USE OF A RECONFIGURABLE VME MODULE TO MEASURE BEAM ENERGY AT THE LOS ALAMOS PROTON STORAGE RING *

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Abstract

Custom instrumentation has been developed at the Los Alamos Neutron Science Center (LANSCE) to measure the Proton Storage Ring (PSR) beam energy. The PSR accumulates up to $4 \bullet 10^{13}$ protons from the linear accelerator for delivery to a spallation neutron source. The energy of the beam injected into the PSR must be adjusted so that the revolution frequency matches the ring buncher frequency, otherwise a large momentum spread will cause increased losses in high-dispersion areas such as the extraction line. Errors in injected beam energy appear as deviations from the ideal 2.8 MHz revolution frequency. A low-cost reconfigurable VME module developed at LANSCE has been configured to calculate the PSR revolution frequency in real-time. The module connects directly to a raw analog wall current monitor output and uses analog signal conditioning electronics, an analog to digital converter, field programmable gate arrays (FPGAs) and an embedded floating-point digital signal processor (DSP) to calculate the revolution frequency. The module is compliant with the EPICS based accelerator control system and calculation results are sent through the network to the control room. This is an improvement over the existing method of manually measuring the frequency with an oscilloscope. Accelerator physicists can now simply observe the PSR frequency, which is dependent on beam energy, on a control room display.

INTRODUCTION

During normal operation the Los Alamos Proton Storage Ring (PSR) accumulates up to $4 \bullet 10^{13}$ protons over 600-700 µs with a repetition rate of 20 Hz, corresponding to a current of 125µA to the Lujan Neutron Science Center. At these intensities careful tuning of injection and the ring is paramount to maintain acceptable beam loss levels. It is important to properly adjust the energy of the injected beam so that the revolution frequency matches the 2.8 MHz ring buncher reference frequency. An offset in beam energy leads to a large momentum spread and to increased losses in high-dispersion areas like the extraction line. The method presently used to determine the beam energy is a time-of-flight measurement: beam is injected for 50 to 100 µs, then coasts for 50 µs, which corresponds to 150 turns. A wall current monitor pickup and an oscilloscope are used to acquire a wideband beam current waveform. After 600 turns, the time difference is measured between the beam current signal and 2.8 MHz buncher reference. The energy of the injected beam is then corrected by adjusting the phase of the last linac module before injection into the ring so that the two signals coincide within about 20 ns. Beam energy can then be adjusted to the nominal 800 MeV with a precision of 1 part in 10^4. Momentum spread in the injected beam causes the signal from the wall current monitor pickup to deteriorate after a few hundred turns, making this method less than optimal for daily operational use. Instead, the DSP module can digitize and process the wall current monitor signal and deliver a resulting beam energy measurement to the control room. The revolution frequency and its deviation from the buncher reference frequency can then be determined with the same precision as, but considerably less effort than the time-of-flight method. A comparison of the time-of-flight measurement with the new DSP based measurement is presented.

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TIME OF FLIGHT MEASUREMENT

Measurements were done to insure that the new DSP based measurement is as accurate as the time-of-flight method. Simultaneous measurements were made using both methods as the phase of the linac was adjusted through five degrees.

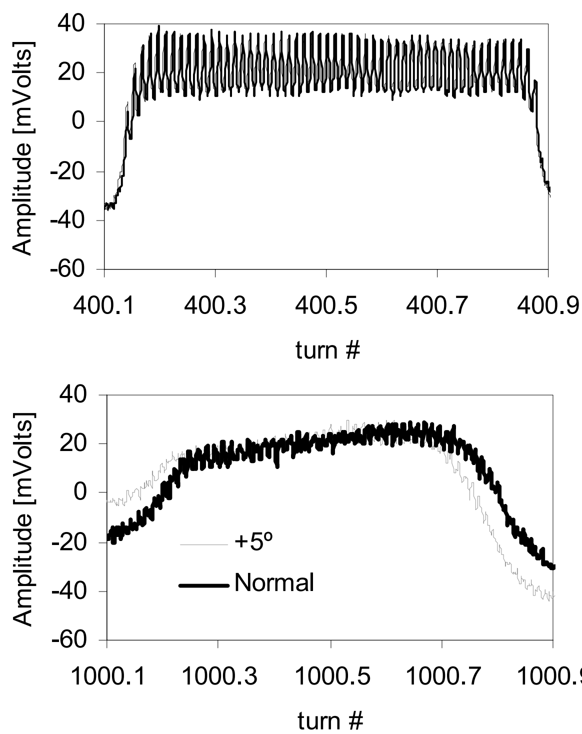

Figure 1: Wall current monitor signal.

