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RF front-end for digital beam position monitor signal processor

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Abstract RF circuit board has a significant impact on performance of the Digital Beam Position Monitor (DBPM) in storage ring of a synchrotron radiation facility. In this paper, a front-end RF board is designed for DBPM, and schematics of the RF board and the test results are given. In view of the inevitable inconsistency in the multi-channel circuit, a calibration circuit is designed to reduce such an influence. The test results show that the calibration method is useful for beam current dependence which is sensitive to channels inconsistency.

Key words DBPM, RF Front-end, Beam current dependence, Calibration

1 Introduction

The commissioning and machine studies of accelerators are largely depended on performance of beam position monitor (BPM)[1]. Signal processing is done in analog module in traditional BPM[2] due to limitation of the performance of analog to digital (A/D) module and digital signal processor. As the development of the electronics, digital beam position monitor (DBPM) has been used in accelerators[3,4]. Fig.1 shows a diagram of DBPM[5].

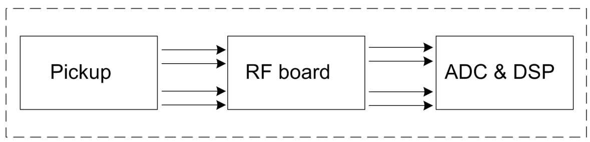

Fig.1 Diagram of the DBPM.

The pickup signals are preprocessed by a radio frequency (RF) front-end board, whose performance affects the DBPM greatly. The RF front-end board has four analog process blocks, and an inevitable channel inconsistency deteriorates the DBPM performance. Libera, a widely employed DBPM signal processor in many accelerator labs, introduces the quasi-crossbar technique to reduce the influence from channel inconsistency[6].

However, the resolution of the wide-band beam position will be decreased due to the switching noise which was added to the source signal within this architecture. According to the experience from Libera, the calibration is used to suppress the influence, and the beam current dependence which is sensitive to channels inconsistency can be decreased from 160 to 25 μm. In this paper, schematics of the RF front-end board for DBPM is described, and test results of the RF front-end board are given.

2 Board design

2.1 Signal of pickup

There are many kinds of BPM pickups[7]. In the following sections, IDBPM is described as an example. Fig.2 shows the simulated waveform of IDBPM [8]. The input signal to the RF front-end board from BPM pickup is a very fast bi-polar pulse, with a rising edge of less than 0.2 ns. The power spectrum of the waveform mainly distributes from 0 to 15 GHz. The simulated wave is a Gauss-shaped beam of 1-mA current, 4.2-mm length and 1-nC charge. The power spectrum of the button pick-up is shown in Fig.3[8].

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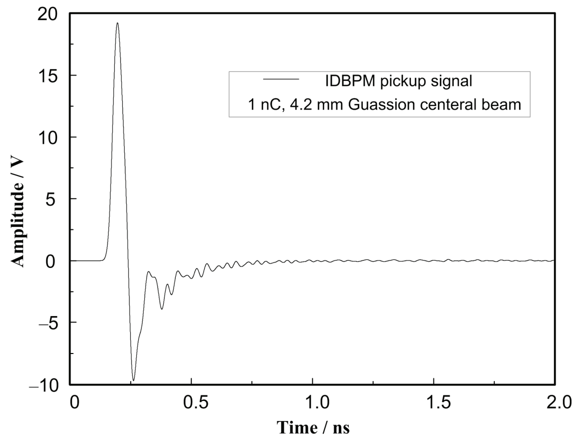

Fig.2 The waveform of IDBPM pickup.

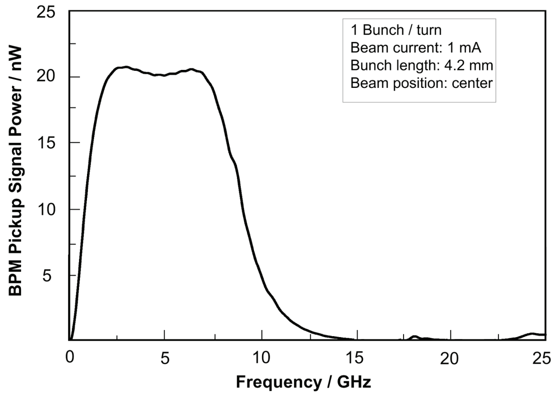

Fig.3 Power spectrum of IDBPM pickup.

2.2 Schematics of the RF front-end board

The RF front-end board consists of four channels of the same structure. Its main function is to process the signal acquired from the pickup and provide appropriate signal for the follow-up module. As shown in Fig.4, it consists of the filter, amplitude adjusting, calibration and control parts.

