SLAC-PUB-5111 Rev
March 1990
(I/A)

THE ELECTRONICS AND DATA ACQUISITION SYSTEM FOR THE WIRE IMAGING SYNCHROTRON RADIATION DETECTOR AT THE SLC*

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Abstract

The Stanford Large Collider (SLC) located at the Stanford Linear Accelerator Center collides electrons and positrons produced in the linear accelerator pulse by pulse. We determine the energy of each beam by measuring the angle of deflection of the beam in the SLC extraction lines. Each extraction line consists of two bending magnets that produce synchrotron radiation, and a spectrometer analyzing magnet that deflects the beam. We detect the synchrotron light by using the emisson of electrons produced by Compton scattering off Cu-Be wires. We detect the $\sim$ 180 fC of charge on the wire by using the electronics system described in this paper. We also discuss the performance of the system, including the equivalent noise charge, crosstalk x channels, stability, and reliability.

INTRODUCTION

The Wire Imaging Synchrotron Radiation Detector (WISRD) measures the energy of a 50 GeV electron or positron beam pulse at the Stanford Linear Collider.[1] The WISRD measures the distance between two swaths of synchrotron light produced by the beam pulse in the Extraction Line Spectrometer (ELS)[2] by detecting the charge ejected from an array of wires that intercept each swath. Each beam produces a narrow (undispersed) and a wide (dispersed) swath. Typically, the undispersed swath is about four wires wide and the dispersed swath is about eight. The areas are expected to be equal, roughly 180 fC/10^{10} incident particles.[3] The electronic system must be able to detect the presence of these small signals and be stable over the time between electronic calibrations. Noise and instability in gains and offsets contribute to the error in the measured energy.

The WISRD electronics system has been described elsewhere.[4] Figure 1 is a block diagram of the system under consideration. The sequence control signals for the WISRD originate from the Timing Generator Module, and are generated from a downloaded pattern, in response to the start signal which is derived directly from the accelerator. The pattern comprises a list of ordered pairs of clock values and output values exhibited as an array of digital signals which comprise the Auxiliary Timing Bus.

The timing of three sequence control signals with respect to the beam determines the response of the WISRD electronics: The time of the calibration strobe (ϕ_{cal}), and the times of two successive write strobes to the analog memory (ϕ_{w1} and ϕ_{w2}). The integration time-constant of the write strobes is very much shorter than the shaping time sampled, and we approximate the results as instantaneous samples rather than gated integrals of the analog waveform. We adjusted ϕ_{w1} to sample the peak of the beam-induced signal, ϕ_{w2} to sample its minimum, and ϕ_{cal} to match the analog response of the calibration to that of the beam-induced signal. We measure the charge ejected from the wire by taking the difference in pulse height of the two samples; this is done in software. The samples at ϕ_{w1} and ϕ_{w2} are written to analog memory in parallel, over 24 channels. These samples are read out serially and separately digitized, encoded, transmitted over $\sim$ 1000 ft of cable, decoded, and stored for CAMAC readout. Each wire in the detector is connected to its own electronics channel. However, there are a few instances of shorted pairs of wires.

We calibrate the WISRD by injecting known charge into the front end of each preamp channel; this is accomplished by pulsing calibration capacitors on the DAQ modules with a voltage selected through the Cal/Comm board.

CALIBRATION OF THE WISRD

The CAL/COMM board drives five independent calibration buses as shown in Fig. 1. All buses share the same amplitude, but each may be pulsed individually. CAMAC control provides eight possible configurations:

- pulse none or external calibration;
- pulse the first channel;
- pulse the second channel,
- third channel, or
- fourth channel in every set of four adjacent channels;
- pulse all even channels;
- pulse all odd channels; or
- pulse all channels.

Except for edge-effects at the level of 24 channels per DAQ module, nearest-neighbor wires are connected

* Work supported by Department of Energy contracts DE-AC03-76SF00515 and DE-AM03-76SF00010.

Presented at the IEEE 1989 Nuclear Science Symposium, San Francisco, January 15-19, 1990.

