Updating Calibration Values in the Booster BPM System

July 10, 2007
Craig Drennan

Introduction

In conjunction with the Booster Corrector Magnet Upgrade, new BPM detectors were designed to fit in the bore of the corrector package in order to meet the beam line space requirements. Though these new detector are very similar to the originals they are expected to have a different position sensitivity calibration value.

The purpose of this note is to detail how this new calibration is implemented in the electronics and software of the BPM readout system.

Background Information

References are typically placed at the end of a paper, but these are significant enough that they were put here on the front page.

[1] R. Shafer, "Beam Position Monitor Design Note #1, Expected Calibration and Calibration Tolerances of the Beam Position System", Nov. 3, 1981, Beams-doc-1584.

[2] R. Webber, "Calibration of the Booster BPM System", Sept. 18, 1986, Beams-doc-2085.

Reference [1] provides a detailed description of the contribution made by the BPM system components on the final system calibration. The BPM system components described include the detector, cabling, RF Module, and the Analog Box.

The readout electronics, particularly the RF module signal digitization, is different than what is described in these references as the Analog Box. The Analog Box has been replaced by 2 MHz Comet, VME Digitizer cards. The final conversion of the digitized signals from the RF Modules into beam positions is performed on the MVME crate processor. The crate processor reads the data from the Comet digitizers over the VME interface and then executes the proper conversion using look-up tables.

The RF Module itself implements an amplitude modulation to phase modulation transformation followed by a phase detector. The additional references particular to this module are:

[3] S. P. Jachim, R. C. Webber, R.E. Shafer, "An RF Beam Position Measurement Module for the Fermilab Energy Doubler", IEEE Transactions on Nuclear Science, vol. NS-28, No. 3, pg. 2323, June 1981.

[4] R. C. Webber, "Booster Accelerator Beam Position Monitor RF Module", Fermi Electrical Schematic, Drawing No. 0381.00-EE-37626.

The Formula for Determining Beam Position

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

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

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 described in [3]. The rigorous mathematical description of the AM/PM conversion is provided in Appendix A, page 23, of [1].

A quicker illustration of the conversion is provided in Figure 1 and Figure 2. In the figures the phase and amplitude of signals A and B are represented by vectors. Figure 1 illustrates the case where signal B is greater than signal A resulting in Sum and Difference signals of equal amplitude with a phase difference greater than 90 degrees. Figure 2 illustrates the case where A is greater than B resulting in the Sum and Difference signals having a phase difference less then 90 degrees. Here the assumption is that signals A and B are in phase with one another at the input.

From the trigonometric evaluation of the AM/PM conversion in Appendix A of [1] we have

$$\frac{A}{B} = Tan\left(\frac{\theta_\Sigma - \theta_\Delta}{2}\right)$$

where

$\theta_\Sigma - \theta_\Delta$ = phase difference between the AM/PM outputs.

