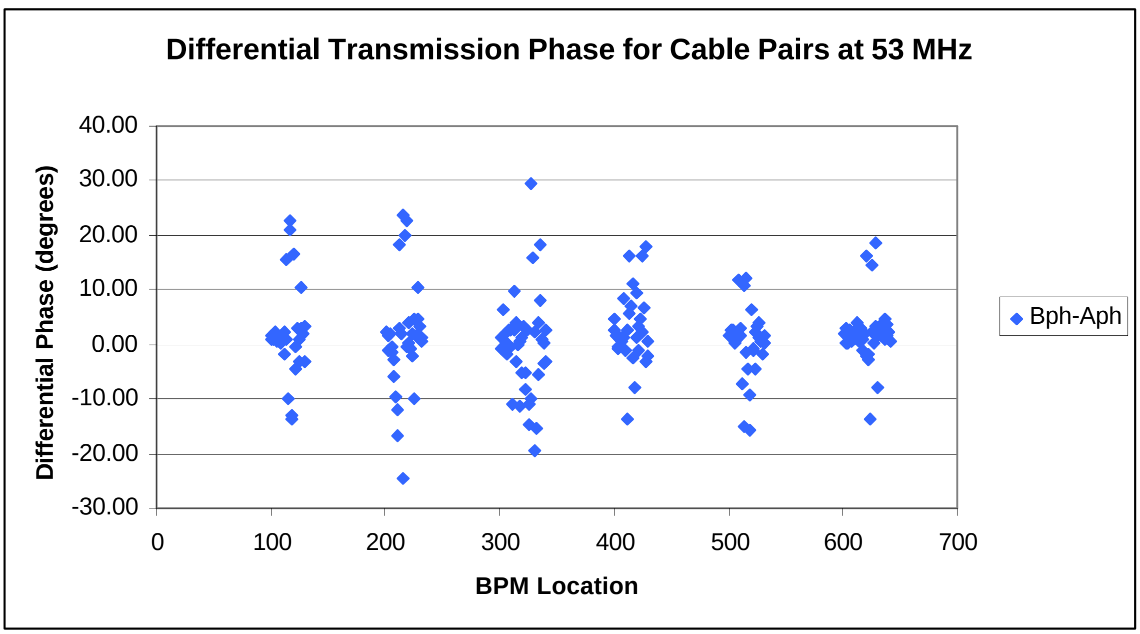

Figure 12. Transmission phase differences for cable pairs at 53MHz

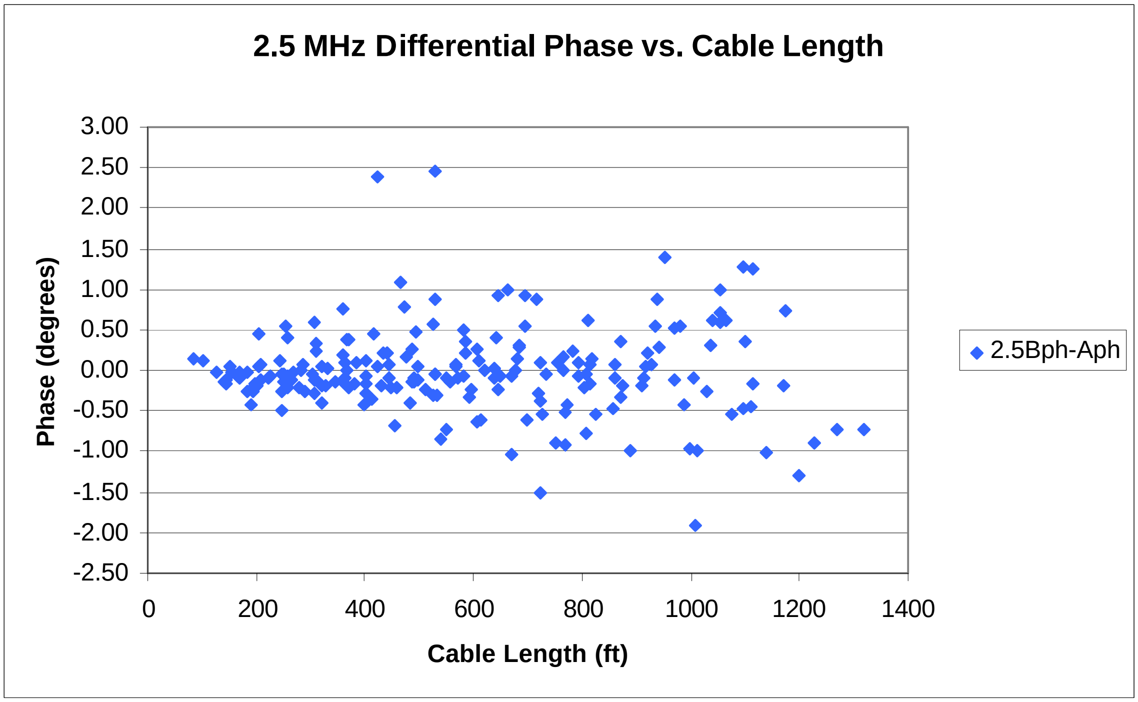

Figure 13. Phase differences of cable pairs vs. cable length at 2.5 MHz

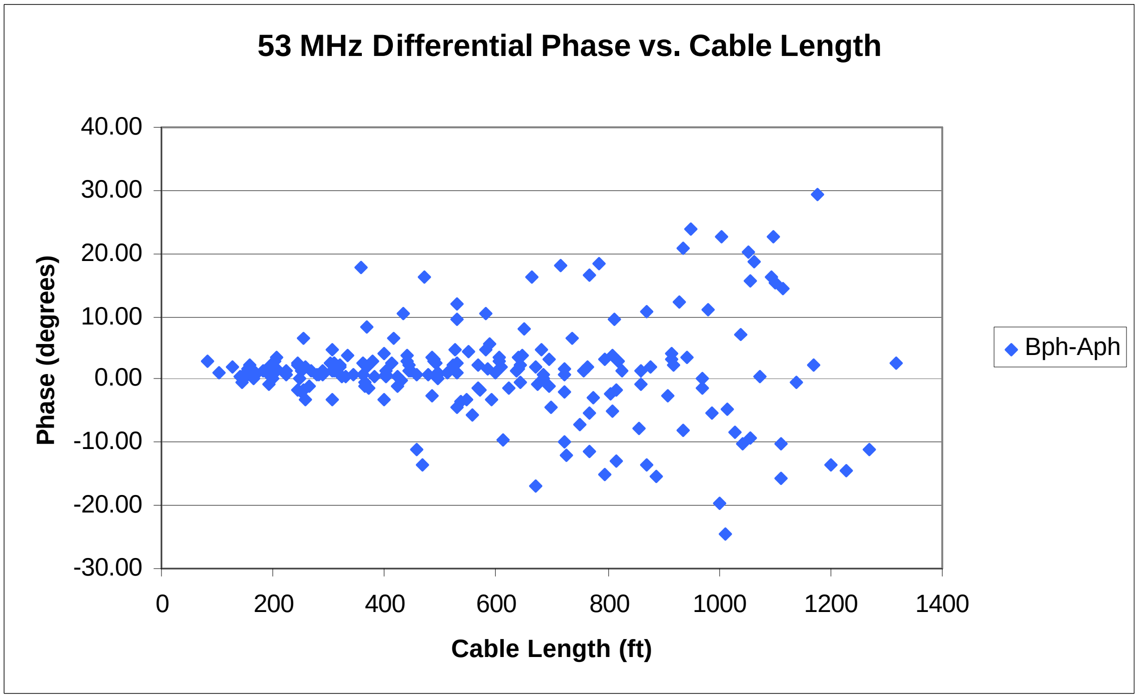

Figure 14. Phase differences of cable pairs vs. cable length at 53 MHz

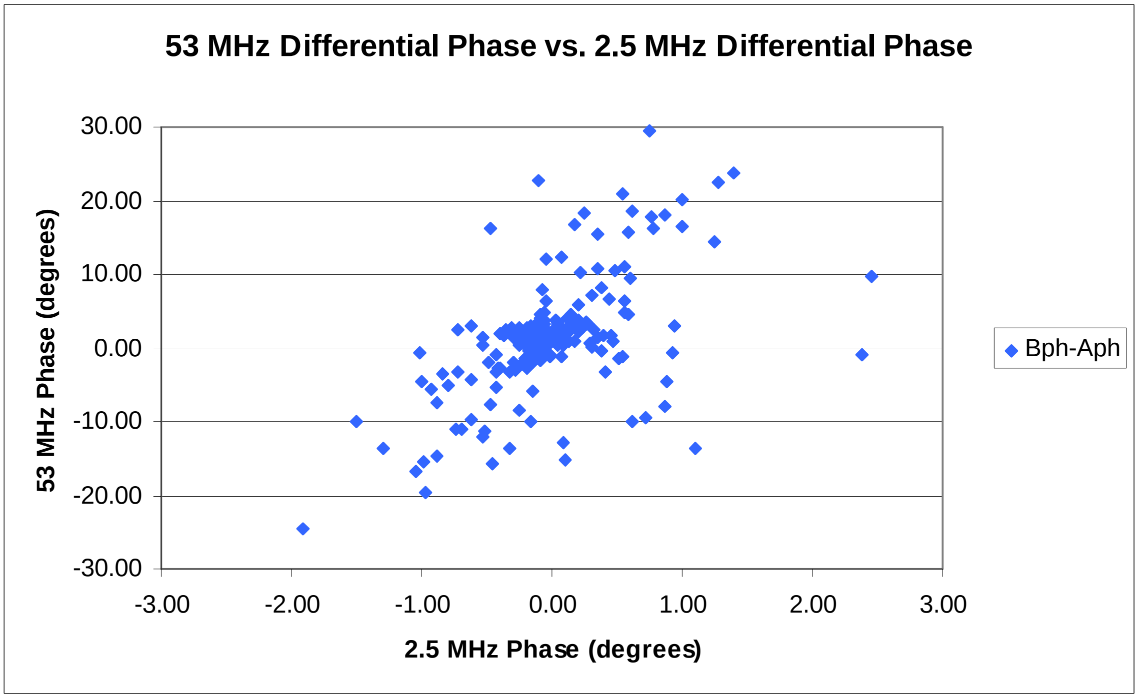

Figure 15. Correlation plot of cable pair differential transmission phases at 53 MHz and 2.5 MHz

Comparison to Classical MI BPM Electrical Offset Values

The pre-upgrade Main Injector BPM system applied various corrections to reported beam positions to compensate for known imperfections in the system. Values of one correction parameter, the electrical offset, had been determined by applying signals to the tunnel end of the cables (much like this recent test) and reading out the reported position through the operating BPM electronics. (The upgraded electronics could not be included in the present tests since they have not yet been installed.) It is reasonable to compare the results of the recent cable measurements to these classical electronic offset values on the theory that the cable mismatches might have dominated over the errors of the old electronics. Unfortunately it is not possible to separate the effect of cables from the effect of electronics in the classical offset values.

