COMPARISONS OF SELECTED COTS AND CUSTOM HARDWARE FOR BEAM POSITION AND PHASE MEASUREMENTS FOR LANSCE*

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Abstract

Beam Position and Phase Monitors (BPPMs) planned for the LANSCE diagnostics refurbishment will be required to measure beam position and phase of the 201.25-MHz bunched beam in the proton linac. One method to do this is direct down conversion to in-phase and quadrature-phase data of the BPPM signals using either commercial digitizers or custom designed hardware. We are evaluating selected hardware for systems with emphasis on commercial-off-the-shelf COTS hardware to the extent practical. Approximate system requirements include a beam current range of 27 db, position resolution of 0.25% of beam aperture and relative phase measurement with 0.25 degree resolution at 201.25 MHz [1]. We present our results to date on two approaches, ZTEC Instruments ZT-410 digitizers, and a custom four-channel ADC analog front end board combined with National Instruments, Inc. digital I/O board. These two systems use PCI cards in a standard PC running Windows® XP. Our primary points of comparison include measured position resolution, phase resolution, phase linearity, minimum cycle rate and approximate cost for these portions of a BPPM system.

INTRODUCTION

As in our previous designs, such as those for the Spallation Neutron Source, we are planning to add phase measuring BPPMs to the LANSCE linac [2-4]. Rather than analog downconversion, we plan to use direct down conversion, and we want to use COTS hardware where practical.

In this paper we compare the performance of a pair of ZTEC Instruments ZT-410 oscilloscope cards (two channel, 250 MHz BW, 14-bit, 500 MSPS PCI) with a custom designed (four-channel 700 MHz, 16-bit, 130 MSPS) analog front end (AFE) mated to a pair of National Instruments NI PCI-6542 digital I/O cards. Each of these solutions represents $11k-$12k in hardware costs.

Both systems were evaluated using the same PC running Windows XP and a BPPM application written in LabVIEW®. The BPPM application contains all of the functionality needed for correctly calibrating, calculating and displaying the beam position and phase. Additional gain and analog calibration circuits will be required on the real system and these will be a custom design.

TEST CONFIGURATIONS

The computer PCI cards and their interfaces are shown in Figure 1. The ZTEC cards have BNC inputs that we use for top, bottom, right and left signals. The clock and trigger signals are routed in parallel to each card in both the ZTEC and the NI system.

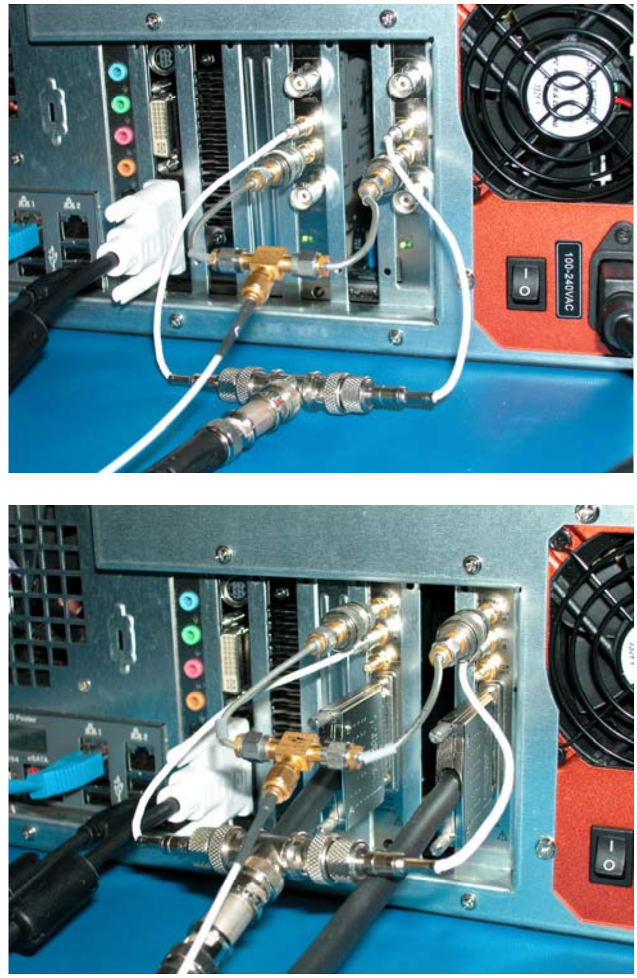

Figure 1: BPPM computer interfaces showing the ZTEC cards (top) and the NI/custom AFE (bottom).

