TESLA Report 2005-11

Direct wire read out electronics for the Hasylab-Zeuthen-Wirescanner

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Abstract

Wire scanners are used to measure the profile and the position of particle beams and are therefore ubiquitous in accelerator facilities. A wire passes through the electron beam, causing a charge on the wire and the deflection of beam particles itself. The particles bended by the wire are detected by a scintillation counter. The maximum of the photomultiplier signal corresponds with the center of the beam profile. Independent information is provided when detecting the charge deposited on the wire.

Following, is a short introduction of the physical difficulty of detecting the signal influenced on the wire, a possible realization of the necessary electronics and showing preliminary results of measurements carried out at the Tesla Test Facility TTF I in Hamburg and the Photon Injector PITZ at Zeuthen.

Physical problems of direct wire read out

The electron beam consists of several single short bunches, separated in time by up to one microsecond. The time of interaction between the wire and a single bunch is in the order of picoseconds. If one presumes a single charge transfer for this interaction, a basic equation has to be taken into account, which correlates the stationary and nonstationary behavior of a linear, causal and time invariant mathematical system, approximated by a first order low pass filter:

$$t \quad * f \quad = \quad 0.35$$

where **t** is the pulse rise time (10% – 90% of the signal) and **f** is the -3dB cut-off frequency of the system. Obviously, a pulse rise time in the order of picoseconds requires an upper cut-off frequency in the order of THz with corresponding very expensive electronics. Standard electronics (GHz - range) become available when stretching the original pulse induced by a factor of thousand.

Realization of the read out electronics

The classical approach for such problem is a conventional charge amplifier with an input capacitor in the 1 nF region and a RC feedback-network with a resistor R of several ten MΩ and a capacitor C of few tenth of pF [1]. The new concept consists of the application of a logarithmic amplifier with an adapted input range of several orders of magnitudes (nV to mV) and a peak signal detection capability with an output signal direct and linear proportionally to the input voltage. A matching input network with a capacity of a few pF guaranties the analog storage of the ultra short input pulse. An additional feature is the input / output resistance of about 50 Ω with subsequent acceptable signal-to-noise ratio in the noisy environment of the beam pipe. This specialized charge preamplifier is realized on the basis of an evaluation kit, available from the Integrated Circuit supplier Analog Devices [2]. Initially this type of electronics was implemented at TTF I and PITZ I in the bidirectional RF couplers between the klystrons, the gun and the booster cavities. Later on a manufacturer's design error of the evaluation kit forced us to develop our own peak envelope detector (PED) board, carrying two RF detector channels for detection of forward and reflected RF signals originating from the bidirectional RF couplers. Figure 1 gives an impression of the new developed charge amplifier.

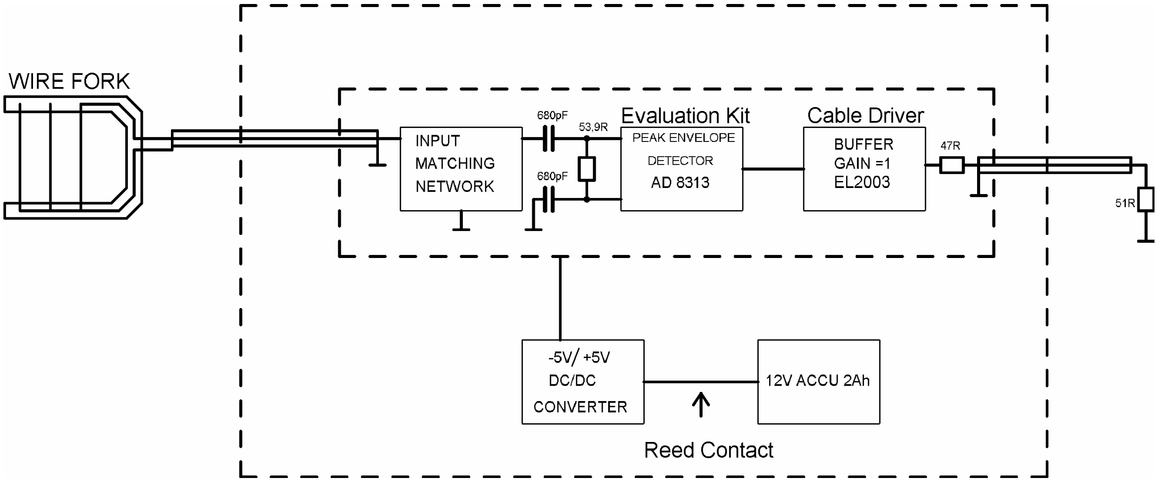


Figure 1: Circuit diagram of the direct wire read out electronics for the wire scanner. Only one of three wires is connected.