The classical offsets are maintained in millimeter units. Equivalent center offsets in millimeters corresponding to the measured 53 MHz cable differences are computed using the BPM scale factors cited earlier, 1.67 mm/db in the vertical plane and 1.13 mm/db in the horizontal. The resulting center position offsets from cable mismatches are plotted in Figure 16 as a function of BPM location; several are larger than 2 mm. Figure 17 plots the correlation between the classical electronic offsets and offsets from the 53 MHz cable data. There is clearly a contribution from cable effects in the classical offset values, but the electronics contribution is apparently also significant. Differences between the classical and the cable-only offsets, shown in Figure 18, are large on the millimeter scale. So the comparison to classical offsets, while interesting, seems not particularly useful.

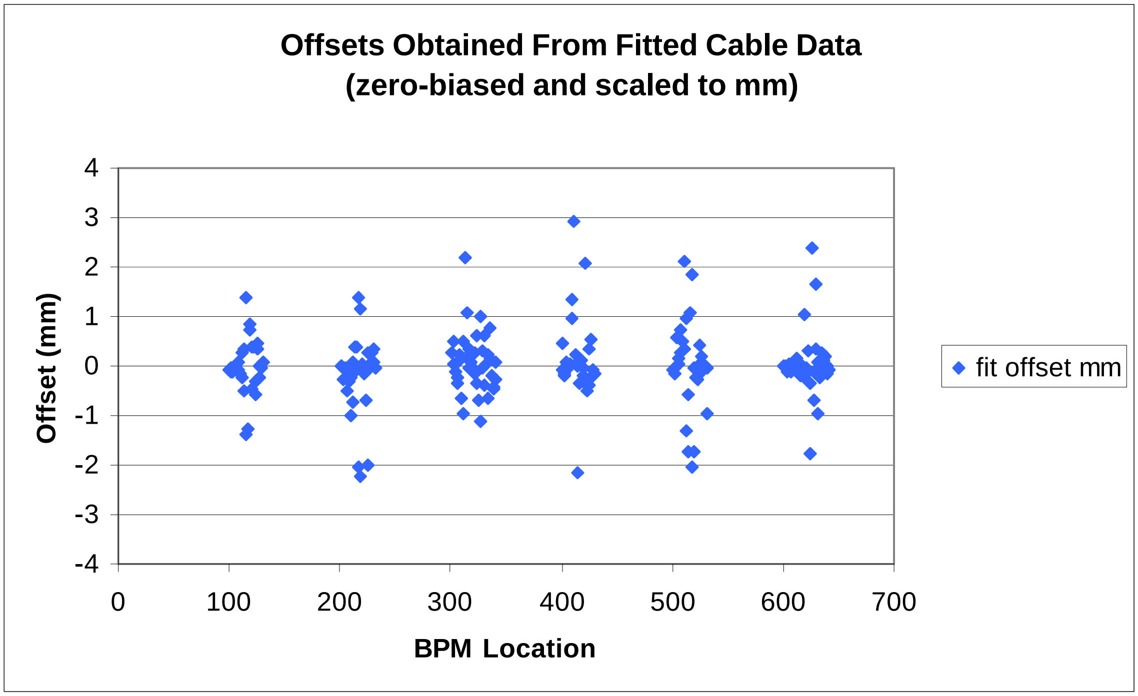

Figure 16. Center position offsets due to differential cable attenuation at 53 MHz

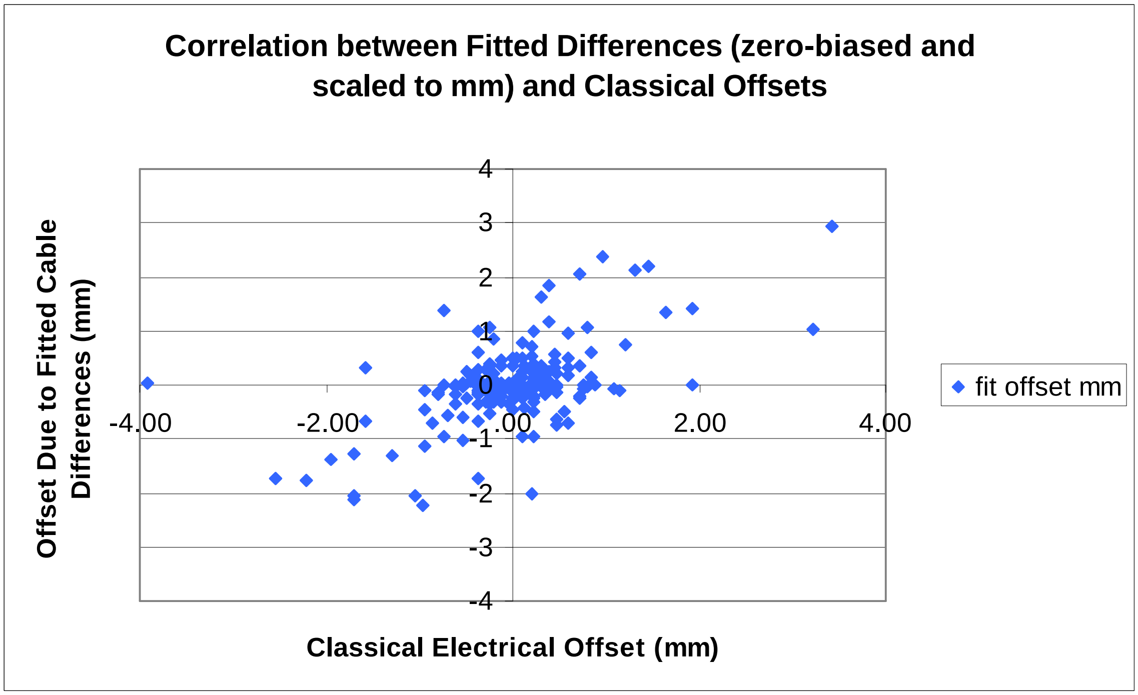

Figure 17. Correlation between offsets from cable data and classical electronic offsets