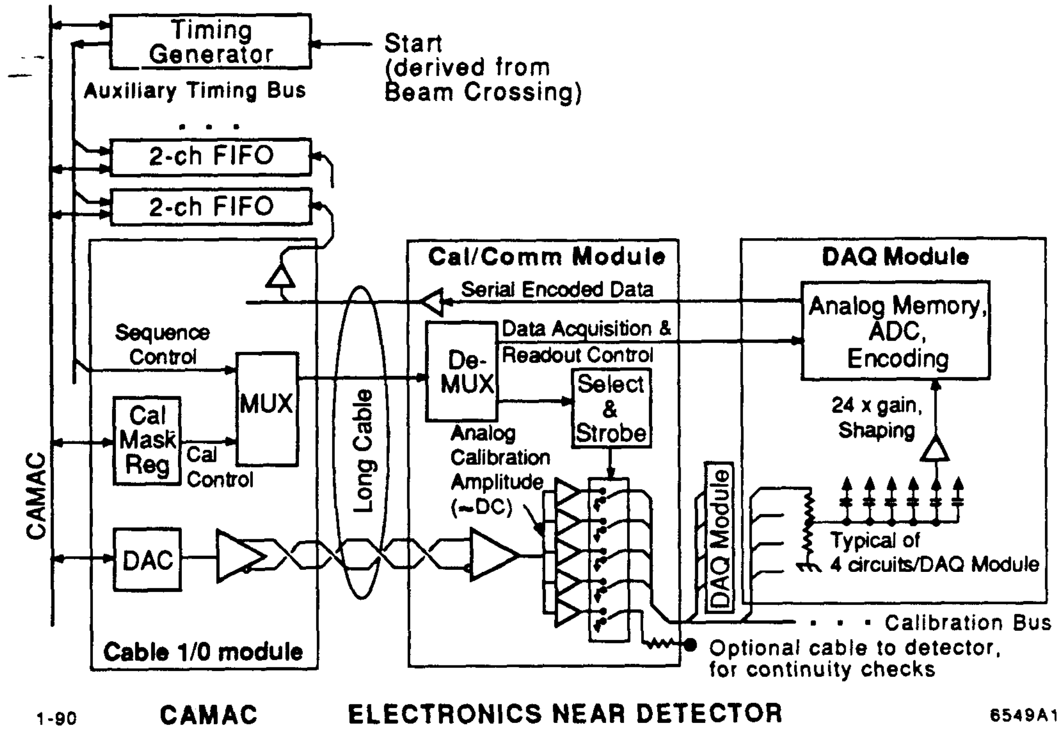

Fig. 1. WISRD electronics block diagram.

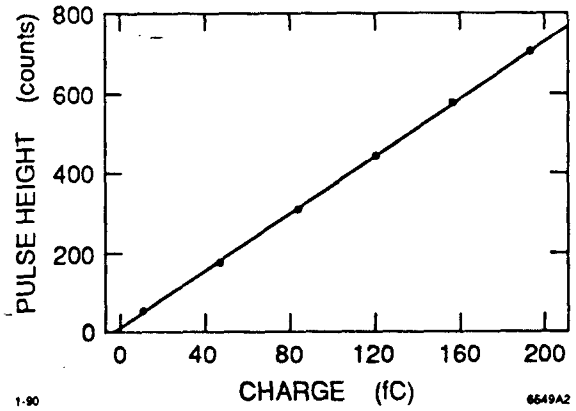

Fig. 2. Calibration response of a single channel. The response is typically linear in the range of 0 to 200 fC.

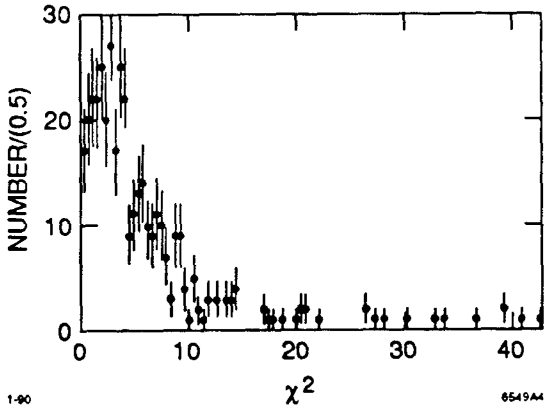

Fig. 3. Distribution of χ^2 from linear fit to channel transfer function in the calibration range.

to nearest-neighbor channels. We make no distinction between crosstalk among wires and crosstalk among channels. We pulsed only even and odd channels to determine the crosstalk. We calibrated all channels normally and determined the gain. The average gain of the unpulsed channels was then divided by 2 (because two pulsed channels are adjacent to every unpulsed channel). The crosstalk was determined to be 5% on average. We do not expect this effect to contribute greatly to the error in determining the energy.

