Simple Check on Calibration Booster BPMs B:HP24L and B:HP24S

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A simple check of the calibration of two Booster BPM readout channels was performed during the last week of March 2013. The readout channel consists of the RF Module that converts the difference in magnitude between the RF signals from the BPM plates into a voltage that is digitized and converted to a beam position by the front end crate processor.

The beam displacement from the center of the BPM in a single plane with no orthogonal displacement is predicted by

$$x = \frac{1}{s} \cdot 20\ Log\left(A/B \right) = \frac{1}{s} \cdot \left[20 Log(A) - 20 Log(B) \right] = \frac{1}{s} \cdot \left(A/B \right)_{dB}$$

Where

$x =$ displacement in mm.

$A =$ amplitude of the signal from plate A.

$B =$ amplitude of the signal from plate B.

$s =$ the detector position sensitivity in (dB/mm).

In deriving the ratio $\left(A/B \right)$ the RF module uses the amplitude modulation to phase modulation (AM/PM) technique. A simple explanation of this is given in Beams-doc-2757.

The formula that predicts the RF Module Position Voltage output given the difference in the magnitudes of the RF from BPM plate A and plate B, is given as

$$V_{POS} = \left(\frac{1}{F \cdot C_1} \right) \cdot \left[Arctan\left(10^{(F/20) \cdot (A/B)_{dB}} \right) - \frac{\pi}{4} \right] \qquad (1)$$

Where $F = 1.14,\ C_1 = 0.2974$

Position is computed in the digitizer crate front end processor using the digitized value of the position voltages. The relationship between the computed position and the position voltages is given as

$$Pos = \left(\frac{1}{s}\right)\left(\frac{20}{F}\right) \cdot Log_{10}\left[Tan\left(F \cdot C_1 \cdot V_{POS} + \frac{\pi}{4}\right)\right] \qquad (2)$$

Figure 1 Illustrates the setup for the test. A signal from one of the BPM plates, plate 'B' in this case, is split to both RF Module RF inputs. By varying the attenuation in each input channel, we vary the magnitude of the same signal into the 'A' and 'B' channels. We can then both predict the position voltage out and the position computed by the front-end processor using equations (1) and (2) above. We then compare the computed values to those measured on the scope and DMM and read from ACNET.

Not shown in the figure is the Local Oscillator signal input to the RF Module. This Local Oscillator RF signal sweeps in frequency with the Booster RF with an offset of +28.3 MHz. The RF Module uses this to mix the RF signals from the BPM plates down to this 28.2MHz intermittent frequency. A second set of tests on the BPM readout electronics uses a signal generator for the RF input in place of the actual BPM signal. For this case the input does not sweep in frequency and we must provide a second RF signal to act as the Local Oscillator.

Another thing to keep in mind when testing the RF Module is that the Plate 'A' and Plate 'B' RF inputs are required to be close in phase with one another for the signal processing method to work. This is why each leg from the signal splitter to the RF inputs are kept equal in length and we do not simply put an attenuator in one leg.

The tables of data that follow are explained in the paragraphs below them.