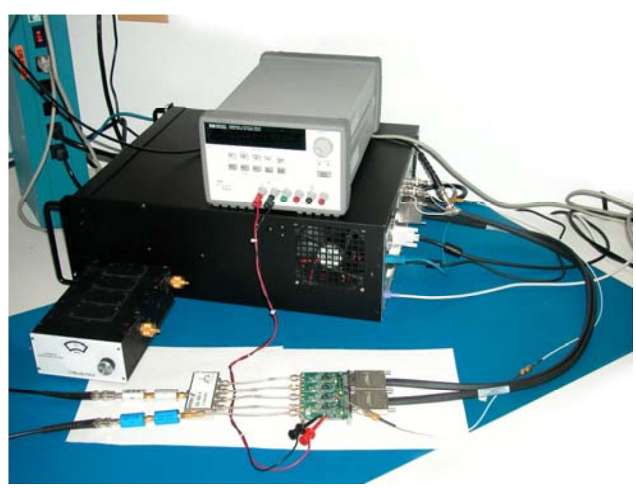

Figure 2: The custom AFE connected to the NI digital I/O cards. The filters and splitter are used to test both systems.

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The custom AFE and RF cables can be seen in Figures 2 and 3. Both systems are driven from a three-channel IFR 2026 RF generator which provides coherent sampling clocks and RF drive to the 4-way splitter with relatively low phase noise.

The ZTEC cards are clocked at 230 MHz, which is internally divided by each card to 115 MHz. The custom AFE is clocked at 35 MHz. These frequencies are correct for I/Q sampling of 201.25 MHz. Unfortunately the ZTEC cards cannot run as low as 35 MHz (after division) and the NI cards cannot be clocked higher than 100 MHz, therefore the systems must be compared as we would probably use them and not under exactly the same clocking rate. The NI cards could be clocked at other frequencies higher than 35 MHz and less than 100 MHz, but we would have had to build a custom synthesizer to generate the clock.

Figure 3: The custom four-channel AFE using Linear Technology LTC2208 ADCs. RF inputs are on the left and connections to the PCI cards are on the right.

DATA TAKING AND ANALYSIS

The metrics we use for comparison are system update rate, position resolution (relative to a 44.5-mm aperture LANSCE BPM), phase resolution and phase accuracy.

A typical screen shot of one tab of the BPPM test application is shown in figure 4. Here we see the raw magnitude and phase data for the four channels, after I/Q processing, but before gain and phase normalization on the NI/custom system.

Maximum Update Rate

While we don't need the BPPM measurements to update at the maximum 120 Hz machine rate, we want the rate to be as high as practical for human machine tuning procedures. For LANSCE operation we need to take beam data for up to1 ms.

The maximum cycle rate for the ZTEC system was about 1.3 Hz with a 1-µs averaging window and 1.39 Hz with 5-µs or longer averaging windows. The NI/custom AFE system ran at 12.8 Hz and 25.4 Hz respectively. The averaging reduces the number of final position and phase calculations performed by up to a factor of 1/t, where t is the averaging time, so the rates increase for lower measurement bandwidths.

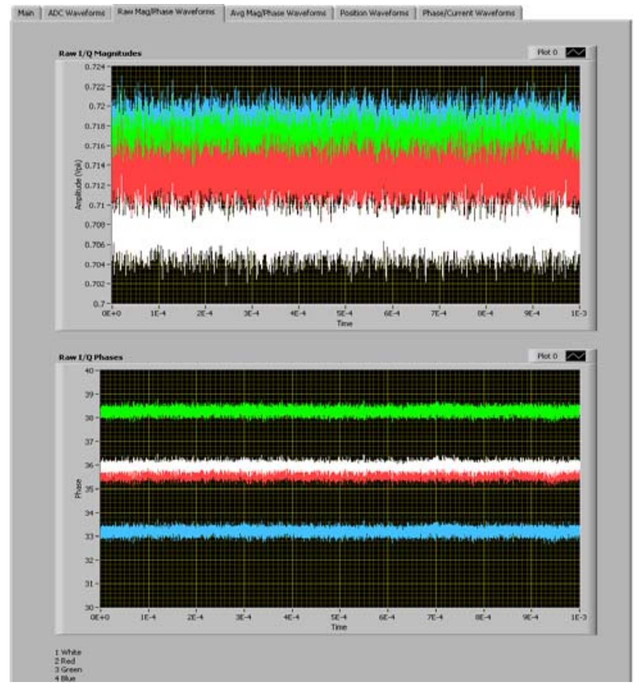

Figure 4: An example LabVIEW application screen showing the four channels of data before gain and phase normalization for the NI/custom AFE system.

Position and Phase Resolution

The LANSCE machine primarily operates at about 1 mA of peak beam current and can run with up to near 20 mA in some cases. Lower peak currents are not required, so the beam current range of interest about 26 dB.

We have selected a 6-dB headroom before ADC overflow, and we assume the centered-beam-amplitude to be 15 dB below that, or -21 dBFS for the ADCs. For these tests we define -21 dBFS as 20 mA, and -41 dBFS as 1 mA of centered beam respectively. We measured the position and phase resolution for each system at these two levels and for various averaging times of from 1 to 100 µs. The resulting data is presented in Figure. 5.

The NI/custom AFE system has no gain adjustment, so there were no changes made to the setup between the 1 and 20 mA beam cases. The ADC is set to 1.5 Vpk-pk as full scale, or 7.5 dBm for a 50-ohm differential input impedance. The ZTEC oscilloscope has multiple gain ranges of from 0.1 to 10 Vpk-pk, so we used the 2 Vpk-pk setting for the 20 mA beam case and the 0.1 Vpk-pk case for the 1 mA beam case.