An example of a calibration is shown for channel 250 in Fig. 2. We see that the response is linear in the regime of interest (0 to 180 fC.) The calibration loop saturates at 350 fC. We fit all channels to a linear response function to measure the gains and the offsets.

Figure 3 shows the distribution of the χ^2 residuals of the linear fit as a function of wire number. We used six separate calibration amplitudes in the fit, and therefore the fit has four degrees of freedom. Groups of

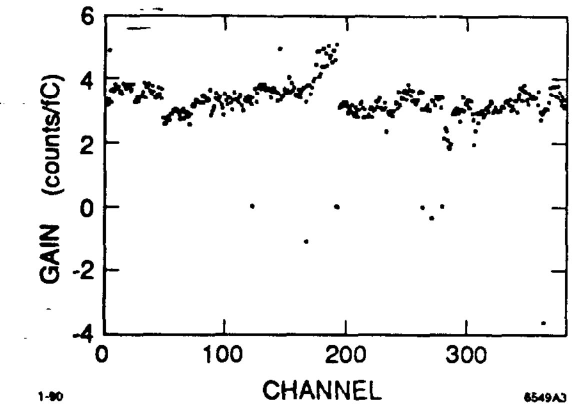

Fig. 4. Distribution of channel gains. The average gain is 3.3 counts/fC.

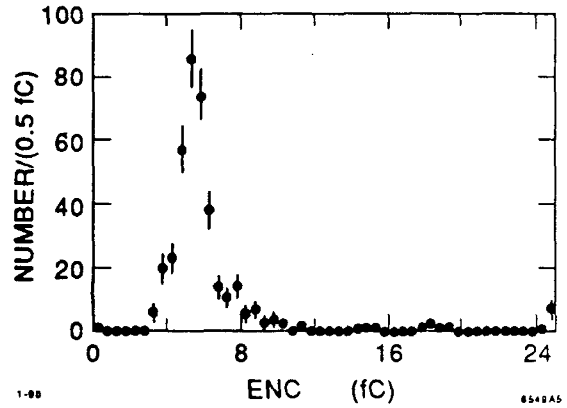

Fig. 6. Auto-correlation of gains. The average gain drift amounts to 1% over 14 hours.

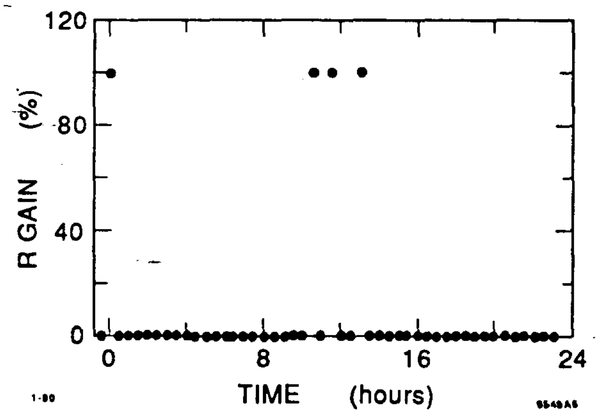

Fig. 5. Distribution of equivalent noise charges for the electronics.

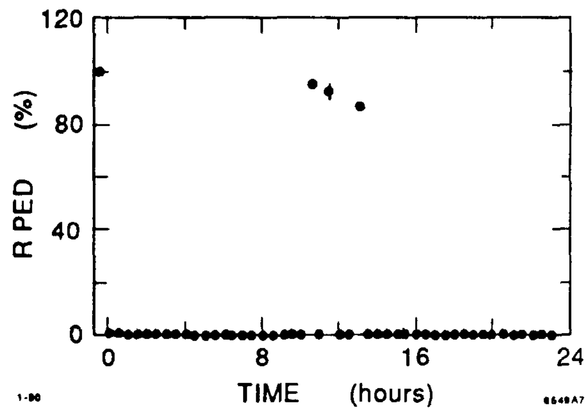

Fig. 7. Auto-correlation of offsets. The average rms offset drift amounts to 0.77 fC over 14 hours.