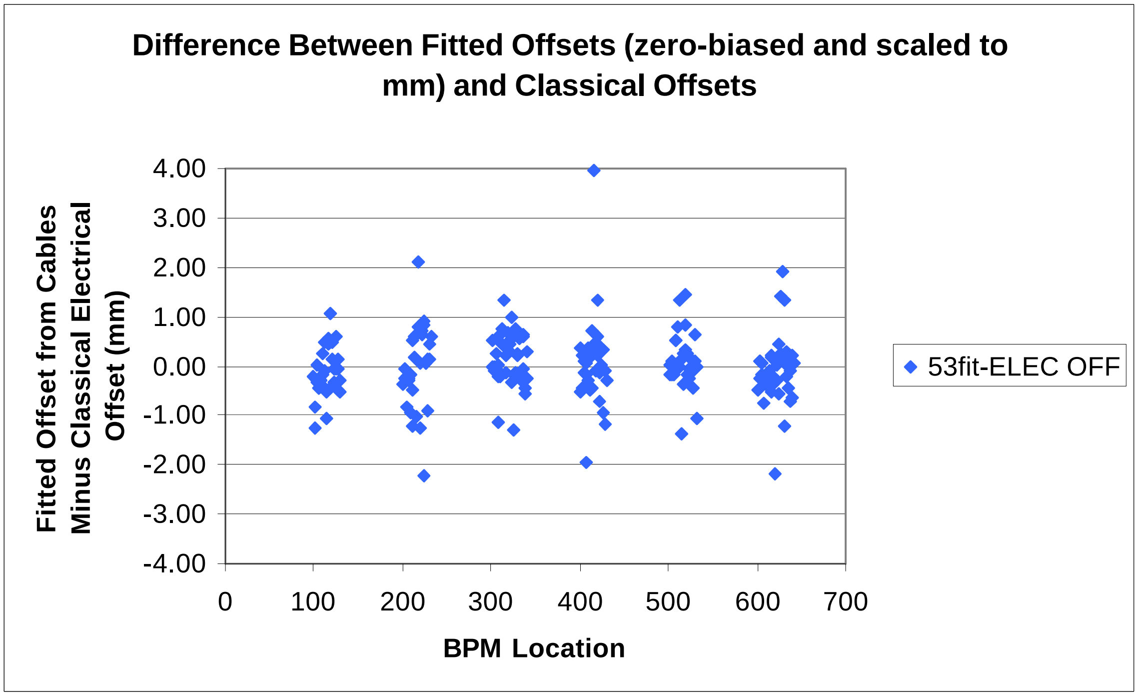

Figure 18. Difference between offsets from cable data and classical electronic offsets

One More Check

In light of the difficult-to-interpret and highly frequency sensitive S11 measurement results, it was decided to verify that transmission through a sample of these cables does vary smoothly and only slowly as a function of frequency. Three cable pairs were tested in the same manner as described above with signal frequencies that were varied from 45 MHz to 65 MHz. Results are displayed in the three plots of Figure 19. BPMs 114 and 115 each have cable runs of approximately 1000 ft.; BPM 201 cables are about 150 ft.

The blue trace in each plot shows the average attenuation normalized to the 45 MHz value. This varies smoothly by about 3.5 db for the long cable runs and 0.8 db for the short run. The pink traces show the differential attenuation for the pairs of cable. The differentials are less sensitive to frequency, but trend toward larger magnitudes for the higher frequencies as might be expected. The green traces show the phase difference between cables of a pair. The phase differences increase more or less linearly with frequency.

These checks confirm that there are no unexpected, rapidly changing frequency sensitivities to confound the interpretation of the single frequency measurement data.

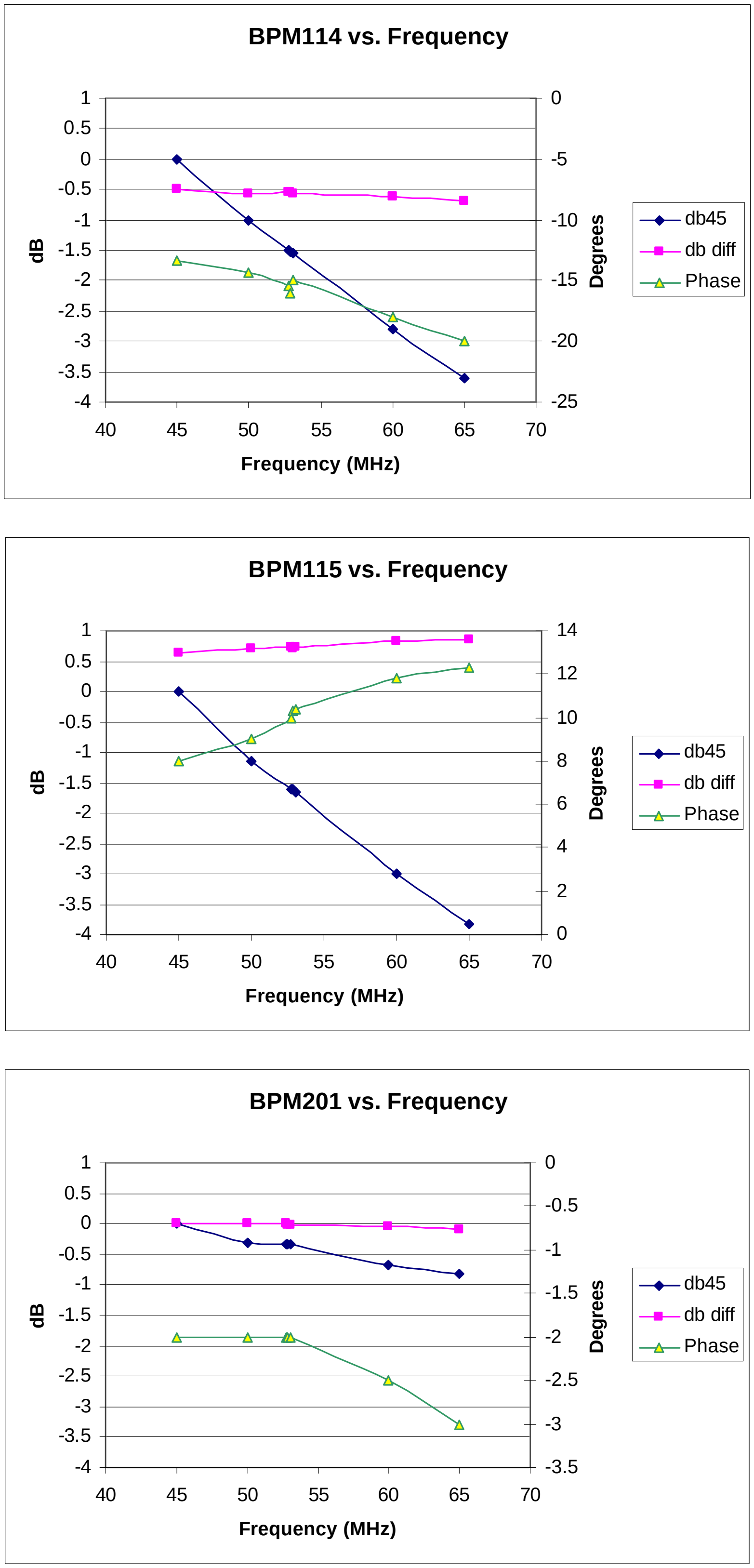

Figure 19. Frequency sensitivity of transmission and phase between 45 MHz and 65 MHz for three cable pairs (two long runs, one short run).

Application of Results

These cable measurement results can provide the basis for a set of correction factors to be applied in the upgraded BPM system to compensate for the cable pair transmission mismatches. In a simple model, the cable transmission coefficient or attenuation appears mathematically as a (frequency dependent) linear gain factor on the beam signal amplitude. With a suitable table of numbers, appropriate gain correction can be applied by the BPM software prior to or as a part of the beam position computation. Such a table has been generated as described below from the cable measurement data.