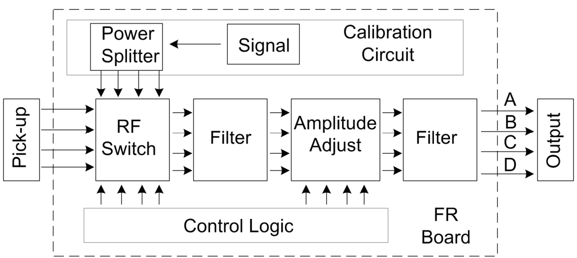

Fig.4 Schematics of the RF circuit.

2.3 Filter circuit

Narrow-band pick-up signal with centre frequency of 499.654 MHz is needed to collect the position data of beam. The sampling rate of the follow-up A/D module is 117.2799 MHz. The cut-off frequencies of the RF font-end board are calculated as[7]:

Cut-off freq 1: (117.2799 / 2)×8 = 469.1196 MHz

Cut-off freq 2: (117.2799 / 2)×9 = 527.7596 MHz

Attenuation value of the cut-off frequencies is preferably over –40 dB. The band of turn-by-turn from the DBPM is 694 kHz, so –3 dB band of the RF front-end circuit should be wider than 694 kHz[7]. Both SAW filter and discrete filter are adopted in this circuit. The former is the commercial TAI-SAW TA0506[9], and the latter was assembled with discrete capacitors and inductors.

2.4 Amplitude adjust circuit

Output power of the pickup has a wide dynamic range. From the simulated output power of IDBPM in Fig.5 [8], output power of the pickup ranges from –66 to –3 dBm as the beam current rises from 1 to 300 mA.

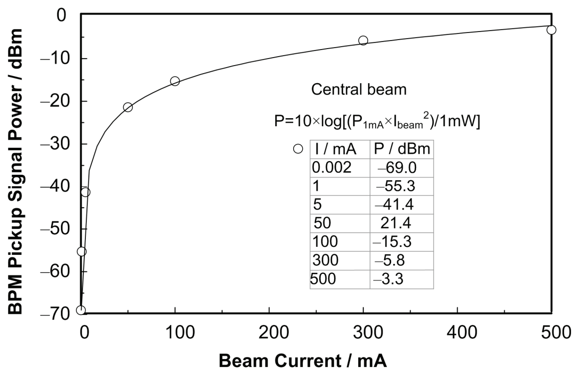

Fig.5 Output power of BPM pickup.

Multi-level amplifier and attenuator cascade circuit are used to match the high dynamic range of the input signal. The amplifier is Gali05/52, a mini-circuit broadband low-noise amplifier[10]. The attenuator consists of two kinds of attenuators: adjustable and fixed attenuation. The attenuation range is designed from 0 to 63 dB, with a minimum adjustable step of 0.5 dB. The maximum amplification factor is better than 60 dB.

2.5 Calibration circuit

There are four signal channels from the BPM pickup. Due to nonlinearity of the circuit and inconsistency of the components, the four channels cannot give the same performance. The inconsistency affects the DBPM performance, especially the beam current dependence of the DBPM. A calibration method was designed to reduce inconsistency of the board.

As shown in Fig.4, a standard signal can be divided into four ways by power-splitter. In the calibration mode, the four standard signals are input signals of the RF processing circuit by setting the RF switches, while in the normal mode, the signal from BPM pickup is the input of RF processing circuit.

The standard signal is generated with phase locking loop (PLL) technique. Analog device ADF4360-7 is used as the PLL chip[11], and Silicon Lab F330D as the control chip[12]. The standard signal is a sine wave with the frequency of 499.654 MHz, which is the same with the beam.

2.6 Control circuit

The control circuit is used to adjust standard signal circuit, RF switches and attenuators. The control logic is implemented with a Xilinx CPLD, with VHDL as the programming language.

3 Board testing

The methods to test the board are the calibration test, and the basic function test which is completed by spectrum analyzer and network analyzer. The equipment and modules used in the test are: Signal generate: Rohde & Schwarz SMA 100A; Network analyzer: Agilent N5230A; Spectrum analyzer: Tektronix RSA6114A; ADC board: GE ICS-1154.

3.1 Frequency response

The network analyzer was used to test the frequency response of the RF board. Fig.6 shows the attenuation value of cut-off frequency.