A first test of the charge amplifier was performed in the laboratory by mean of a MODEL 10050 PULSE GENERATOR from Picosecond Pulse Labs and a Tektronix TDS 3054B DPO 8GS/s sampling oscilloscope. The AC-coupled unipolar rectangular input signal had a 10 mVpp amplitude and a minimal impulse length of 100 ps (note that we expect a signal, which is a hundred times shorter). Figure 2 shows the Gaussian-like response of the charge amplifier to a 100 ps rectangular input signal.

By comparing the input charge

$$Q_{in} = I_{in} * t_{in} = U_{in}/50\Omega * t_{in} = 10\text{mV}/50\Omega * 0.1 \text{ ns} = 0.02 \text{ pC}$$

(invisible in Figure 2) with the output charge (for simplicity the Gaussian curve is approximated by a rectangle with 40 mV by 40 ns)

$$Q_{out} = \text{Uout}\backslash 50\Omega * t_{out} = 40\text{mV}/50\Omega * 40 \text{ ns} = 32 \text{ pC}$$

we conclude that the charge amplification factor is about 1600 and the time-stretching factor is about 400. The asymmetrical output signal of the detector electronics with a typical voltage of a few 10 mV and time duration of a few 10 ns is well suited with the requirement of long coax cables from the preamplifier to the final read out electronics.

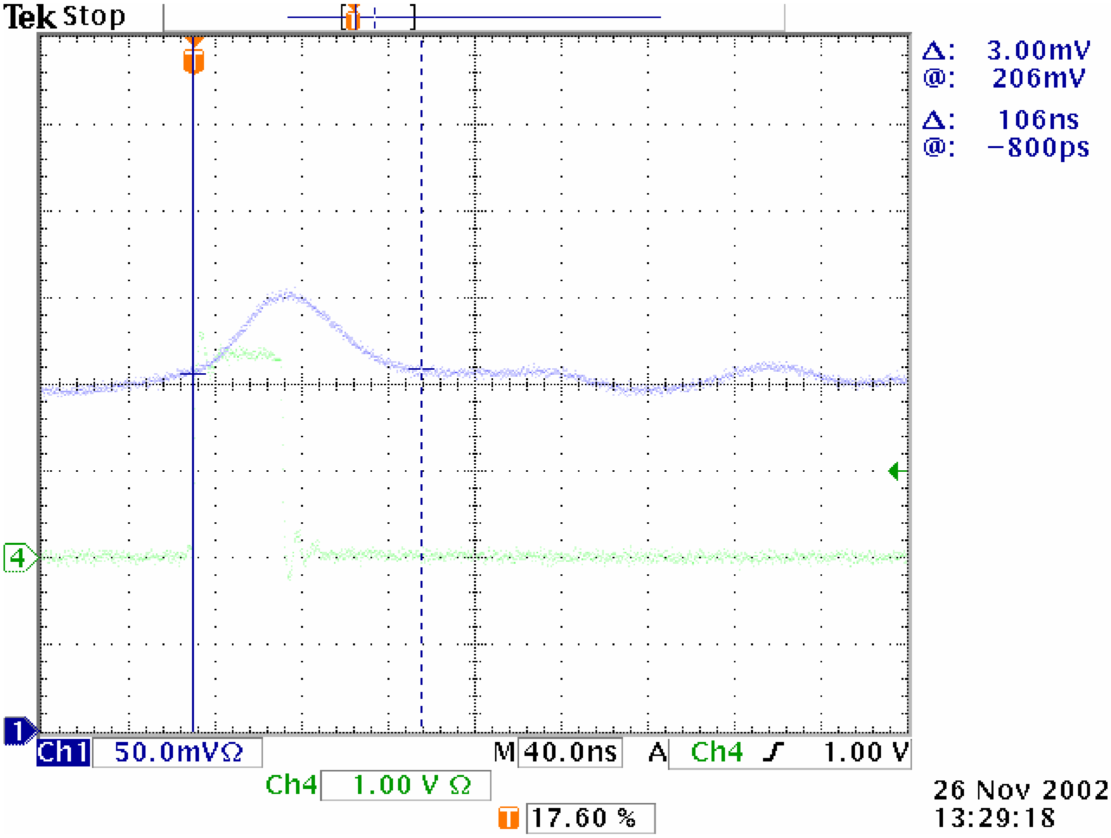
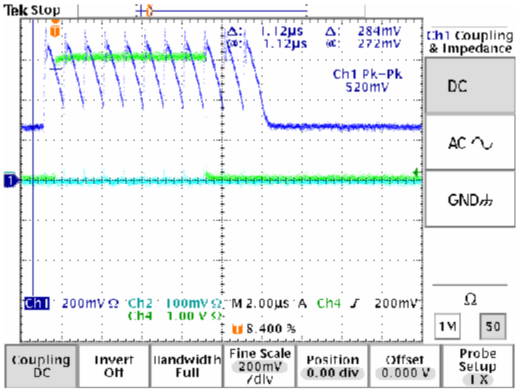