As a first step in computing correction values, the systematic, non-unity average ratio of observed “B” and “A” signals is removed from the data. The ratio of observed “B” signal to “A” signal, |B|/|A|, is computed for each cable pair and the average over all cable pairs is found at each test frequency. The average ratio is 1.006:1 at 2.5 MHz and 1.013:1 at 53 MHz. Each “A” signal amplitude is then multiplied by this average to yield a set of “corrected A” signals without the systematic differences relative to the “B” signals. The gain correction factors are then obtained by taking the ratio of “B” to “corrected A” amplitudes for each cable pair. These factors, when used to multiply respective “A” signal magnitudes, compensate for the differential cable pair transmission errors. This is done separately for both signal test frequencies. The resulting gain correction factors are provided in file “_normalized_ratios.txt” and listed in Appendix 3.

Convention reminder: the gain factors thus created should be used to multiply “A” beam signal amplitudes before difference-over-sum computations. “B” signals thus require no correction.

Note that using the average ratio method, as was done here to define and remove systematic measurement system errors, produces slightly different results from using the average decibel value as was done to generate data for Figures 9-11 and 16-18 in this note. These differences are insignificant in terms of absolute position (~5 microns) since the systematic corrections are small to start, ~0.03 mm equivalent beam position, and the difference between the two methods is only about 15%.

Conclusion

Relative electrical signal transmission coefficients were measured for all Main Injector BPM tunnel-to-service building cable pairs. The results met several ‘sanity checks’ and are presented here from numerous perspectives. The equivalent position offsets due to the measured cable mismatches are compared to the classical electronic offsets used in the original MI BPM system. A table of gain correction factors to compensate for the transmission unbalance of each cable pair at 2.5 MHz and at 53 MHz is provided.

Appendix 1 –

Received signal amplitudes and phases from fitted data

This is a listing of file "_outputfile.txt", the observed signal amplitudes and phases for 215 BPM cable pairs from the fitted oscilloscope data taken in March and May 2006. Column 1 is the MI lattice BPM location, Columns 2 and 3 are the observed 2.5 MHz signal amplitudes from the A and B cables respectively (in volts), Columns 4 and 5 are the observed "A" and "B" signal amplitudes (in volts) at 53 MHz, and Columns 6 and 7 are the observed "A" and "B" 53 MHz signal phases (in degrees) relative to the oscilloscope reference. Horizontal locations are listed first, followed by vertical locations.

```
// Datafile written by Mathcad
// 05/31/06 13:00:14

.MATRIX 0 0 216 7
 "  BPM " "   A2.5v " "  B2.5v  " "  A53v  " "  B53v  " " A53deg " " B53deg"
 "HP100"       2.81      2.821      2.029      2.036       4.41      5.242
 "HP101"      2.889      2.904      2.242       2.25      4.793      6.251
 "HP102"      2.921      2.932      2.458      2.473      4.233      5.112
 "HP104"      2.883      2.897       2.18      2.198      4.533      6.681
 "HP106"      2.791      2.803      1.886      1.897      3.937      4.426
 "HP108"       2.75      2.757      1.658      1.667      3.751      4.131
 "HP110"      2.661      2.668      1.387      1.384      2.985      3.992
 "HP112"      2.547      2.574      1.087       1.13      2.439      4.564
 "HP114"       2.23      2.224     0.5083     0.4887      18.13      33.56
 "HP116"      2.303      2.278     0.5462     0.4797      17.05      39.78
 "HP118"      2.361      2.372     0.6878      0.759      13.58   -0.02048
 "HP120"      2.475      2.481     0.8706     0.8407      14.11      30.74
 "HP122"      2.565      2.608      1.046      1.099      12.17      11.63
 "HP124"      2.678      2.676      1.284      1.223      9.981      6.749
 "HP126"      2.721      2.738      1.483      1.555      8.422      18.77
 "HP128"      2.866       2.88       1.89      1.911      6.234      8.159
 "HP130"      3.003      3.007      2.273      2.318      5.459      8.904
 "HP202"      2.969      2.977      2.268      2.296      5.735       7.38
 "HP204"      2.838      2.847       1.85      1.866      6.096      8.205
 "HP206"      2.724      2.729      1.503      1.487      9.242      8.961
 "HP208"      2.616      2.651      1.255       1.23      11.05      5.272
 "HP210"      2.576      2.579      1.052     0.9596      13.03     -3.751
 "HP212"      2.477      2.481     0.8338     0.8492      15.64      33.96
 "HP214"       2.38      2.374     0.7073     0.7083      13.27      15.11
 "HP216"      2.281      2.303     0.5738     0.4714      7.781     -16.71
 "HP218"      2.247       2.28     0.4507     0.5133      20.27      42.83
 "HP220"      2.275       2.28     0.5078     0.5152      18.51      18.73
 "HP222"       2.34      2.358     0.8473      0.847      14.57      17.29
 "HP224"      2.406      2.424     0.7887     0.7448      12.87      14.86
 "HP226"      2.496       2.51     0.8824     0.9176      11.46      16.08
 "HP228"      2.548      2.557      1.069       1.08       13.9      24.34
 "HP230"      2.655      2.676      1.211      1.268      12.18      15.53
 "HP232"       2.75      2.766       1.49      1.502      8.222      8.938
 "HP302"       2.83      2.848      1.797      1.825      5.664      6.973
 "HP304"      2.963      2.979      2.268      2.301      4.519        6.6
 "HP306"      2.977      2.975      2.349      2.298      4.584      4.656
 "HP308"      2.844       2.86      1.884      1.955        4.4      7.105
 "HP310"      2.741      2.756       1.56      1.606      7.437      10.03
 "HP312"      2.702      2.723      1.321      1.406      8.967       11.5
```

"HP314"	2.591	2.611	1.177	1.216	9.746	6.429
"HP316"	2.513	2.555	0.9101	0.954	12.77	12.84
"HP318"	2.453	2.482	0.8784	0.9154	13.31	2.027
"HP320"	2.393	2.401	0.7408	0.748	11.25	12.65
"HP321"	2.324	2.334	0.68	0.68	12.11	15.33
"HP322"	2.293	2.314	0.5955	0.6195	14.04	8.755
"HP324"	2.071	2.093	0.3038	0.2962	24.33	26.88
"HP326"	2.162	2.174	0.4009	0.3614	22.74	8.113
"HP328"	2.208	2.23	0.4446	0.4641	20.72	10.62
"HP330"	2.266	2.276	0.5594	0.545	16.95	-2.628
"HP332"	2.331	2.373	0.6558	0.6662	14.7	-0.8405
"HP334"	2.473	2.479	0.8053	0.7616	16.84	11.38
"HP336"	2.586	2.598	1.036	1.066	13.54	21.59
"HP338"	2.612	2.634	1.227	1.189	12.18	8.646
"HP340"	2.683	2.718	1.482	1.514	10.59	13.37
"HP400"	2.807	2.823	1.711	1.72	8.881	11.48
"HP402"	2.847	2.847	2.155	2.18	5.578	6.515
"HP404"	2.947	2.964	2.472	2.497	4.522	4.013
"HP406"	2.896	2.916	2.116	2.135	4.511	5.159
"HP408"	2.798	2.836	1.807	1.835	4.837	6.251
"HP410"	2.616	2.715	1.319	1.532	3.905	2.883
"HP412"	2.655	2.662	1.239	1.259	4.214	6.91
"HP414"	2.237	2.21	0.5231	0.4256	17.58	33.92
"HP416"	2.307	2.312	0.6265	0.637	14.82	25.89
"HP418"	2.366	2.378	0.6405	0.6562	14.36	6.6
"HP420"	2.451	2.458	0.9277	0.9206	14.96	16.32
"HP422"	2.55	2.553	0.9952	0.9736	13.71	17.11
"HP424"	2.664	2.658	1.353	1.319	10.86	13.07
"HP426"	2.722	2.753	1.534	1.639	6.234	12.85
"HP428"	2.8	2.818	1.848	1.831	8.743	5.673
"HP430"	2.929	2.95	2.278	2.268	4.283	4.729
"HP502"	2.915	2.933	2.243	2.231	4.407	7.162
"HP504"	2.793	2.822	1.814	1.944	4.291	6.772
"HP506"	2.677	2.694	1.458	1.479	10.85	11.2
"HP508"	2.632	2.645	1.193	1.299	12.35	24.3
"HP510"	2.531	2.549	0.9303	0.9767	15.4	16.99
"HP512"	2.444	2.45	0.9511	0.8412	14.78	7.477
"HP514"	2.351	2.349	0.7559	0.7211	17.88	28.67
"HP516"	2.282	2.293	0.4844	0.5465	19.6	18.13
"HP518"	2.205	2.228	0.4328	0.5279	21.59	12.18
"HP520"	2.466	2.484	0.7904	0.7965	13.85	20.28
"HP522"	2.559	2.579	1.141	1.153	10.71	12.84
"HP524"	2.602	2.654	1.103	1.165	9.826	5.241
"HP526"	2.7	2.715	1.317	1.333	8.113	9.402
"HP528"	2.81	2.831	1.666	1.689	6.555	7.156
"HP530"	2.861	2.88	2.071	2.094	5.011	3.183
"HP532"	2.963	2.983	2.309	2.326	4.953	5.154
"HP602"	3.037	3.059	2.71	2.739	3.826	6.795
"HP604"	2.963	2.972	2.21	2.215	5.406	7.277
"HP606"	2.989	3.004	2.64	2.656	4.993	5.452
"HP608"	3.03	3.036	2.713	2.733	3.87	4.657
"HP610"	2.961	2.973	2.228	2.234	7.953	9.374
"HP612"	2.835	2.845	2.007	2.022	7.901	9.207
"HP614"	2.8	2.81	1.735	1.743	9.179	9.654
"HP616"	2.695	2.702	1.32	1.313	11.41	14.28
"HP618"	2.614	2.63	1.255	1.271	11.55	10.28
"HP620"	2.55	2.56	1.147	1.178	12.62	7.947
"HP622"	2.445	2.458	0.7845	0.7848	21.46	18.68
"HP624"	2.131	2.132	0.4276	0.3618	24.2	10.54
"HP626"	2.19	2.224	0.3981	0.5133	20.85	35.36
"HP628"	2.221	2.221	0.5673	0.5346	15.73	34.3
"HP630"	2.319	2.376	0.6118	0.7317	14.47	6.423
"HP632"	2.441	2.461	0.8638	0.8822	14.58	17.82