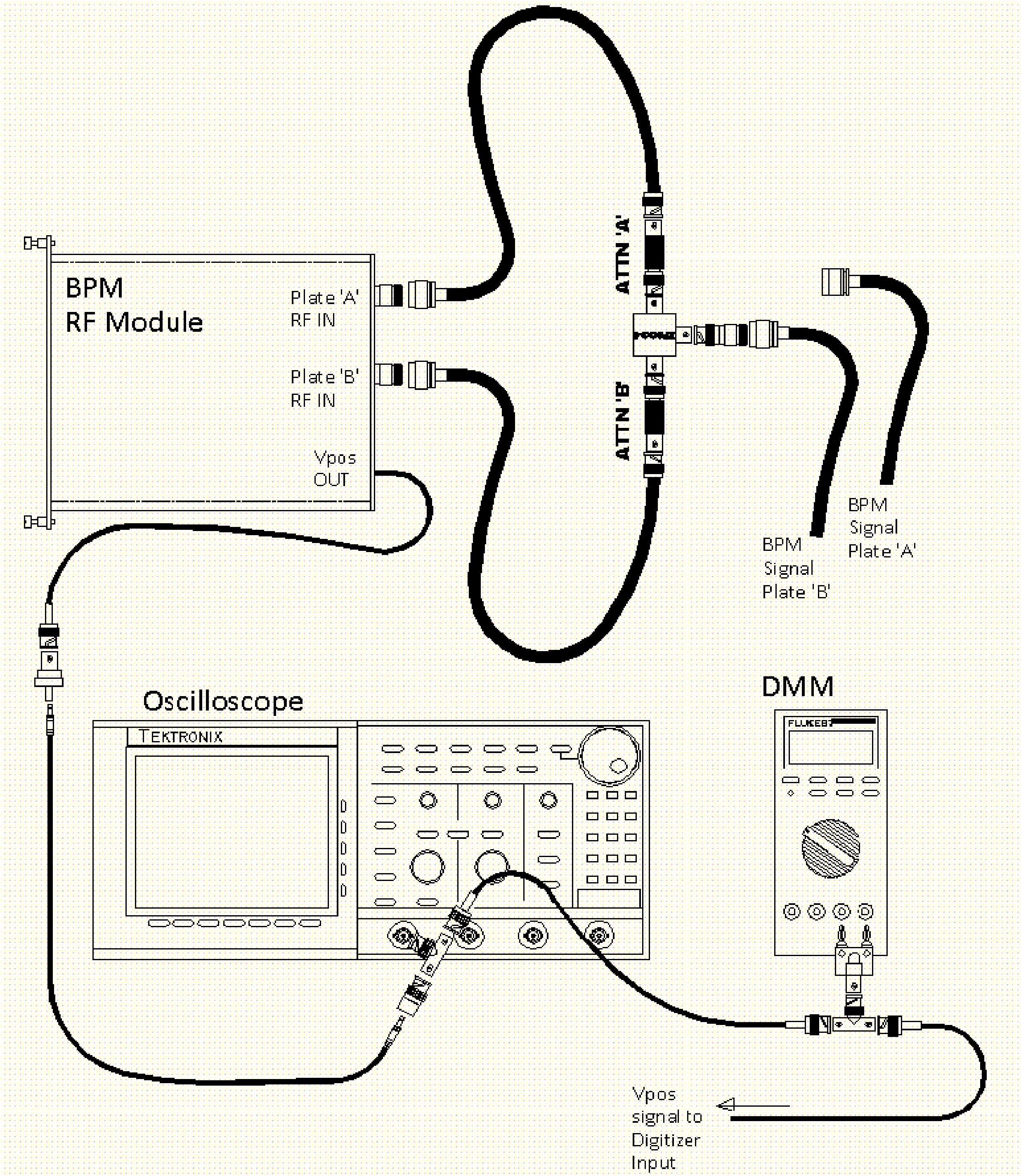

Figure 1. Illustration of the test setup.

Table 1 Computed values of RF Module Volts Out and Position

Delta, dB	Expected Volts	Pos for s=0.58 db/mm
0.00	0.0000	0.0000
1.00	0.1922	1.7172
2.03	0.3884	3.5000
3.00	0.5662	5.1724
4.00	0.7409	6.8966
5.00	0.9055	8.6259
6.00	1.0571	10.3448
7.00	1.1967	12.0690
8.00	1.3237	13.7931
9.00	1.4386	15.5224
10.00	1.5411	17.2414
11.00	1.6328	18.9655
12.00	1.7145	20.6897
13.00	1.7868	22.4138
14.00	1.8508	24.1379
15.00	1.9073	25.8621
16.00	1.9571	27.5862
17.00	2.0010	29.3103
18.00	2.0396	31.0345
19.06	2.0754	32.8621
20.00	2.1033	34.4828
21.00	2.1294	36.2069
22.00	2.1524	37.9310
23.00	2.1725	39.6552
24.00	2.1902	41.3793
25.00	2.2058	43.1034
26.00	2.2194	44.8276
27.00	2.2313	46.5517
28.00	2.2418	48.2759
29.00	2.2510	50.0000

The values in Table 1 are computed from equations (1) and (2), and were used as a lookup table for the data tables.