As shown in Fig.5, the attenuation value of cut-off frequency 1 is about 78 dB, and attenuation of frequency 2 is about 35 dB, which is not as good as cut-off frequency 1 due to performance limitation of the SAW filter IC[9]. Although the attenuation of cut-off frequency 2 has not reached our ideal goal, it does not affect the system performance in comparing the test results. As shown in Fig. 7, the –3 dB bandwidth of the board is 12 MHz, which is much wider than 694 kHz, i.e., the design meets the technical requirements.

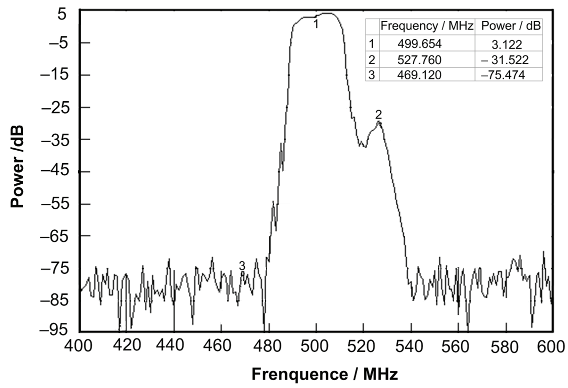

Fig.6 Frequency response of the RF board.

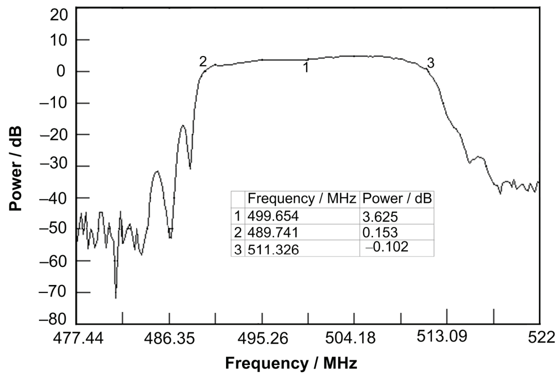

Fig.7 Frequency response of the RF board (3 dB bandwidth).

3.2 Dynamic range test

Output power of the pickup range is from –67 dBm to –3 dBm (Fig.5). Three different amplitudes (–67 dBm, –35 dBm and –3 dBm) of sine waves were used as input signal of the RF board.

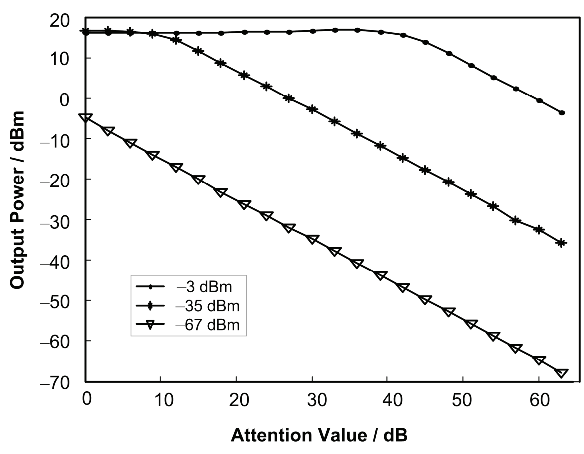

Fig.8 Dyanmic rang of the RF front-end board.

Fig.8 shows the test results. The attenuation is not a straight line when the input power is –3 dBm and –35 dBm. Because the amplifier was saturated, the 1 dBm compression point of the RF board was about 16 dBm. If the input is very low (–67 dBm), the attenuation value shall be as low as possible (0 dB) to gain larger output (–4.8 dBm). If the input power is high (–3 dBm), the attenuation shall be over 44 dB to avoid saturation of the amplifier. The attenuation value is set according to the needs of the following-up A/D module. The test results show that the dynamic range meets the requirements.

3.3 Calibration test

A prototype DBPM was established to test the calibration method. A commercial ADC board (GE ICS-1154)[13] was used to digitize the output of RF board. The processing algorithm was performed on a PC. The programs written in Matlab to complete the digital processing parts in the DBPM are base on software Radio, which is widely used in communication. Amplitude of pickup is obtained by a digital down converter(DDC) in the programs[14,15], and the difference-over-sum method was used to calculate the beam position[16]. A diagram of calibration test system is shown in Fig.9.

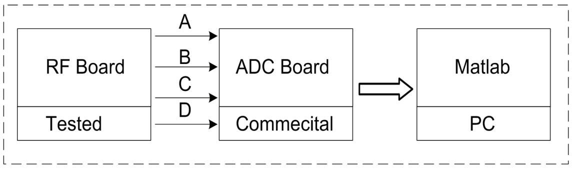

Fig.9 Diagram of calibration test.

