A CALIBRATION METHOD FOR THE RF FRONT-END ASYMMETRY OF THE DBPM PROCESSOR*

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Abstract

Digital Beam Position Monitor (DBPM) processor, designed to measure the beam positions in the LINAC, booster and the storage ring of a particle accelerator, has been used in many synchrotron radiation facilities. Channels asymmetry, which deteriorates the performance of the DBPM, is inevitable since the RF front-end needs four exactly same blocks. Recently, an RF front-end board for DBPM has been made with calibration circuit which clears the switching noise. The calibration method will be described in detail, including an overview of the RF board. The beam current dependence, which is sensitive to channels asymmetry, decreases from 160um to 25um after the calibration in the lab test.

INTRODUCTION

Digital Beam Position Monitor (DBPM) processor is a widely used monitor in accelerator Labs [1]. Four exactly same blocks are needed, so channels asymmetry which will impair the performance is unavoidable. There are two widely used ways to suppress the influence. One is channels share technology or channels switch technology, such as MX-BPM [2] and Libera [3]. They both suppress the effect of the channels asymmetry. However, the resolution of the wide-band beam position information (Turn by Turn, for example) will decrease due to the switching noise which cannot be avoided, (Libera, for example). The other way is calibrating the four channels with a standard signal. An RF Front-end board for DBPM was designed with calibration circuit. The following sections will show the overview of the board and the descriptions of the calibrate method.

RF FRONT-END BOARD

The main function of the RF board is to process the pickup signal and calibration the channels asymmetry of DBPM.

The RF board is made up of signal process part and calibration part. Figure 1 shows the schematic of the RF front-end board.

RF Signal Process Part

The signal process part of the board is composed of two parts: a filter part and a gain control part. The filter part is a narrow band band-pass filter, whose central frequency is 499.654 MHz, and -3dB band width is about 694 KHz which is same as Turn-by-Turn frequency of SSRF storage ring [4].

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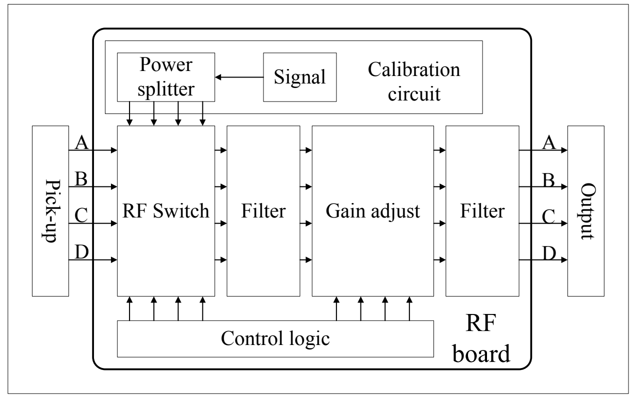

Figure 1: Schematic of the RF circuit.

The gain control parts contain an amplifier and some digital control attenuations. The gain can be adjusted from 0 to 63dBm which covers most signals with different beam currents.

Calibration Part

The calibration circuit consists of a signal generator, an RF switch and a control logic circuit. A standard signal is generated with phase locking loop (PLL) technology. Output of the standard signal is sine waveform whose frequency is 499.600 MHz. The output amplitude rang is from 0 to -50dBm. The standard signal is divided into four nearly identical signals by a power splitter. With the help of the RF switch the four signals will act as the input calibration signals of the RF board in the calibration module. Figure 2 shows the RF board without the electromagnetic shield case.

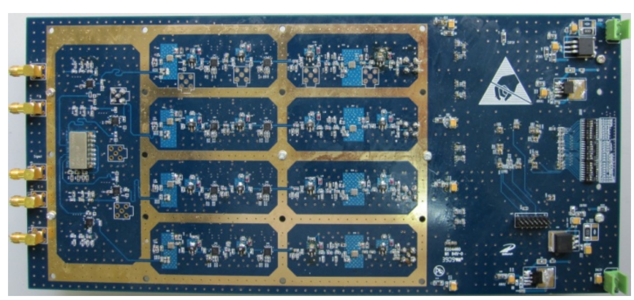

Figure 2: Picture of RF board.

CALIBRATION METHOD

Devices of the same type do not have the exact same parameters, such as the gains of two amplifiers. These differences are the main source of channel asymmetry. The calibration method is to fit the amplitude response function of the four channels. Then the function is used to correct the asymmetry signals. Crosstalk of the four channels is very small, so the RF board could treat them as four independent functions, as showed in figure 3.