"HP634"	2.535	2.551	1.043	1.054	12.58	14.47
"HP636"	2.597	2.618	1.262	1.269	10.19	14.7
"HP638"	2.67	2.685	1.499	1.547	11.37	15.11
"HP640"	2.759	2.775	1.745	1.767	3.842	6.01
"VP101"	2.907	2.921	2.242	2.25	4.793	6.251
"VP103"	2.911	2.923	2.413	2.42	4.628	5.896
"VP105"	2.817	2.834	2.046	2.059	4.125	5.005
"VP107"	2.779	2.798	1.769	1.783	4.142	4.793
"VP109"	2.666	2.687	1.508	1.532	3.461	4.262
"VP111"	2.577	2.594	1.224	1.22	2.979	1.22
"VP113"	2.5	2.513	1.003	1.04	13.97	14.74
"VP115"	2.235	2.303	0.478	0.5328	19.15	9.047
"VP117"	2.378	2.363	0.6683	0.6198	14.07	34.94
"VP119"	2.43	2.472	0.7206	0.7673	13.17	0.2582
"VP121"	2.511	2.529	0.9915	1.03	12.89	8.508
"VP123"	2.612	2.601	1.173	1.163	11.04	14.01
"VP125"	2.724	2.738	1.318	1.376	10.07	10.98
"VP127"	2.822	2.815	1.71	1.701	7.231	10.21
"VP129"	2.881	2.899	2.078	2.096	6.429	3.276
"VP201"	2.969	2.988	2.491	2.52	5.247	7.466
"VP203"	2.885	2.89	2.067	2.053	6.079	4.857
"VP205"	2.812	2.82	1.691	1.701	6.606	5.071
"VP207"	2.693	2.697	1.367	1.335	9.878	7.225
"VP209"	2.591	2.591	1.153	1.148	12.38	2.719
"VP211"	2.466	2.484	0.9305	0.8955	14.27	2.307
"VP213"	2.449	2.475	0.7692	0.7983	16.63	19.54
"VP215"	2.368	2.361	0.6089	0.6335	15.42	39.26
"VP217"	2.273	2.257	0.4835	0.5378	18.82	38.94
"VP219"	2.217	2.204	0.4307	0.3739	21.02	20.47
"VP221"	2.289	2.31	0.5485	0.5548	17.72	21.78
"VP222"	2.389	2.399	0.8473	0.847	14.57	17.29
"VP223"	2.406	2.419	0.6899	0.6929	14.57	12.4
"VP225"	2.449	2.447	0.9301	0.8192	11.19	1.239
"VP227"	2.539	2.544	0.9846	0.999	10.42	11.87
"VP229"	2.628	2.648	1.186	1.222	12.4	17.21
"VP231"	2.677	2.693	1.426	1.449	10.64	11.95
"VP301"	2.764	2.834	1.587	1.636	7.042	6.096
"VP303"	2.883	2.901	2.058	2.157	5.218	11.61
"VP305"	2.975	2.995	2.578	2.589	3.999	4.42
"VP307"	2.902	2.916	2.075	2.066	4.173	2.535
"VP309"	2.837	2.825	1.747	1.69	6.113	5.77
"VP311"	2.698	2.711	1.471	1.393	8.256	-2.726
"VP313"	2.665	2.694	1.207	1.421	9.649	19.34
"VP315"	2.561	2.597	1.004	1.094	11.26	15.11
"VP317"	2.488	2.505	0.865	0.874	13.71	14.3
"VP319"	2.436	2.467	0.8136	0.8278	14.54	9.368
"VP321"	2.337	2.349	0.68	0.68	12.11	15.33
"VP323"	2.247	2.291	0.5572	0.5883	15.38	7.03
"VP325"	2.136	2.142	0.3325	0.3205	22.53	11.47
"VP327"	2.161	2.169	0.3925	0.4255	22.93	52.35
"VP329"	2.252	2.266	0.5049	0.5089	18.61	34.39
"VP331"	2.327	2.362	0.5771	0.6094	13.88	16.15
"VP333"	2.407	2.421	0.7054	0.7251	13.8	17.65
"VP335"	2.479	2.482	0.8546	0.9115	16.04	34.13
"VP337"	2.556	2.612	1.102	1.1	13.15	14.23
"VP339"	2.695	2.717	1.318	1.291	11.73	11.88
"VP341"	2.741	2.745	1.592	1.582	9.591	6.4
"VP401"	2.813	2.828	1.85	1.935	8.205	12.75
"VP402"	2.876	2.89	2.155	2.18	5.578	6.515
"VP403"	2.981	3	2.299	2.294	4.33	3.502
"VP405"	2.937	2.961	2.271	2.312	4.796	6.211
"VP407"	2.833	2.859	1.951	1.972	4.863	6.108
"VP409"	2.783	2.805	1.517	1.639	4.668	12.9