Table 2a Data taken using the Plate ‘B’ signal from Booster BPM B:HP24L

measured	ACNET				Computed Pos = f(volts)			
Delta, dB	Page Pos.				Expected Pos.	% Error		
	min	max	range	avg		avg	min	max
0.00	-0.400	0.040	0.440	-0.180	0.000			
1.00	1.500	1.570	0.070	1.535	1.717	11%	13%	9%
2.03	3.180	3.270	0.090	3.225	3.500	8%	9%	7%
5.00	7.600	7.970	0.370	7.785	8.626	10%	12%	8%
9.00	14.200	14.500	0.300	14.350	15.522	8%	9%	7%
19.06	31.200	31.800	0.600	31.500	32.862	4%	5%	3%
-19.06	-29.980	-29.500	0.480	-29.740	-32.862	10%	9%	10%
-9.00	-14.320	-14.030	0.290	-14.175	-15.522	9%	8%	10%
-5.00	-8.070	-7.840	0.230	-7.955	-8.626	8%	6%	9%
-2.03	-3.220	-2.780	0.440	-3.000	-3.500	14%	8%	21%
-1.00	-1.870	-1.610	0.260	-1.740	-1.717	-1%	-9%	6%

The first column corresponds with the difference between the values of attenuators inserted as ATTN ‘A’ and ATTN ‘B’. The next two columns are the minimum and maximum position readings for each case as observed on an ACNET page for several Booster acceleration cycles. The ‘range’ and ‘average’ columns are determined from the ‘min’ and ‘max’ values. The Expected position is that computed from equation (2) given Delta dB. The %Error is the Expected Position minus the measured value then divided by the Expected Position.

Table 2b Data taken using the Plate 'B' signal from Booster BPM B:HP24L

B:HP24L					
measured	Computed Volts = g(pos)				
Delta, dB	Volts given Page Pos.				+/- 5V 12 bit ADC
	min	max	range	avg	range in No. Bits
0.00	-0.045	0.004	0.049	-0.020	20
1.00	0.168	0.176	0.008	0.172	3
2.03	0.354	0.363	0.010	0.358	4
5.00	0.809	0.844	0.035	0.827	14
9.00	1.352	1.372	0.020	1.362	8
19.06	2.043	2.055	0.012	2.049	5
-19.06	-2.017	-2.005	0.011	-2.011	5
-9.00	-1.360	-1.340	0.020	-1.350	8
-5.00	-0.854	-0.832	0.022	-0.843	9
-2.03	-0.358	-0.310	0.048	-0.334	20
-1.00	-0.209	-0.180	0.029	-0.195	12

The table above ***computes*** the position voltage output of the RF Module based on the positions read off of the ACNET page. The final column indicated the number of analog to digital converter bits associated with the range of values.

Table 3a Data taken using the Plate 'B' signal from Booster BPM B:HP24S

measured Delta, dB	ACNET Page Pos. min	max	range	avg	Computed Pos = f(volts) Expected Pos.	% Error avg	min	max
0.00	-0.300	0.200	0.500	-0.050	0.000			
1.00	1.520	1.630	0.110	1.575	1.717	8%	11%	5%
2.03	3.140	3.500	0.360	3.320	3.500	5%	10%	0%
5.00	7.980	8.360	0.380	8.170	8.626	5%	7%	3%
9.00	14.640	14.970	0.330	14.805	15.522	5%	6%	4%
19.06	32.070	32.460	0.390	32.265	32.862	2%	2%	1%
-19.06	-28.750	-28.360	0.390	-28.555	-32.862	13%	13%	14%
-9.00	-14.160	-13.960	0.200	-14.060	-15.522	9%	9%	10%
-5.00	-8.360	-7.690	0.670	-8.025	-8.626	7%	3%	11%
-2.03	-3.560	-3.160	0.400	-3.360	-3.500	4%	-2%	10%
-1.00	-1.920	-1.540	0.380	-1.730	-1.717	-1%	-12%	10%

The first column corresponds with the difference between the values of attenuators inserted as ATTN 'A' and ATTN 'B'. The next two columns are the minimum and maximum position readings for each case as observed on an ACNET page for several Booster acceleration cycles. The 'range' and 'average' columns are determined from the 'min' and 'max' values. The Expected position is that computed from equation (2) given Delta dB. The %Error is the Expected Position minus the measured value then divided by the Expected Position.