The results of the resolution measurements show that either system can meet our requirements which are 22 µm-rms position resolution for the 44.5 mm pickups and 0.25 degrees-rms of phase resolution. Note that either system requires at least 10 µs of averaging to meet the position resolution specification, which is acceptable for our requirements.

Phase Linearity

The phase linearity of the two systems was measured under the larger beam current condition, as harmonic distortion is largest in this case. The linearity data is shown in the upper graph in Figure 5, where the ZTEC data is in blue. Both systems show excellent linearity; much better than ±0.5 degrees. Not surprisingly, the NI/custom AFE shows less distortion as there are no amplifiers on the front end of the ADCs. In reality, gain will be necessary for this system, so careful selection of amplifier harmonic distortion will be required.

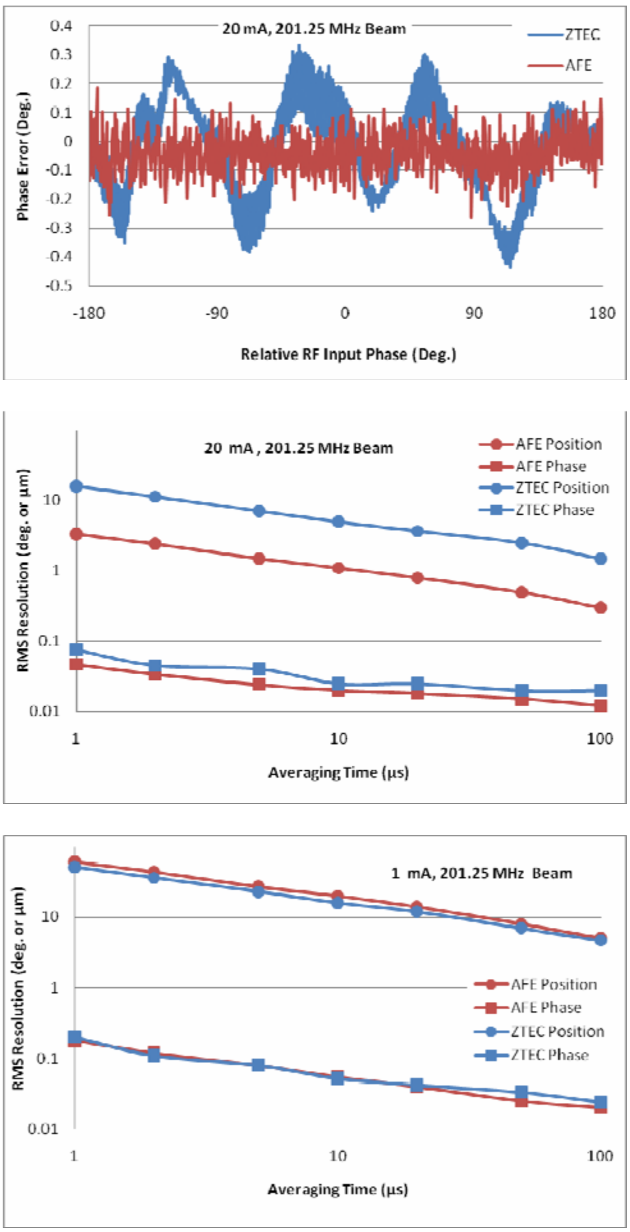

Figure 5: Comparison of phase linearity for 20 mA beam (top), RMS position and phase resolution for 20 mA beam (middle) and RMS position and phase resolution for 1 mA beam (lower) for the ZTEC and custom AFE systems.

Other Observations

There are differences between the two systems that don't directly relate to our requirements that were observed and worth mentioning.

The ZTEC sampling clock is internally divide by two, which requires more care in keeping the two independent digitizer cards synchronized at a known phase. Choices of sampling frequencies are also limited to those above 40 MHz, requiring more data to be transferred over the PCI bus, which may not be done as a DMA transfer. The NI PCI-6542 does not seem to work at sample rates much below 20 MHz in addition to being limited to 100 MHz.

Programmable gain of the ZTEC card is nice, and in fact is required to be used to meet the resolution requirements. Leaving the cards at the same gain settings for both current ranges leads to poor resolution performance at the lower current condition.

The ZTEC cards have an analog bandwidth of 250 MHz while the custom AFE has an analog bandwidth beyond 700 MHz. It is in fact very usable at 201.25, 402.5 and 805 MHz, all of the cavity frequencies used at LANSCE. Even at 805 MHz, this system would meet all of our requirements at averaging times of 20 µs or greater.

The worst case channel-to-channel isolation of the ZTEC cards is about 41 dB at 201.25 MHz. The custom AFE has over 80 dB of isolation at 805 MHz and below.

CONCLUSION

Both of these two prototype systems meet most our basic requirements for beam position and phase measurement. They are of similar cost and performance. Based on the superior performance of the custom AFE and its faster cycle cycling rate, it is our preferred choice between these two. We hope to evaluate additional systems before a final selection is made.

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