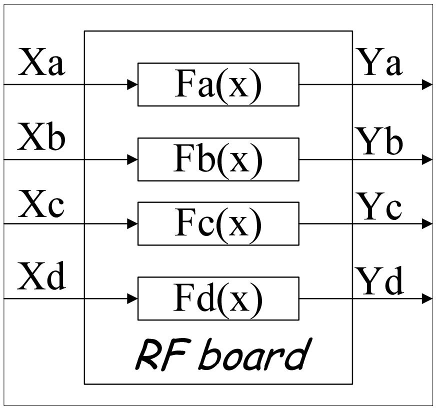

Figure 3: Response function of RF board.

The amplitude response functions are

$$Y_a = F_a(X_a) \tag{1}$$
$$Y_b = F_b(X_b) \tag{2}$$
$$Y_c = F_c(X_c) \tag{3}$$
$$Y_d = F_d(X_d) \tag{4}$$

Where

Y_a, Y_b, Y_c, Y_d : Output of the RF board

X_a, X_b, X_c, X_d : Input of the RF board

$F_a(X), F_b(X), F_c(X), F_d(X)$: Response functions

Figure 4 shows the amplitude response of the four channels. According to the shape of the curves, linear function could be used as the target function. Calibration algorithm will be implemented in FPGA in the next design. Linear algorithm will consume less resource.

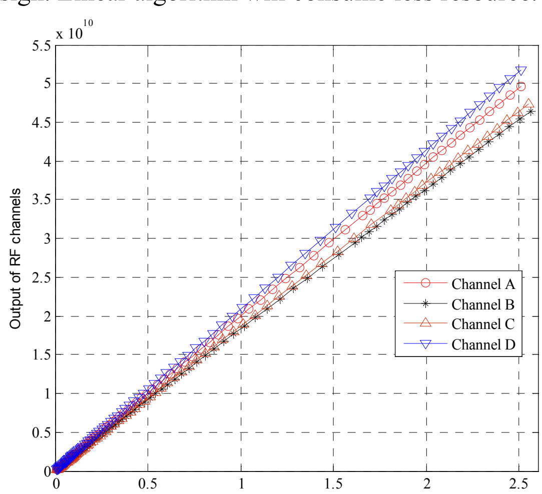

Figure 4: Amplitude response of four channels.

Dynamic range of the board is about 60dBm, the deviation is very large if linear function is used as the target function. Other complex functions will consume too many resources, or even cannot be implemented, when they are implemented in FPGA. To balance the precision and complexity, the piecewise linear function was finally adopted as the target function.

Target function is

$$F(X) = \begin{cases} k_1 X + m_1, & x_0 \le X \le x_1 \\ k_2 X + m_2, & x_1 \le X \le x_2 \\ \ldots & \ldots \\ k_n X + m_n, & x_{n-1} \le X \le x_n \end{cases} \tag{5}$$

Where

$k_1, k_2 \ldots k_n$: Slope coefficients

$m_1, m_2 \ldots m_n$: Offset coefficients

$x_1, x_2 \ldots x_n$: Amplitude range of input signals

n : Sections of the curve divided

CALIBRATION TEST

A test platform was built to assess the performance of the calibration method. Figure 5 shows the diagram of the test platform. An ADC board combined with a capture board was used to digital the output of the RF board. The sample rate and the resolution of each ADC are 117.2799MHz and 16bit, respectively.

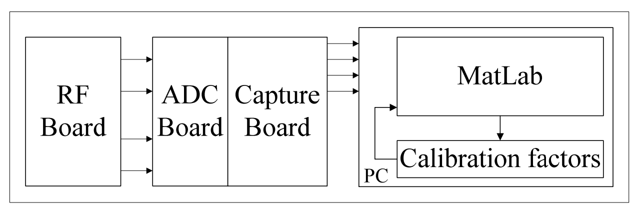

Figure 5: Diagram of calibration test.

Digitized signals were processed in Personal Computer (PC) with MatLab. DDC (Digital down converter) algorithm is used to calculate the amplitude of the input signals [5]. Other algorithms are also implemented in MatLab. Figure 6 shows the hardware picture of the calibration platform.