Table 3b Data taken using the Plate 'B' signal from Booster BPM B:HP24S

B:HP24S					
measured	Computed Volts = g(pos)				
Delta, dB	Volts given Page Pos.				+/- 5V 12 bit ADC
	min	max	range	avg	range in No. Bits
0.00	-0.034	0.022	0.056	-0.006	23
1.00	0.170	0.183	0.012	0.176	5
2.03	0.349	0.388	0.039	0.369	16
5.00	0.845	0.881	0.036	0.863	15
9.00	1.381	1.403	0.022	1.392	9
19.06	2.060	2.068	0.007	2.064	3
-19.06	-1.987	-1.978	0.010	-1.982	4
-9.00	-1.349	-1.335	0.014	-1.342	6
-5.00	-0.881	-0.818	0.063	-0.849	26
-2.03	-0.395	-0.351	0.043	-0.373	18
-1.00	-0.215	-0.172	0.042	-0.194	17

The table above ***computes*** the position voltage output of the RF Module based on the positions read off of the ACNET page. The final column indicated the number of analog to digital converter bits associated with the range of values.

The scope plots on the next page show the position voltage output of the RF module. The complexity of the output is almost entirely do to the complexity of the BPM RF input. When a single frequency RF Module input is used the output is essentially flat even at the full bandwidth of the scope (perhaps 20 mVpp broadband noise).

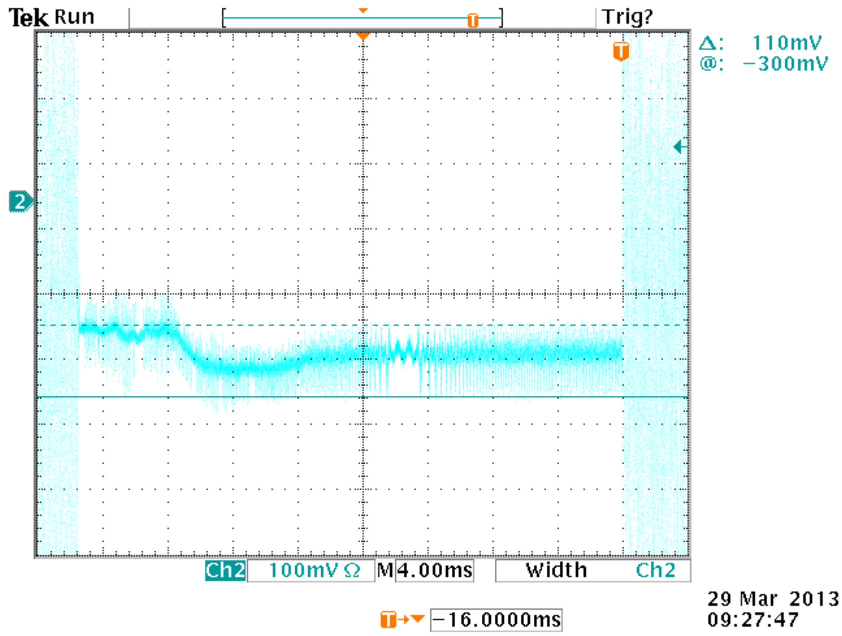

Figure 2 Position Voltage output with BPM signal input, 100 MHz bandwidth

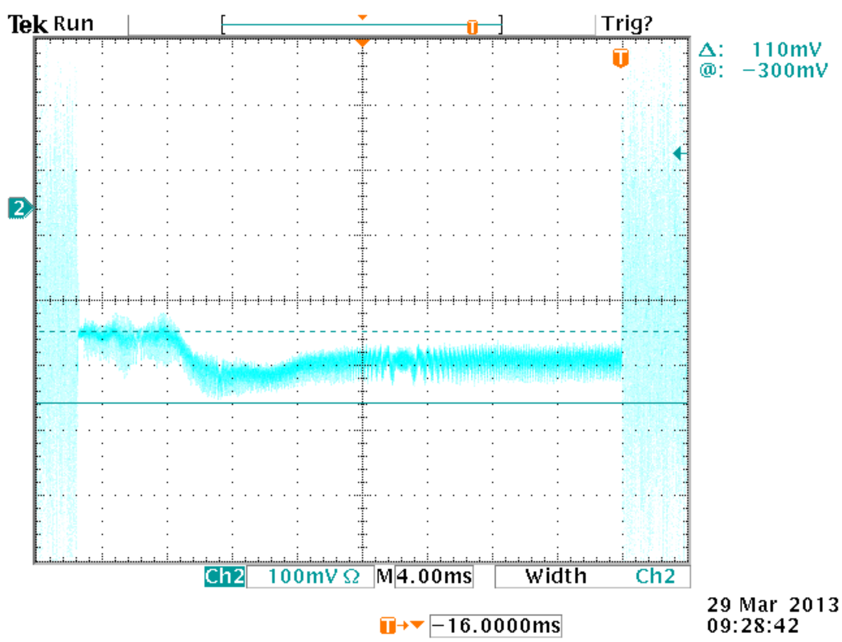

Figure 3 Position Voltage output with BPM signal input, 1.9 MHz bandwidth.