24 channels with large χ^2 indicate module-level problems. The remainder exhibit values near that expected for a four degrees of freedom fit.

Figure 4 shows the distribution of channel gains as a function of channel number. We see that there are seven channels with gain near zero (these channels are dead), two channels with substantial negative gain (they have a simple electronic problem), and the remainder with an average gain of 3.3 counts/fC.

The wire-to-wire spacing is approximately 100 μm. A change of 17 MeV in beam energy corresponds to a change of one wire spacing in the distance between the synchrotron stripes. We determine the position of the synchrotron beam by fitting a Gaussian function to the charge distribution on the wires. The relative wire positions are known to the level of 5 μm from a survey of wires. The contribution of the electronic calibration toward the systematic error in determining the energy of the beam derive from the stability of the gains (1%), the stability of the offsets (an average RMS change of 0.77 fC), and the dispersion of the calibration capacitance ($\sim$ 10%). The errors add in quadrature with the RMS change, with the offsets contributing 0.77 fC out of the typical signal of 30 fC or 2.5%. Obviously we are currently dominated by the dispersion of calibration capacitances. We intend to measure the calibration capacitances by using an external calibration. Even so, we estimate the contribution of the calibration to the error in determining the energy of the beam to be 10.4% of a wire spacing or 1.7 MeV.

Figure 5 shows the distribution of equivalent noise charge (ENC) for all channels. We measure the ENC by averaging the root-mean-square (RMS) deviations at each calibration amplitude in ADC counts. We then divide the number so derived by the gain of the channel to convert this value to fC. The average ENC per channel is nearly 6 fC. Dead channels (those with gain near zero) therefore have high ENC and are not included in the average. We expect to reduce the average ENC by a factor of 2 by replacing the cables between the electronics with shorter cables of higher impedance.

We estimate the contribution of the ENC to the systematic error in determining the energy by assuming that the 180 fC of collected charge is distributed evenly over eight channels. Then, the error in the position measurement is approximately:

$$\delta x \frac{\sigma_{ENC}}{Q} \quad , \tag{1}$$

where δx is the RMS of a box eight wires wide (or $8/\sqrt{12}$) and Q is the total charge in that box. We therefore expect the error to be 9% of a wire spacing or 1.5 MeV.

Figures 6 and 7 show the autocorrelations of the gains and offsets as functions of time. We take the autocorrelation to be:

$$R_{o,g}(t) = \frac{\mathbf{v}(0) \cdot \mathbf{v}(t)}{\sqrt{[\mathbf{v}(0) \cdot \mathbf{v}(0)]\,[\mathbf{v}(t) \cdot \mathbf{v}(t)]}} \quad , \tag{2}$$

where $\mathbf{v}$ is a vector with a dimension for each channel measured, and each component value is the offset or gain measured at time t. The data consists of a total of five calibrations taken over a 12-hour period. The binning of the plot is in one-half hour periods. Two calibrations were done within one-half hour of a each other yielding an error bar on one entry. This plot shows that the calibrations are reasonably stable as a function of time. Only the calibration 14 hours later has a correlation of less than 90%. The MARK II detector at SLAC is generally recalibrated every eight hours. We therefore expect that our calibrations will be stable enough to keep the contribution of electronic drifts to the energy error to $\sim$ 1.5 MeV.

Conclusions

This paper has presented the current electronic performance of the WISRD. The electronics is linear and stable. We see an equivalent noise of 6 fC in the electronics of the device. We estimate that the total contribution of the WISRD electronics to the systematic error in determining the beam energy is 2.3 MeV. We expect to improve this number to 1 MeV as we reduce the equivalent noise charge and measure the calibration capacitances.

Acknowledgments

The authors thank Mark Petree and David Wilkinson for their continuing support of this endeavor.

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