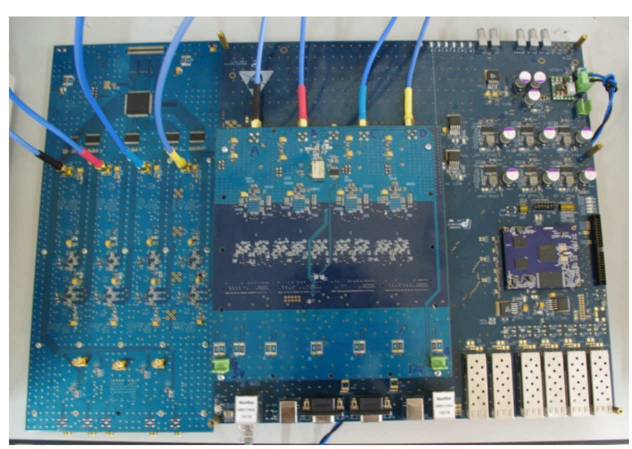

Figure 6: Picture of calibration test.

Calibration Procedures

The goal of the calibration is to optimize the whole DBPM electronic system, not only the asymmetry of the RF board will be adjusted, but other module (such as ADC module) will be taken into account in the test procedure.

The first procedure is fitting the correction factors. The input of the RF processing circuit is switched to be the calibration signals. The amplitude of the outputs are acquired from PC. The amplitude of the calibration signal was changed step by step, and the corresponding outputs were acquired simultaneously. Then Equation 5 is used as the fitting function to evaluate the correct factors.

Correct factor is used to correct the asymmetry of four channels in the next procedure. RF switches are set to normal mode. Input signal of the RF processor comes from a signal generator which is used to simulation the output of the BPM pick-up. In this mode, the input signal will calibrate with the factor s.

Calibration Results

Beam current dependence is sensitive to channels inconsistency, so it could used to evaluate the calibration method. Figure 7 shows the calibration result. In this test linear function (Equation 5, n=1) is used as the fitting function. Beam current dependence decreases from 160um to 75um after calibration.

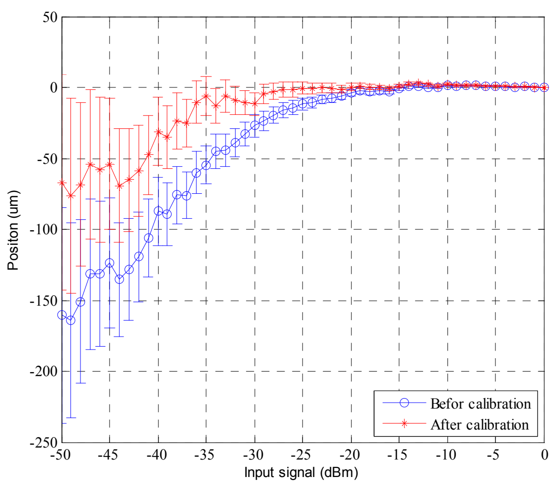

Figure 7: Beam current dependence (linear function).

To increase the fitting precision piecewise linear function was used as the target function. As shows in Figure 8 the curve is smoother than the upper one. Beam current independences decrease from 160um to 25um.

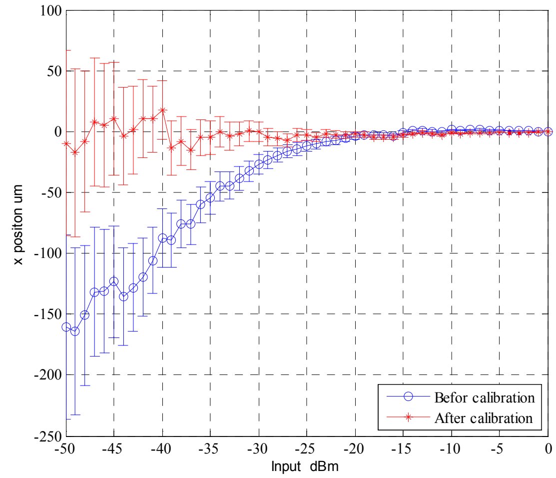

Figure 8: Beam current dependence (piecewise linear function).

CONCLUSIONS

From the result of the test, the calibration is proven to be valid. The more sections (Equation 5, n) the curve was divided, the better calibration precision the calibration would get. The method will be implemented in FPGA in the designed digital board in the future. Since too many resources will be consumed if the number of the sections is too large, it should be optimized to get adequate accuracy as well as to minimize the resource consumption.

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