"VP411"	2.635	2.694	1.138	1.409	4.572	-9.11
"VP413"	2.58	2.575	1.104	1.136	13.12	18.85
"VP415"	2.241	2.258	0.567	0.5732	16.43	23.54
"VP417"	2.318	2.323	0.5811	0.5738	15.99	13.35
"VP419"	2.445	2.44	0.838	0.8456	15.73	25.2
"VP421"	2.489	2.529	0.8865	1.034	14.99	13.79
"VP423"	2.567	2.58	1.107	1.082	12.8	17.56
"VP425"	2.672	2.696	1.413	1.465	10.69	26.81
"VP427"	2.79	2.792	1.662	1.657	9.826	27.59
"VP429"	2.875	2.888	2.048	2.06	4.52	2.552
"VP501"	2.943	2.958	2.527	2.543	4.324	5.942
"VP503"	2.863	2.88	2.028	2.044	4.25	6.354
"VP505"	2.769	2.788	1.596	1.63	10.32	12.42
"VP507"	2.662	2.684	1.297	1.336	11.92	12.77
"VP509"	2.555	2.574	1.042	1.091	13.58	15.09
"VP511"	2.49	2.515	0.8867	1.039	15.99	19.02
"VP513"	2.397	2.438	0.7709	0.8345	17.8	2.644
"VP515"	2.329	2.323	0.6789	0.609	14.38	26.6
"VP517"	2.252	2.258	0.5848	0.5137	16.53	11.87
"VP519"	2.178	2.197	0.4678	0.42	20.65	5.061
"VP521"	2.522	2.536	0.9091	0.9052	12.14	11.29
"VP522"	2.559	2.574	1.141	1.153	10.71	12.84
"VP523"	2.558	2.575	1.031	1.025	10.74	13.1
"VP525"	2.684	2.698	1.205	1.206	9.053	12.21
"VP527"	2.749	2.759	1.497	1.533	6.83	10.87
"VP529"	2.831	2.876	1.914	1.938	5.396	6.091
"VP531"	2.954	2.938	2.247	2.13	4.716	6.308
"VP601"	2.974	2.991	2.494	2.526	4.112	6.154
"VP603"	2.981	3.001	2.445	2.453	4.248	4.595
"VP605"	2.869	2.893	1.978	1.994	5.68	5.89
"VP607"	2.974	2.982	2.468	2.479	7.11	7.701
"VP608"	3.004	3.019	2.713	2.733	3.87	4.657
"VP609"	2.968	2.979	2.383	2.409	7.277	8.279
"VP611"	2.919	2.924	2.079	2.108	8.434	11.04
"VP613"	2.834	2.84	1.75	1.788	9.706	13.6
"VP615"	2.71	2.72	1.452	1.45	9.941	12.24
"VP617"	2.662	2.672	1.193	1.192	11.91	12.88
"VP619"	2.571	2.577	1.029	1.024	11.51	13.4
"VP620"	2.526	2.547	1.147	1.178	12.62	7.947
"VP621"	2.487	2.498	0.8529	0.8604	20.08	18.07
"VP623"	2.43	2.446	0.7106	0.7351	23.44	21.7
"VP625"	2.16	2.161	0.4687	0.4636	18.26	20.57
"VP627"	2.216	2.229	0.5441	0.546	16.23	16.62
"VP629"	2.304	2.322	0.6431	0.6656	13.93	17.29
"VP631"	2.408	2.411	0.8116	0.768	15.26	16.7
"VP633"	2.469	2.465	0.8382	0.8345	15.13	16.84
"VP635"	2.565	2.575	1.114	1.149	11.75	15.28
"VP637"	2.649	2.662	1.378	1.407	12	12.79
"VP639"	2.735	2.737	1.643	1.645	10.65	12.14
"VP641"	2.787	2.804	1.887	1.899	4.348	4.803

Appendix 2 –

Phases of received signals

This is a listing of file “_phases.txt”, the measured transmission phases for signals through 215 MI BPM cable pairs from the fitted oscilloscope data taken in March and May 2006. Column 1 is the MI lattice BPM location, Columns 2 and 3 are the observed 2.5 MHz signal phases (in degrees) from the “A” and “B” cables respectively, and Columns 4 and 5 are the observed 53 MHz “A” and “B” signal phases (in degrees). Horizontal locations are listed first, followed by vertical locations.

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// Datafile written by Mathcad
// 05/31/06 13:00:14

.MATRIX 0 0 216 5
 " BPM     " "     A2.5deg " "       B2.5deg " "       A53deg " "       B53deg "
 "HP100"        -0.06394         -0.2755           4.41           5.242
 "HP101"           3.002           2.971          4.793           6.251
 "HP102"         -0.3376         -0.4415          4.233           5.112
 "HP104"          0.2338          0.3546          4.533           6.681
 "HP106"         -0.2562         -0.4322          3.937           4.426
 "HP108"         -0.4834         -0.5494          3.751           4.131
 "HP110"          -0.086         -0.3252          2.985           3.992
 "HP112"        -0.06698         -0.3009          2.439           4.564
 "HP114"           1.596           1.951          18.13           33.56
 "HP116"           1.298           1.196          17.05           39.78
 "HP118"           1.687           1.357          13.58        -0.02048
 "HP120"           2.508           2.687          14.11           30.74
 "HP122"           2.639           3.571          12.17           11.63
 "HP124"            2.41            1.69          9.981           6.749
 "HP126"           2.986           3.201          8.422           18.77
 "HP128"           2.677            2.28          6.234           8.159
 "HP130"           2.469           2.511          5.459           8.904
 "HP202"           2.597           2.676          5.735            7.38
 "HP204"           2.648           2.703          6.096           8.205
 "HP206"           2.149           1.972          9.242           8.961
 "HP208"           1.423           1.283          11.05           5.272
 "HP210"           1.622          0.5775          13.03          -3.751
 "HP212"           1.967           2.212          15.64           33.96
 "HP214"           1.474           1.276          13.27           15.11
 "HP216"           1.894        -0.01656          7.781          -16.71
 "HP218"           1.375           2.654          20.27           42.83
 "HP220"          0.1157         0.01029          18.51           18.73
 "HP222"         -0.3481         -0.4452          14.57           17.29
 "HP224"         -0.8932         -0.8887          12.87           14.86
 "HP226"         -0.5382         -0.3847          11.46           16.08
 "HP228"          0.2276          0.7162           13.9           24.34
 "HP230"          0.7059          0.9763          12.18           15.53
 "HP232"           2.343           2.181          8.222           8.938
 "HP302"           2.938           2.833          5.664           6.973
 "HP304"           2.595           2.429          4.519             6.6
 "HP306"           2.036           1.848          4.584           4.656
 "HP308"           2.989           3.228            4.4           7.105
 "HP310"           2.263           1.909          7.437           10.03
 "HP312"           3.113            2.98          8.967            11.5
 "HP314"           3.007           2.682          9.746           6.429
 "HP316"           3.186            3.49          12.77           12.84
 "HP318"           3.158           2.649          13.31           2.027
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"HP320"	3.716	3.791	11.25	12.65
"HP321"	0.868	0.8663	12.11	15.33
"HP322"	3.865	3.44	14.04	8.755
"HP324"	1.328	0.6056	24.33	26.88
"HP326"	0.8881	0.0008646	22.74	8.113
"HP328"	-0.4231	-0.5821	20.72	10.62
"HP330"	-0.6176	-1.585	16.95	-2.628
"HP332"	-0.2969	-1.284	14.7	-0.8405
"HP334"	-0.4517	-1.372	16.84	11.38
"HP336"	0.4347	0.3558	13.54	21.59
"HP338"	0.3533	-0.4832	12.18	8.646
"HP340"	0.3841	0.5936	10.59	13.37
"HP400"	0.581	0.7741	8.881	11.48
"HP402"	0.3013	0.2515	5.578	6.515
"HP404"	0.9689	0.8067	4.522	4.013
"HP406"	0.6325	0.5541	4.511	5.159
"HP408"	0.7603	0.656	4.837	6.251
"HP410"	0.171	2.554	3.905	2.883
"HP412"	0.7225	0.4173	4.214	6.91
"HP414"	0.9121	0.4475	17.58	33.92
"HP416"	0.6675	1.219	14.82	25.89
"HP418"	0.8806	0.417	14.36	6.6
"HP420"	1.058	1.156	14.96	16.32
"HP422"	0.8995	0.7981	13.71	17.11
"HP424"	0.9838	0.6732	10.86	13.07
"HP426"	0.7769	1.219	6.234	12.85
"HP428"	0.03668	-0.2379	8.743	5.673
"HP430"	-0.005781	-0.2567	4.283	4.729
"HP502"	-0.0485	-0.2468	4.407	7.162
"HP504"	-0.08858	0.2347	4.291	6.772
"HP506"	-0.1343	-0.08291	10.85	11.2
"HP508"	0.7254	0.6864	12.35	24.3
"HP510"	0.7792	1.18	15.4	16.99
"HP512"	1.054	0.1654	14.78	7.477
"HP514"	0.9884	1.336	17.88	28.67
"HP516"	-0.09207	0.4231	19.6	18.13
"HP518"	-0.1254	0.5913	21.59	12.18
"HP520"	3.932	3.884	13.85	20.28
"HP522"	3.792	3.784	10.71	12.84
"HP524"	3.598	4.479	9.826	5.241
"HP526"	3.916	3.824	8.113	9.402
"HP528"	2.893	2.751	6.555	7.156
"HP530"	2.389	1.905	5.011	3.183
"HP532"	2.657	2.597	4.953	5.154
"HP602"	3.492	3.638	3.826	6.795
"HP604"	3.868	3.666	5.406	7.277
"HP606"	4.98	4.918	4.993	5.452
"HP608"	2.781	2.909	3.87	4.657
"HP610"	2.937	2.818	7.953	9.374
"HP612"	2.904	2.976	7.901	9.207
"HP614"	2.522	2.608	9.179	9.654
"HP616"	3.426	3.291	11.41	14.28
"HP618"	2.965	3.045	11.55	10.28
"HP620"	3.096	4.096	12.62	7.947
"HP622"	2.9	2.483	21.46	18.68
"HP624"	-0.9832	-2.278	24.2	10.54
"HP626"	1.306	2.551	20.85	35.36
"HP628"	1.568	2.182	15.73	34.3
"HP630"	1.553	2.424	14.47	6.423
"HP632"	1.364	1.306	14.58	17.82
"HP634"	1.218	1.14	12.58	14.47
"HP636"	0.8715	0.7855	10.19	14.7
"HP638"	-0.2283	-0.01851	11.37	15.11