The calibration method has two procedures. The first procedure is to obtain the correction factors of the RF front-end board. Detailed steps are as follows: a calibration signal at the same frequency as the beam signal was switched to the input of the RF processing circuit. The four amplitude data were acquired from the PC. By changing the amplitude of the calibration signal, amplitude data of different calibration signals were acquired. Fig.10 shows the amplitude unbalance of the RF front-end board. To correct the inconsistency of the four channels, curve fitting was used to calculate the correction factors. According to curve of the four channels, a first degree polynomial was used to fit the input-output response of the four channels. The fitted coefficient of the polynomial was used as the correction factors.

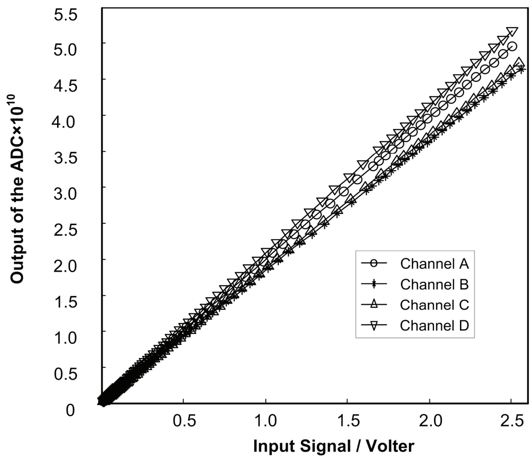

Fig.10 Amplitude unbalance of four channels.

The next procedure is to calibrate the data with the correction factors. RF switches were set to the normal mode, and BPM pickup signals were switched to RF front-end processing circuit. As the previous procedure, the amplitude data were calculated by PC. The difference is correction factors were used to fix the amplitude data.

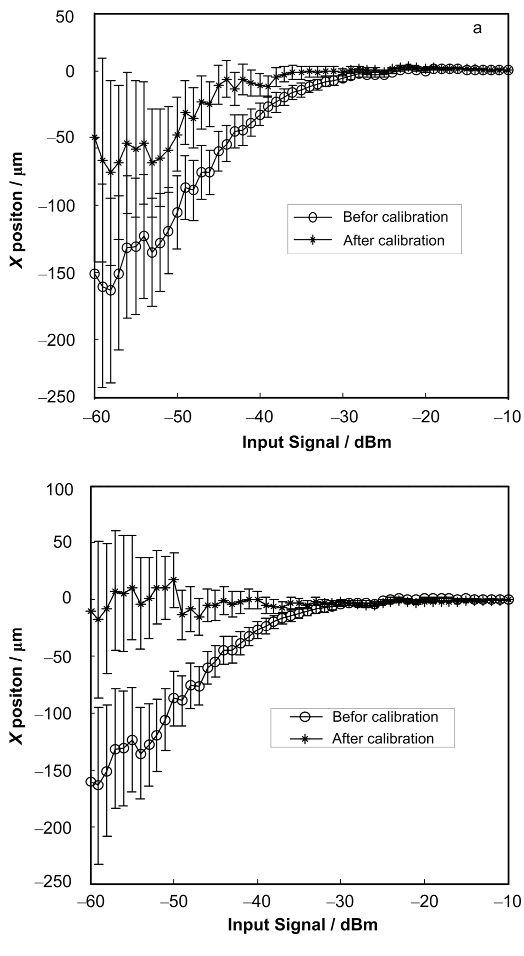

Fig.11 Beam current dependence, fitted by dividing the curve into (a) six and (b) 12 sections.

Beam current dependence, which is sensitive to channels inconsistency, was tested to evaluate the calibration method. Fig.11(a) shows the result of the calibration method. The beam current dependence decreases from 160 to 75 μm after calibration.

The curve fitting method may affect the calibration accuracy. For a more accurate fitting, the response curve of the front-end in Fig.11(a) was divided into six sections and fitted separately. The results of fitting the curve in 12 sections are given in Fig.11(b), where the beam current dependence decreased from 160 to 25 μm. However, fitting a larger number of sections means a calibration that consumes more resource, especially when it is performed by an on-line processor. The number of divided sections should be balanced between accuracy and resource consumed.

4 Conclusions

The test results show that overall performance is satisfactory compared with the target values; the design is proven to be valid. Channels inconsistency was resolved efficiently when the calibration method is used to fix the data. The RF front-end board satisfies the requirements of DBPM signal processor.

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