CALIBRATION ALGORITHM 09.25.06 J.Gullotta

For any calibration, three aspects of the BPM operation must be calibrated. Those three aspects are as follows:

- Offset
- Gain
- Sample and hold delay timing

The offset measurement is taken by injecting no calibration signal into the electronics and reading the value being returned by the digitizer.

The gain measurement, henceforth called the "peak measurement", is the value the digitizer reports when the electronics are triggering on a calibration signal. This is effectively the "gain" of the signal path.

The sample and hold delay timing is the setting that allows fine tuning of the sample and hold trigger. This makes it possible to compensate for timing inaccuracies in the printed circuit board down to 20 picoseconds.

It is possible to calibrate the electronics with an external signal, or to use the on-board calibration pulser. However, there is an inherent error between the internal and external signal paths. The difference is caused by resistors with 5% tolerance. The accumulated error of the 5% tolerance is enough to cause considerable difference in the signal paths.

We assume that the difference between the internal and external signal paths is a zeroth order offset. It is assumed that with component drift and age, the difference between internal and external signal paths will not change. This difference will manifest itself as an error between $A_{cor}$ and $B_{cor}$ (peak measurement) if the electronics are calibrated internally and data is taken externally, or vice versa. The error is probabilistic, ranging between $^{+}/_{-}$ 500 in the worst case. This renders a simple calibration with the internal signal source unusable.

The alternative to a "simple" calibration is one where we take "baseline" calibrations that we compare to establish a correction factor between the internal and external signal paths. Any subsequent internal calibrations will use this correction factor to reference the internal calibration to

the external signal path. The internal calibration will then be valid for signals taken in through the external path.

*<u>Note:</u> The algorithm only needs to modify the peak measurement coefficients. The offset measurement is the same for internal and external signals. The sample and hold delay timing values are never updated, the values used for operations are the values obtained during the last external baseline calibration.*

The more complex calibration procedure requires several different flavors of calibration to use the new algorithm. These new flavors are called:

- External Baseline
- Internal Baseline
- Internal Recent

The external baseline calibration provides a baseline calibration measurement that was taken through the external signal path. The internal baseline calibration, similarly, provides a baseline calibration measurement that was taken through the internal signal path. These two calibrations should be taken concurrently so the current state of the electronics is captured without any error being added due to drift from temperature changes and age. Once stored, the algorithm has all of the information necessary to make coefficient updates using the internal pulser. These updates are called "internal recent" calibrations. The algorithm uses the internal recent calibration data and adjusts it based on the difference in the signal paths known from the internal and external baseline calibration data that is stored in memory. This corrected calibration data is then stored as the new calibration and it is used until the board is recalibrated.

The algorithm modifies two coefficients called $C_3$ and $C_4$. These are the peak values of the calibration signal, and therefore represent the overall gain of the signal path for each channel. $C_3$ represents channel A, while $C_4$ represents channel B. The modified coefficients are then called "operational coefficients" and belong to the operational block of coefficients.

It is necessary to force the common mode value of the internal baseline coefficients and the internal recent

coefficients to be the same as the common mode value of the external baseline coefficients. The normalizations below, $({}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{recent})$ and $({}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{IBL})$, are the result.

$$\Delta = A_{cor} - B_{cor} = C_3 - C_4$$

$$K_{offset} = \Delta^{ext} - \Delta^{int}$$

$$C_3^{ext} - C_4^{ext} = C_3^{int} - C_4^{int} + K_{offset}$$

$${}^{AVG}\Delta^{IBL} = (C_3^{IBL} + C_4^{IBL}) / 2$$

$${}^{AVG}\Delta^{EBL} = (C_3^{EBL} + C_4^{EBL}) / 2$$

$${}^{AVG}\Delta^{recent} = (C_3^{recent} + C_4^{recent}) / 2$$

Operationally:

$$K_{offset} = C_3^{EBL} - C_4^{EBL} - (C_3^{IBL} - C_4^{IBL}) * ({}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{IBL})$$

$$C_3^{oper} - C_4^{oper} = K_{offset} + (C_3^{recent} - C_4^{recent}) * ({}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{recent})$$

Define:

$$C_3^{oper} = (C_3^{recent} * {}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{recent}) + K_{offset}$$

$$= (C_3^{recent} * {}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{recent}) + \Delta^{EBL} - (\Delta^{IBL} * {}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{IBL})$$

$$C_4^{oper} = (C_4^{recent} * {}^{AVG}\Delta^{EBL} / {}^{AVG}\Delta^{recent})$$

Also:

$C_0^{oper} = C_0^{EBL}$ or $C_0^{recent}$ , whichever comes last

$C_1^{oper} = C_1^{EBL}$ or $C_1^{recent}$ , whichever comes last

$$C_6^{oper} = C_6^{EBL}$$

$$C_7^{oper} = C_7^{EBL}$$

The coefficients $C_0^{oper}$, $C_1^{oper}$, $C_3^{oper}$, $C_4^{oper}$, $C_6^{oper}$, and $C_7^{oper}$ are the six elements of the operational coefficient block. These are the coefficients that are used to correct the raw data returned from the digitizer in real-time. The above set of equations explains how the operational coefficients are derived from the baseline and recent measurements.