Figure 2: Channel CH1 – charge amplifier response of a 100 ps rectangular input signal of 10 mVpp (not shown). The signal at channel CH4 is the scope trigger.

First peak envelope detector (PED) results at the TTF and PITZ

A first test of the direct wire read out was performed with wire scanners installed at TTF and PITZ. During the test run, the PED output signals were recorded by the TDS 3054B sampling oscilloscope and the data was saved via internet. This procedure had the disadvantage that measuring one spectrum took several minutes. Since the wire in the beam pipe acts like an antenna we amplified all electronically background created when the beam was produced and transported trough the pipe. Instead of a ‘quiet’ line with a small overloading of ‘white’ noise we detected a saw-tooth-like signal, strictly correlated to the laser beam, consisting of 11 pulses with 1 µs distance between each other (multimode-regime). This can be seen in figure 3. Now we moved the wire into the neighborhood of the beam. Figures 4, 5 and 6 show the signal (dark blue) of the direct wire read out as the wire approaches the beam. The signal (light blue) of the photomultiplier is given as a reference. We discovered a clear signature of the direct read out signal strongly correlated with the measured PMT-signal.



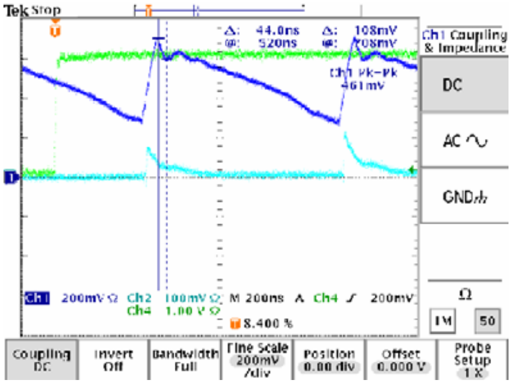
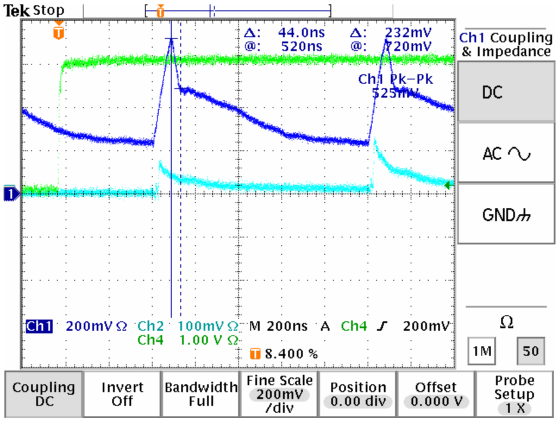


Figure 3: Channel CH1 shows a sequence of 11 beam induced pulses at the output of the PED. Channel CH2 holds the PMT output pulses, the signal at channel CH4 is the scope trigger.

Figure 4: Channel CH1 gives the direct wire read out signal with the wire out of the beam.