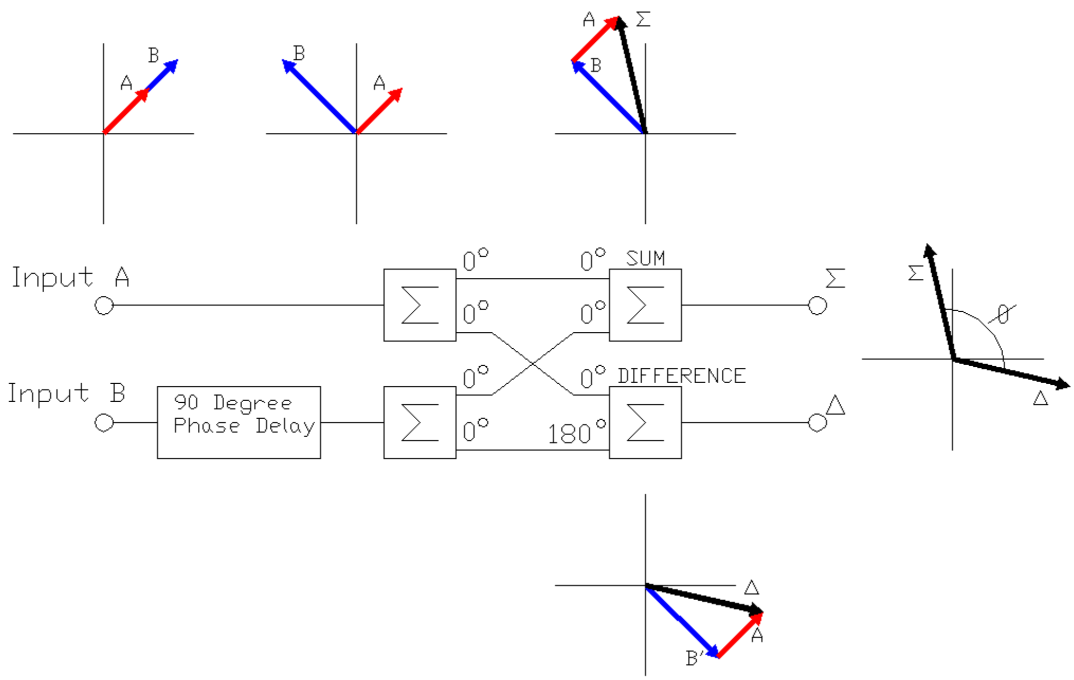

Figure 1. AM/PM conversion illustration with signal B greater than signal A.

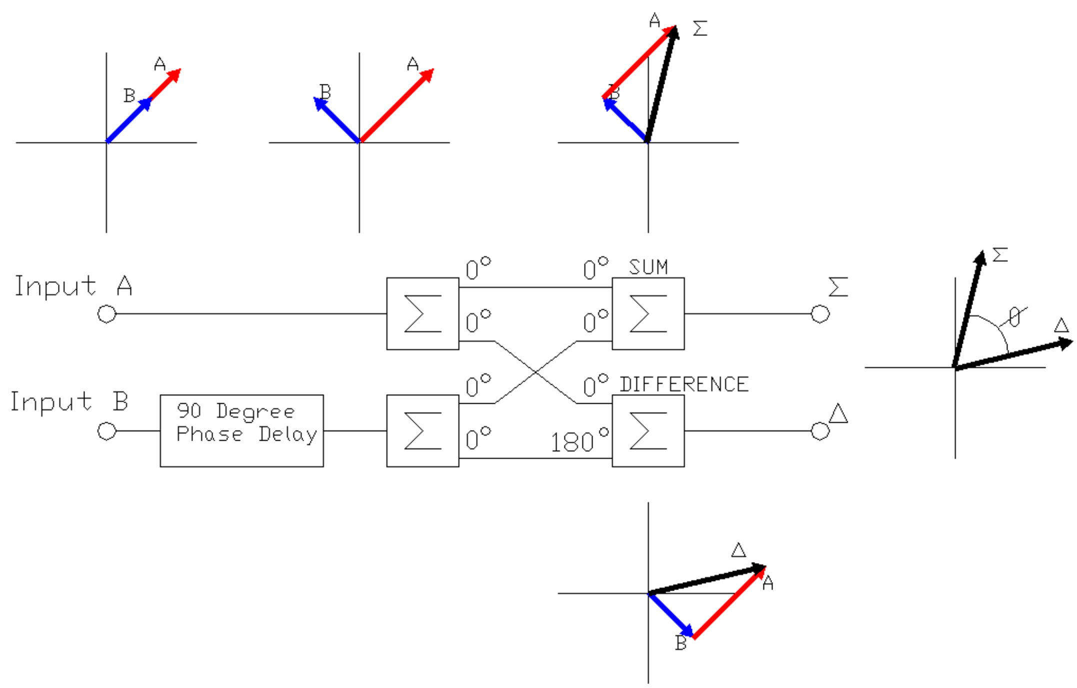

Figure 1. AM/PM conversion illustration with signal A greater than signal B.

The output of the RF Module is a voltage V with the following relationship

$$F \cdot C_1 \cdot (V - V_0) + \frac{\pi}{4} = \frac{\theta_\Sigma - \theta_\Delta}{2}$$

where

$C_1 =$ Calibration gain term.

$V_0 =$ Calibration term.

$F =$ Calibration linear fit term $(= 1.14)$.

The equation for determining beam position from the output of the RF Module is

$$x = \frac{1}{s} \cdot \frac{1}{F} \cdot 20 Log\left[Tan\left(F \cdot C_1 \cdot (V - V_0) + \frac{\pi}{4} \right) \right]$$

Computing the Beam Position

The digitizers which digitize the voltage output of the RF Modules has a +/- 5 Volt input with a resolution of 12 bits, and produces digital values with an offset binary representation. That is a digital value of 2048 represents a 0 Volt input and 4096 represents 5 Volts.