The top trace in figure 1 shows the wall current monitor signal at turn 400 when the linac is properly tuned and then adjusted to +5º. Turn 400 is used because this is when injection has completed and coasting begins. At this point, the two traces completely overlap. The bottom trace shows the wall current monitor at turn 1000, which is 600 turns later. The time-of-flight measurement technique requires the accelerator physicist to judge by eye or with the aid of scope cursors the time difference that has developed on the bottom trace after 600 turns [1] [2]. A time difference of 18 ns is observed. At 2.8 MHz, the revolution period is about 357 ns. The difference in frequency between the two signals is then computed as 234 Hz as shown in equation 1.

$$\frac{18ns \cdot 2.8MHz}{600turns \cdot 357ns} = 234Hz \qquad (1)$$

ARCHITECTURE

The DSP module is a low cost ($3500), custom VME module that was recently designed and built at Los Alamos [3]. It was designed to be a flexible platform for accelerator instrumentation and control. The module was designed to be a part of the distributed and networked EPICS based control system at LANSCE, and as such would integrate well into other similar accelerator control systems [4].

Multiple, interchangeable, custom front end cards may be plugged into the module. These cards may be used for analog or digital input or output. In this application, a 65 million sample per second (MSPS), 12-bit digitizer is used. An on board 64 K word FIFO stores digitized data as it is acquired. Nine Altera Cyclone FPGAs support real time digital signal processing and may be programmed with VHDL or some other hardware description language. For this application, the FPGAs manage the data transport between the FIFO memory and the DSP. There is an Analog Devices 400 MFLOP digital signal processor embedded on the module that can be programmed in C. An architectural block diagram of the module appears in figure 2 [5].

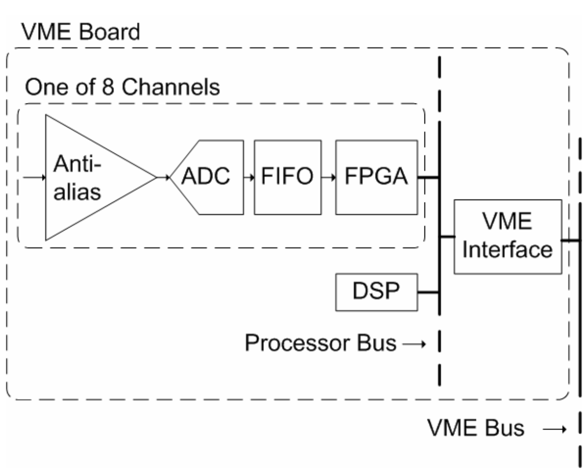

Figure 2: Board level architecture.

SIGNAL PROCESSING

The module has been programmed for this application to be a “PSR Energy Monitor.” Software was written for the embedded DSP to implement the signal processing chain described below.

The module accepts a hardware trigger from the LANSCE master timing system and then generates a gate that defines the boundaries of the acquisition time record. The time record, which is typically 600 μs long, is saved to a FIFO memory. The start and end of the record with respect to the hardware trigger are programmable via EPICS process variables. The hardware gate and the corresponding wall current monitor signal appear in figure 3.

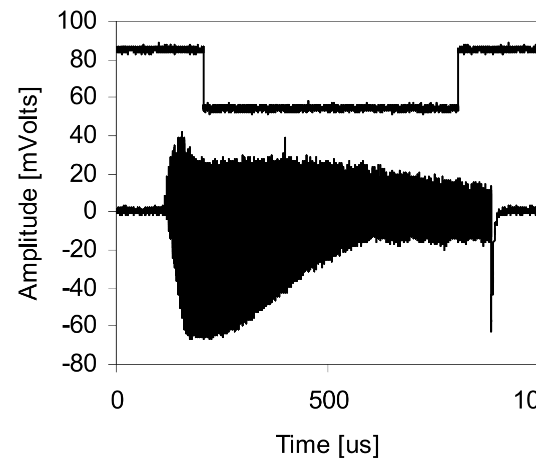

Figure 3: Wall current monitor signal with hardware gate.

An FFT is done on the first 8192 points of this record to give the operator a “rough-in” number for the PSR frequency with a spectral bin resolution of about 8 kHz. This waveform is displayed as an EPICS waveform process variable on a control room display. An operator should observe a peak near 2.8 MHz to get a sense that the module is connected and operating properly. In order to achieve higher resolution, the time record is then mixed down and decimated before another 8K FFT is done.

The 65 MSPS time record is mixed with a 2.5 MHz sine. This is done in software in the DSP after the signal is digitized according to equation 2.

$$y_n = x_n \cdot \sin(2.5MHz \cdot 2\pi nT) \qquad (2)$$

Where n is the sample number and T is the sample time. Samples in the time record are represented by x_n and the resulting mixed down waveform is stored in y_n. The mixing produces sum and difference frequencies which can be seen in the resulting spectrum in figure 4.