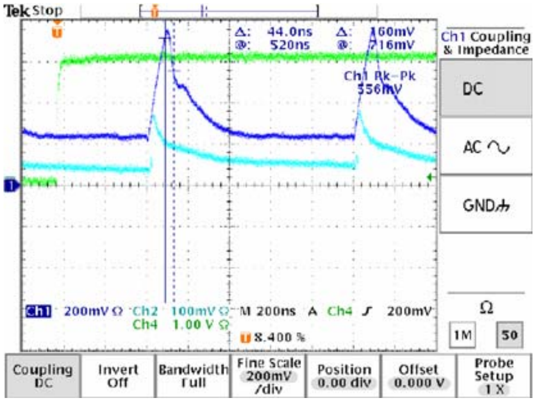


Figure 5: Channel Ch1 direct wire read out signal with the wire in vicinity of the beam.

Figure 6: Channel Ch1 direct wire read out signal with the wire in the beam.

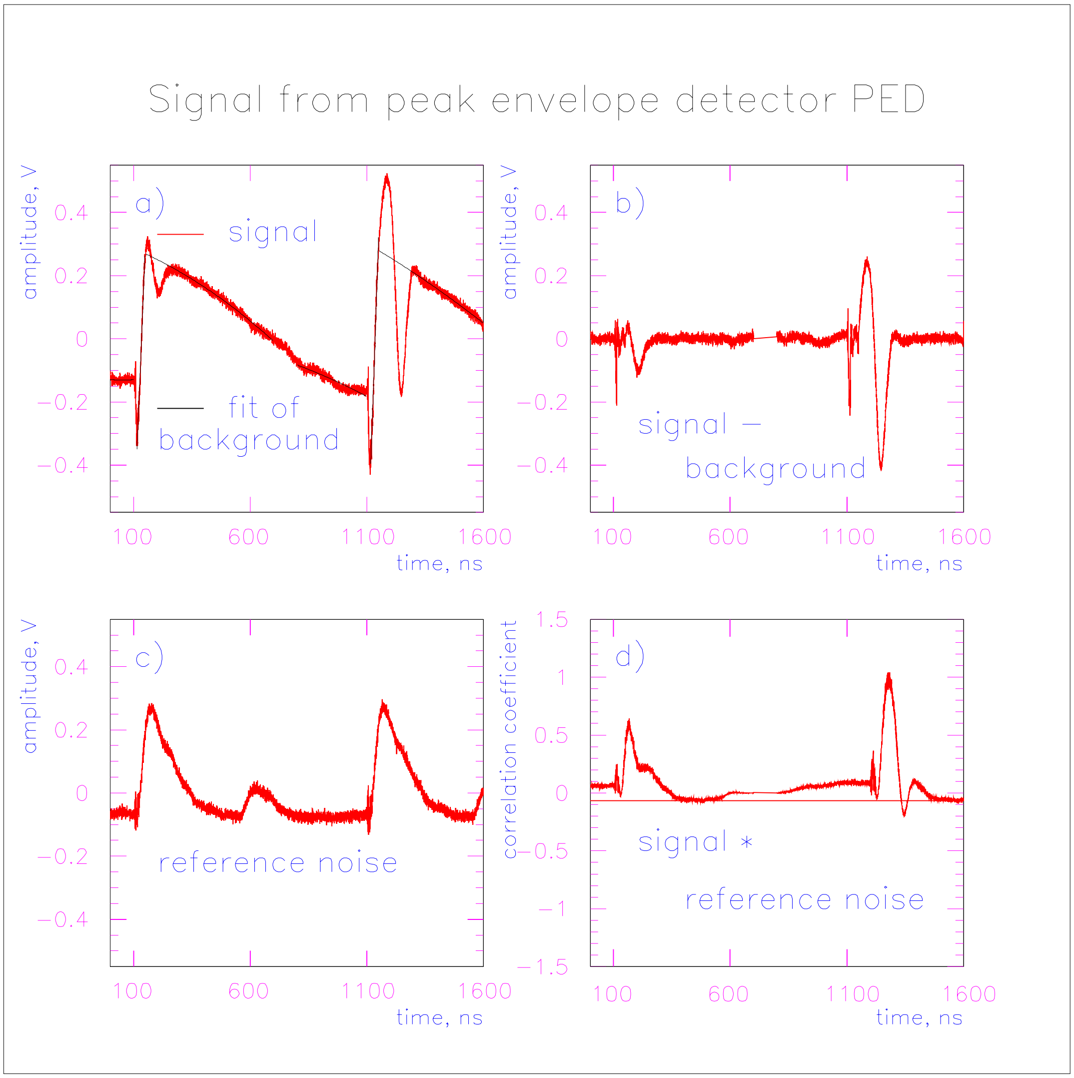


Figure 7: a) Signal with the fit of the background. b) Signal with subtracted background. c) Background (reference noise) taken at a position out of the beam pipe. d) Correlation between the background taken from c) and the signal.

In order to get an impression of the sensitivity of this read out, we performed a scan over the beam region. We moved the wire into the position next to the beam and took a single shot measurement using the oscilloscope. Afterwards, the data was stored and the procedure repeated with the next position. The data analysis was done offline. Two different methods were applied – first we made a least square fit with the background and determined the signal above this background. In figure 7 a) the signal with the fitted background for one step (relative x-position is 2.1 mm) of the scan is shown whereas figure 7 b) represents the signal subtracted by the fitted background. This method is time consuming and needs information of the background and the signal at each step. The second approach is based on a correlation analysis. As a reference we recorded the beam