"HP640"	-0.7185	-0.6262	3.842	6.01
"VP101"	-0.2795	-0.3652	4.793	6.251
"VP103"	-0.6303	-0.8772	4.628	5.896
"VP105"	-0.09958	-0.09379	4.125	5.005
"VP107"	-0.3416	-0.4918	4.142	4.793
"VP109"	0.057	-0.1625	3.461	4.262
"VP111"	0.03123	-0.04978	2.979	1.22
"VP113"	0.3108	0.6016	13.97	14.74
"VP115"	1.626	2.24	19.15	9.047
"VP117"	1.456	2.004	14.07	34.94
"VP119"	1.882	1.965	13.17	0.2582
"VP121"	2.659	2.045	12.89	8.508
"VP123"	2.591	1.966	11.04	14.01
"VP125"	2.001	2.468	10.07	10.98
"VP127"	2.928	2.765	7.231	10.21
"VP129"	2.602	3.013	6.429	3.276
"VP201"	2.417	2.39	5.247	7.466
"VP203"	2.479	2.357	6.079	4.857
"VP205"	2.74	2.534	6.606	5.071
"VP207"	2.219	1.822	9.878	7.225
"VP209"	1.33	0.7173	12.38	2.719
"VP211"	1.525	0.9895	14.27	2.307
"VP213"	1.769	1.902	16.63	19.54
"VP215"	1.268	2.659	15.42	39.26
"VP217"	1.682	2.683	18.82	38.94
"VP219"	1.722	0.7099	21.02	20.47
"VP221"	-0.0478	-0.1313	17.72	21.78
"VP222"	2.472	2.439	14.57	17.29
"VP223"	-0.577	-0.7987	14.57	12.4
"VP225"	-0.4212	-1.922	11.19	1.239
"VP227"	-0.1228	-0.1023	10.42	11.87
"VP229"	0.5161	1.074	12.4	17.21
"VP231"	0.1463	-0.05798	10.64	11.95
"VP301"	2.999	2.903	7.042	6.096
"VP303"	2.778	3.332	5.218	11.61
"VP305"	2.075	1.955	3.999	4.42
"VP307"	2.538	2.339	4.173	2.535
"VP309"	2.275	2.653	6.113	5.77
"VP311"	2.085	1.391	8.256	-2.726
"VP313"	2.875	5.329	9.649	19.34
"VP315"	3.831	3.751	11.26	15.11
"VP317"	3.24	3.327	13.71	14.3
"VP319"	2.936	2.148	14.54	9.368
"VP321"	3.98	4.022	12.11	15.33
"VP323"	4.136	3.881	15.38	7.03
"VP325"	1.435	0.6939	22.53	11.47
"VP327"	0.7638	1.507	22.93	52.35
"VP329"	-0.6062	-0.01516	18.61	34.39
"VP331"	-0.6841	-0.4744	13.88	16.15
"VP333"	-0.1521	-0.2077	13.8	17.65
"VP335"	-0.01442	0.8549	16.04	34.13
"VP337"	0.7529	0.5094	13.15	14.23
"VP339"	0.4673	0.351	11.73	11.88
"VP341"	0.6394	0.2076	9.591	6.4
"VP401"	0.6136	1.209	8.205	12.75
"VP402"	2.721	2.717	5.578	6.515
"VP403"	1.362	0.9316	4.33	3.502
"VP405"	0.6537	0.6257	4.796	6.211
"VP407"	0.336	0.3089	4.863	6.108
"VP409"	0.4489	0.8331	4.668	12.9
"VP411"	0.8703	1.966	4.572	-9.11
"VP413"	0.4695	0.6767	13.12	18.85
"VP415"	1.137	1.44	16.43	23.54

"VP417"	0.4439	0.2566	15.99	13.35
"VP419"	0.9213	1.529	15.73	25.2
"VP421"	0.7769	1.328	14.99	13.79
"VP423"	1.082	1.022	12.8	17.56
"VP425"	0.8382	1.624	10.69	26.81
"VP427"	-0.3024	0.4648	9.826	27.59
"VP429"	-0.02802	-0.1682	4.52	2.552
"VP501"	-0.07145	-0.09047	4.324	5.942
"VP503"	0.06131	0.002969	4.25	6.354
"VP505"	-0.177	-0.1697	10.32	12.42
"VP507"	-0.3357	-0.1663	11.92	12.77
"VP509"	0.978	1.334	13.58	15.09
"VP511"	0.4147	1.349	15.99	19.02
"VP513"	0.7036	0.7998	17.8	2.644
"VP515"	0.5537	0.6314	14.38	26.6
"VP517"	0.3095	-0.6904	16.53	11.87
"VP519"	0.24	-0.217	20.65	5.061
"VP521"	3.523	3.515	12.14	11.29
"VP522"	4.819	4.893	10.71	12.84
"VP523"	3.775	3.83	10.74	13.1
"VP525"	3.661	3.56	9.053	12.21
"VP527"	3.828	3.948	6.83	10.87
"VP529"	2.985	2.738	5.396	6.091
"VP531"	2.434	2.887	4.716	6.308
"VP601"	2.476	2.458	4.112	6.154
"VP603"	3.733	3.604	4.248	4.595
"VP605"	3.799	3.757	5.68	5.89
"VP607"	2.94	2.983	7.11	7.701
"VP608"	1.722	1.66	3.87	4.657
"VP609"	2.858	2.826	7.277	8.279
"VP611"	3.008	2.753	8.434	11.04
"VP613"	2.409	2.432	9.706	13.6
"VP615"	2.379	2.449	9.941	12.24
"VP617"	3.031	2.988	11.91	12.88
"VP619"	2.912	3.029	11.51	13.4
"VP620"	1.501	1.345	12.62	7.947
"VP621"	2.907	2.616	20.08	18.07
"VP623"	2.739	2.576	23.44	21.7
"VP625"	-0.3425	-0.5382	18.26	20.57
"VP627"	1.331	0.7981	16.23	16.62
"VP629"	1.207	1.493	13.93	17.29
"VP631"	1.371	0.8388	15.26	16.7
"VP633"	0.8944	0.53	15.13	16.84
"VP635"	1.016	1.274	11.75	15.28
"VP637"	-0.05673	-0.005584	12	12.79
"VP639"	-0.6979	-0.9861	10.65	12.14
"VP641"	-0.5552	-0.7511	4.348	4.803

Appendix 3 –

Transmitted signal amplitude ratios and gain correction factors

This is a listing of the file "_normalized_ratios.txt," the zero-biased (normalized to unity) Main Injector BPM cable pair transmission ratios at 2.5 and at 53 MHz from the fitted oscilloscope data taken in March and May 2006.