Peaks can be seen at 0.3 MHz and 5.3 MHz which are the difference and sum frequencies of 2.5 MHz and 2.8 MHz. There is a third peak at 3.1 MHz that represents a

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strong unmixed second harmonic at 5.6 MHz in the original signal.

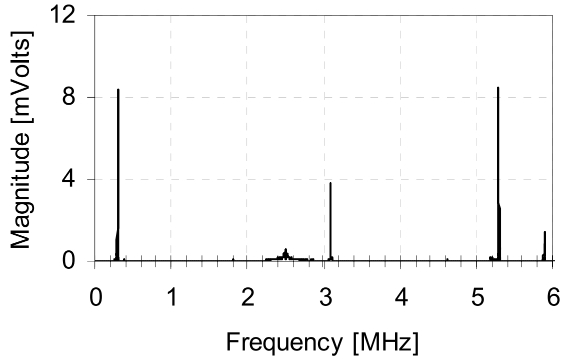

Figure 4: Sum and difference spectrum.

The spectral resolution of an FFT on this data can be improved by focusing on the 0.3 MHz peak representing the original 2.8 MHz signal.

The sum frequency is removed using a six pole low pass filter. The low pass filter is implemented as an infinite impulse response structure in the DSP software. Once the high frequency information is removed from the spectrum, it is safe to resample the signal at a lower sampling rate. High frequency components that would have created aliases have been removed as shown in figure 5.

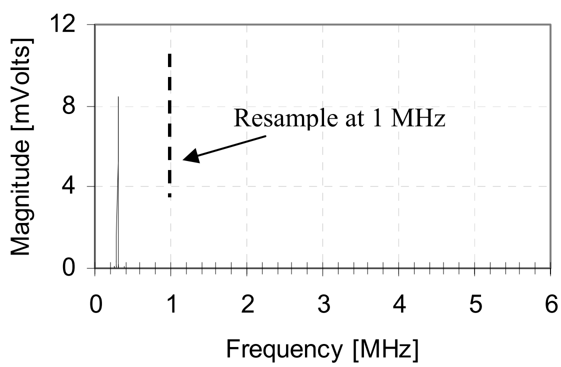

Figure 5: Low passed spectrum.

The time record is then decimated by 64, leaving 1024 points and a resulting resampling rate of about 1 MHz. A zero-padded 8K FFT is then done on this signal, yielding a mixed down spectrum from 2.5 MHz to 3.012 MHz with 127 Hz wide spectral lines. The DSP finds the maximum in the spectrum and reports it as the PSR revolution frequency. This value and the real-time graphical waveforms shown above are available in the control room.

The signal processing chain is summarized in figure 6. Point "A" represents the rough-in spectrum with 8 kHz wide bins and "B" represents the higher resolution spectrum with 127 Hz wide bins.

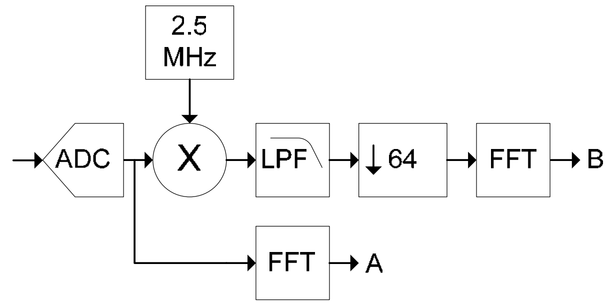

Figure 6: Signal processing chain.

DSP BASED MEASUREMENT

The DSP module was allowed to simultaneously process the same wall current monitor signals shown in figure 1. The resulting spectra are shown below in figure 7.

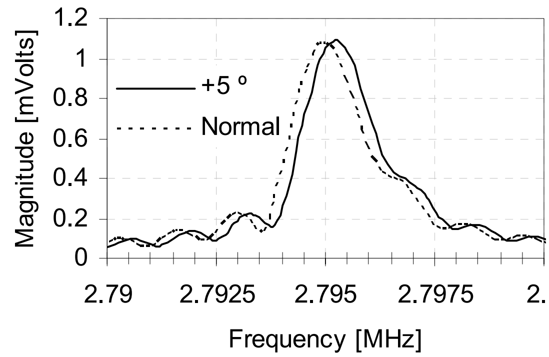

Figure 7: DSP based PSR frequency measurement for normal and +5 º linac conditions.

The figure above shows peaks that are 250 Hz apart, agreeing with results from the manual time-of-flight measurement.

REFERENCES

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