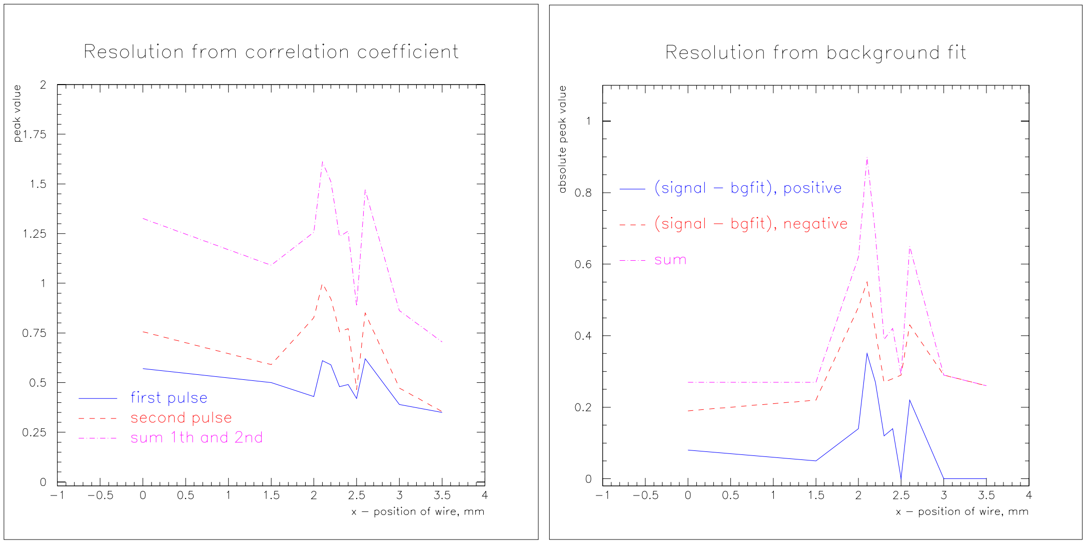


Figure 8: Results of a scan trough the beam. Both methods - correlation coefficient and background fit - give a clear signal above the background.

induced electronically noise with the wire being placed outside of the beam tube. Figure 7 d) shows the relative correlation coefficients calculated at the x-position 2.1 mm. For each step of the scan trough the beam the related correlation function was calculated from the signal and the reference.

In Figure 8 results of the scan through the beam are shown. Visible is a clear signal of the beam above the background. Because the scan was performed over a relative long time period (about one hour) the reason for the two peaks could be either a jump of the beam or missing signals at this position.

Conclusion

A first test of the direct wire read out with a peak envelope detector (PED) was performed. Due to the slow data read out and offline data analysis we had no possibility to improve the set up of our device. Nevertheless we have seen a clear signal above the background. A promising method is a correlation analysis which could be used with a fast real time data acquisition system.

References

[1] R. Fulton et al. NIM A274 (1989), 37-44.

[2] Analog Devices, www.analog.com