These ratios represent the amplitude of observed "B" cable test signals to observed "A" cable test signals, |B|/|A|, for each cable pair after normalization to force the average ratio to unity for each test frequency. (Normalizing factors were 1.006 at 2.5 MHz and 1.013 at 53 MHz). Cable pair mismatches can be compensated in beam position computations by multiplying "A" beam signal amplitudes by the respective values in this listing.

```
// Datafile written by Mathcad
// 05/31/06 13:00:14

.MATRIX 0 0 216 3
 " BPM              " "       2.5MHz_B/A_xmsn        " "        53MHz_B/A_xmsn"
 "HP100"                             0.9981                                0.9905
 "HP101"                             0.9993                                0.9907
 "HP102"                             0.9979                                0.9932
 "HP104"                              0.999                                0.9953
 "HP106"                             0.9984                                0.9929
 "HP108"                             0.9967                                0.9925
 "HP110"                             0.9968                                 0.985
 "HP112"                              1.005                                 1.026
 "HP114"                             0.9915                                0.9491
 "HP116"                             0.9834                                 0.867
 "HP118"                             0.9988                                 1.089
 "HP120"                             0.9966                                0.9532
 "HP122"                              1.011                                 1.037
 "HP124"                             0.9934                                0.9402
 "HP126"                                  1                                 1.035
 "HP128"                              0.999                                0.9981
 "HP130"                             0.9955                                 1.007
 "HP202"                             0.9968                                0.9993
 "HP204"                             0.9973                                0.9957
 "HP206"                              0.996                                0.9766
 "HP208"                              1.007                                0.9675
 "HP210"                             0.9953                                0.9004
 "HP212"                             0.9958                                 1.005
 "HP214"                             0.9917                                0.9885
 "HP216"                              1.004                                 0.811
 "HP218"                              1.009                                 1.124
 "HP220"                             0.9963                                 1.002
 "HP222"                              1.002                                0.9868
 "HP224"                              1.002                                0.9322
 "HP226"                             0.9997                                 1.027
 "HP228"                             0.9977                                0.9973
 "HP230"                              1.002                                 1.034
 "HP232"                             0.9999                                0.9951
 "HP302"                                  1                                 1.003
 "HP304"                             0.9995                                 1.002
 "HP306"                             0.9935                                0.9657
```

"HP308"	0.9998	1.024
"HP310"	0.9996	1.016
"HP312"	1.002	1.051
"HP314"	1.002	1.02
"HP316"	1.011	1.035
"HP318"	1.006	1.029
"HP320"	0.9975	0.9967
"HP321"	0.9984	0.9871
"HP322"	1.003	1.027
"HP324"	1.005	0.9624
"HP326"	0.9997	0.8899
"HP328"	1.004	1.03
"HP330"	0.9985	0.9617
"HP332"	1.012	1.003
"HP334"	0.9966	0.9336
"HP336"	0.9988	1.016
"HP338"	1.003	0.9566
"HP340"	1.007	1.008
"HP400"	0.9998	0.9923
"HP402"	0.9942	0.9986
"HP404"	0.9999	0.9971
"HP406"	1.001	0.996
"HP408"	1.008	1.002
"HP410"	1.032	1.147
"HP412"	0.9968	1.003
"HP414"	0.9822	0.8032
"HP416"	0.9963	1.004
"HP418"	0.9992	1.011
"HP420"	0.997	0.9796
"HP422"	0.9953	0.9657
"HP424"	0.9919	0.9623
"HP426"	1.005	1.055
"HP428"	1.001	0.9781
"HP430"	1.001	0.9828
"HP502"	1	0.9819
"HP504"	1.004	1.058
"HP506"	1	1.001
"HP508"	0.9991	1.075
"HP510"	1.001	1.036
"HP512"	0.9966	0.8731
"HP514"	0.9933	0.9417
"HP516"	0.999	1.114
"HP518"	1.005	1.204
"HP520"	1.001	0.9948
"HP522"	1.002	0.9975
"HP524"	1.014	1.043
"HP526"	0.9997	0.9991
"HP528"	1.002	1.001
"HP530"	1.001	0.9981
"HP532"	1.001	0.9944
"HP602"	1.001	0.9977
"HP604"	0.9972	0.9894
"HP606"	0.9991	0.9931
"HP608"	0.9961	0.9944
"HP610"	0.9982	0.9898
"HP612"	0.9977	0.9945
"HP614"	0.9977	0.9917
"HP616"	0.9967	0.9819
"HP618"	1	0.9997
"HP620"	0.9981	1.014
"HP622"	0.9994	0.9875
"HP624"	0.9946	0.8352
"HP626"	1.01	1.273

"HP628"	0.9942	0.9302
"HP630"	1.019	1.181
"HP632"	1.002	1.008
"HP634"	1	0.9976
"HP636"	1.002	0.9926
"HP638"	0.9997	1.019
"HP640"	0.9999	0.9996
"VP101"	0.9989	0.9907
"VP103"	0.9983	0.99
"VP105"	1	0.9934
"VP107"	1.001	0.995
"VP109"	1.002	1.003
"VP111"	1.001	0.9839
"VP113"	0.9993	1.024
"VP115"	1.024	1.1
"VP117"	0.9879	0.9155
"VP119"	1.011	1.051
"VP121"	1.001	1.025
"VP123"	0.99	0.9787
"VP125"	0.9993	1.031
"VP127"	0.9917	0.9819
"VP129"	1	0.9957
"VP201"	1.001	0.9986
"VP203"	0.9959	0.9805
"VP205"	0.997	0.993
"VP207"	0.9956	0.964
"VP209"	0.9942	0.9829
"VP211"	1.001	0.95
"VP213"	1.005	1.024
"VP215"	0.9912	1.027
"VP217"	0.9872	1.098
"VP219"	0.9883	0.857
"VP221"	1.003	0.9985
"VP222"	0.9983	0.9868
"VP223"	0.9995	0.9914
"VP225"	0.9933	0.8694
"VP227"	0.9961	1.002
"VP229"	1.002	1.017
"VP231"	1	1.003
"VP301"	1.019	1.018
"VP303"	1	1.035
"VP305"	1.001	0.9914
"VP307"	0.999	0.9829
"VP309"	0.99	0.9549
"VP311"	0.9989	0.9348
"VP313"	1.005	1.162
"VP315"	1.008	1.076
"VP317"	1.001	0.9974
"VP319"	1.007	1.004
"VP321"	0.9993	0.9871
"VP323"	1.014	1.042
"VP325"	0.997	0.9515
"VP327"	0.9978	1.07
"VP329"	1	0.995
"VP331"	1.009	1.042
"VP333"	0.9999	1.015
"VP335"	0.9954	1.053
"VP337"	1.016	0.9854
"VP339"	1.002	0.9669
"VP341"	0.9956	0.9809
"VP401"	0.9995	1.032
"VP402"	0.999	0.9986
"VP403"	1	0.985

"VP405"	1.002	1.005
"VP407"	1.003	0.9978
"VP409"	1.002	1.067
"VP411"	1.016	1.222
"VP413"	0.9922	1.016
"VP415"	1.002	0.9979
"VP417"	0.9963	0.9747
"VP419"	0.9921	0.9961
"VP421"	1.01	1.151
"VP423"	0.9992	0.9649
"VP425"	1.003	1.023
"VP427"	0.9949	0.9842
"VP429"	0.9987	0.9929
"VP501"	0.9992	0.9934
"VP503"	1	0.9949
"VP505"	1.001	1.008
"VP507"	1.002	1.017
"VP509"	1.002	1.034
"VP511"	1.004	1.157
"VP513"	1.011	1.069
"VP515"	0.9916	0.8855
"VP517"	0.9968	0.8671
"VP519"	1.003	0.8863
"VP521"	0.9997	0.9829
"VP522"	1	0.9975
"VP523"	1.001	0.9814
"VP525"	0.9993	0.988
"VP527"	0.9978	1.011
"VP529"	1.01	0.9995
"VP531"	0.9888	0.9357
"VP601"	0.9998	0.9998
"VP603"	1.001	0.9904
"VP605"	1.002	0.9951
"VP607"	0.9968	0.9915
"VP608"	0.9991	0.9944
"VP609"	0.9978	0.9979
"VP611"	0.9959	1.001
"VP613"	0.9963	1.009
"VP615"	0.9978	0.9858
"VP617"	0.9979	0.9863
"VP619"	0.9965	0.9823
"VP620"	1.002	1.014
"VP621"	0.9986	0.9958
"VP623"	1.001	1.021
"VP625"	0.9946	0.9764
"VP627"	1	0.9906
"VP629"	1.002	1.022
"VP631"	0.9954	0.9341
"VP633"	0.9925	0.9828
"VP635"	0.998	1.018
"VP637"	0.999	1.008
"VP639"	0.9949	0.9883
"VP641"	1	0.9934