The equation implemented in the processor to determine position is

$$position, mm = M_1 \cdot Ln\left[Tan\left(\frac{i - 2048}{M_2} + .78539816 \right) \right]$$

where

$$M_1 = \frac{20}{\mathrm{s} \cdot \mathrm{F} \cdot \mathrm{Ln}[10]}$$

$$M_2 = \frac{1}{\mathrm{C}_1 \cdot \mathrm{F} \cdot \left(\frac{10}{4096} \right)}$$

$$0.78539816 = \frac{\pi}{4}$$

$$V_0 = 2048$$

Note that the Log function in the code computes the natural log. The decibel representation of the ratio $\left(A/B \right)_{dB}$ is computed using the base 10 Log. The relationship between the two log functions is $Log(X) = Ln(X)/Ln(10)$.

The processor code actually builds look up tables at system initialization using this formula. By using look up tables the digitized voltages can be quickly converted to position values. The C code that currently builds these tables is given in Listing 1

Listing 1: Code written by Sharon Lackey, AD/Controls

```
/**** Calculates Tables for booster BPMs ****/
void calc_tables()
{
int i;
/* new table for bpms around collimators
  from BPM note #23

  x = ([20/s*F*ln10)]*ln[tan(F*C1*((V-Vo)+pi/4)]

  where F = 1.14, s = 0.76 dB/mm, C1 =0.2974, Vo = 0,
  and  v = (n-2048)/409.5  for ± 5v over 0 - 4095 counts
*/
for(i=0; i<78; i++) /* calc blows ups for these values */
new_pickup_table[i] = -7.500e+01;
for (i=78;i<4019;i++)
{ outtan = tan(((i-2048)/1208.1312)+.78539816);
  new_pickup_table[i] = 10.025*(log(outtan));
 }
for(i=4019;i<4096;i++)
new_pickup_table[i] = 7.500e+01;

/* table for standard Booster Bpms with Comet boards
  from BPM note #23

  x = ([20/s*F*ln10)]*ln[tan(F*C1*((V-Vo)+pi/4)]

  where F = 1.14, s = 0.52 dB/mm, C1 =0.2974, Vo = 0,
  and  v = (n-2048)/409.5  for ± 5v over 0 - 4095 counts
*/
for (i=0;i<1100;i++) /* calc blows up for these values */
  booster_table[i] = -107.0;
for (i=1100; i<2997; i++)
{ outtan = tan(((i-2048)/1208.1312)+.78539816);
  booster_table[i] = 14.6523*(log(outtan));
 }
for(i=2997;i<4096;i++)
 booster_table[i] = 107.0;
/* new table for bpms in new corrector packages
  with Comet boards from BPM note #23

  x = ([20/s*F*ln10)]*ln[tan(F*C1*((V-Vo)+pi/4)]

  where F = 1.14, s = 0.58 dB/mm, C1 =0.2974, Vo = 0,
  and  v = (n-2048)/409.5  for ± 5v over 0 - 4095 counts
*/
for (i=0;i<1100;i++) /* calc blows up for these values */
 boosterCorr_table[i] = -95.0;
```

```
for (i=1100; i<2997; i++)
{ outtan = tan(((i-2048)/1208.1312)+.78539816);
  boosterCorr_table[i] = 13.1365542*(log(outtan));
 }
for(i=2997;i<4096;i++)
 boosterCorr_table[i] = 95.0;

}
```

As seen in the code of Listing 1 there are two types of BPM conversion tables set up. For BPM of the first type the lookup table `new_pickup_table` is used. This table has the following calibration values.

$$M_1 = 10.025$$

$$M_2 = 1208.1312$$

$$resulting\ \ from$$

$$F = 1.14$$

$$s = 0.76\ dB/mm$$

$$C_1 = \left(1208.1312 \cdot \left(\frac{10}{4096}\right) \cdot F\right)^{-1} = 0.2974$$

The lookup table, `booster_table` , for the second BPM type has the following calibration values.

$$M_1 = 14.6523$$

$$M_2 = 1208.1312$$

$$resulting\ \ from$$

$$F = 1.14$$

$$s = 0.52\ dB/mm$$

$$C_1 = \left(1208.1312 \cdot \left(\frac{10}{4096}\right) \cdot F\right)^{-1} = 0.2974$$