Table 4a Data taken using a 40 MHz RF signal and a 68.3 MHz Local Oscillator signal generated using a signal generator.

Signal Generator Signal into B:HP24S

measured	DMM	Computed		ACNET				Computed Pos = f(volts)			
Delta, dB	Volts, pos.	Volts(dB)	%Error	Page Pos.				Expected Pos.	% Error		
				min	max	range	avg		avg	min	max
0.00	-0.005	0.000		-0.065	-0.043	0.022	-0.054	0.000			
1.00	0.172	0.192	10.53%	1.482	1.526	0.044	1.504	1.717	12%	14%	11%
2.03	0.361	0.388	7.04%	3.184	3.206	0.022	3.195	3.500	9%	9%	8%
5.00	0.858	0.905	5.24%	7.973	8.025	0.052	7.999	8.626	7%	8%	7%
9.00	1.391	1.439	3.31%	14.499	14.572	0.073	14.536	15.522	6%	7%	6%
19.06	2.058	2.075	0.84%	30.308	30.872	0.564	30.590	32.862	7%	8%	6%
-19.06	-2.020	-2.075	2.67%	-29.351	-29.046	0.305	-29.198	-32.862	11%	11%	12%
-9.00	-1.365	-1.439	5.11%	-14.246	-14.175	0.072	-14.211	-15.522	8%	8%	9%
-5.00	-0.847	-0.905	6.46%	-7.922	-7.896	0.026	-7.909	-8.626	8%	8%	8%
-2.03	-0.364	-0.388	6.27%	-3.274	-3.251	0.022	-3.262	-3.500	7%	6%	7%
-1.00	-0.185	-0.192	3.77%	-1.679	-1.635	0.044	-1.657	-1.717	3%	2%	5%

This data was taken using the single frequency, non-sweeping frequency, input from the signal generator. This test produced a stable position voltage output from the RF Module that could be reliably measured with the Digital Multimeter (DMM). Columns 2 to 4 of the table compare the measured voltage to the predicted values. The rest of the table is the same as Table 2a and Table 3a.

Table 4b Data taken using a 40 MHz RF signal and a 68.3 MHz Local Oscillator signal generated using a signal generator.

Signal Generator Signal into B:HP24S

measured Delta, dB	DMM Volts, pos.	Computed Volts(dB)	%Error	Computed Volts = g(pos) Volts given Page Pos. min	max	range	avg	+/- 5V 12 bit ADC range in No. Bits
0.00	-0.005	0.000		-0.007	-0.005	0.002	-0.006	1
1.00	0.172	0.192	10.53%	0.166	0.171	0.005	0.168	2
2.03	0.361	0.388	7.04%	0.354	0.356	0.002	0.355	1
5.00	0.858	0.905	5.24%	0.845	0.850	0.005	0.847	2
9.00	1.391	1.439	3.31%	1.372	1.377	0.005	1.375	2
19.06	2.058	2.075	0.84%	2.024	2.036	0.012	2.030	5
-19.06	-2.020	-2.075	2.67%	-2.002	-1.995	0.007	-1.998	3
-9.00	-1.365	-1.439	5.11%	-1.355	-1.350	0.005	-1.353	2
-5.00	-0.847	-0.905	6.46%	-0.840	-0.837	0.002	-0.839	1
-2.03	-0.364	-0.388	6.27%	-0.364	-0.361	0.002	-0.363	1
-1.00	-0.185	-0.192	3.77%	-0.188	-0.183	0.005	-0.186	2

Table 4b above is assembled the same as Tables 2b and 3b, except the measured position voltage numbers are included beside the computed voltages for comparison. The number of ADC bits in the range indicate that the position voltage produced by the RF Module is not significantly noisy itself.