PULSE DIGITAL TO OPTICAL CONVERTER FOR NUCLEAR ELECTRONICS

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Abstract: Digital-to-optical converter was developed specially for pile-up and dead-time characterization of nuclear devices, but its application is probably wider. The converter generates 10ns-wide pulses in visible (660nm) range, with 8-bit resolution of the optical power, the data rate is up to 20Ms/s. The output optical pulses are generated by high-luminosity LED diode coupled to the optical fibre. A crucial task of the design is eliminating of influence of the parasitic capacitances in fast switching mode.
Keywords: Digital-to-optical, nuclear electronics, pile-up.

1 INTRODUCTION

Pile-up overloading of nuclear radiation registration devices with solid state semiconductor detectors is one of most common reason of distortion of the registrated energetic spectra and of real intensity of the particle flux. Extended characterization with respect to the pile-up and the dead time effects is a crucial task to eliminate device systematic errors during the data processing. The method proposed employs significant sensitivity of solid state semiconductor detectors to the light, which is normally considered as disadvantage. Application in scintillation systems equipped with the photomultipliers or photodiodes is a matter of course.

Nature of a free charge generation by interaction of a charged energetic particle with semiconductor material consists of coulomb force between the particle and the electrons in the atomic shell. If the energy transferred by the coulomb force is higher than bounding energy of the electron, the electron is set free from the atom. Total charge gathered by the detector electrodes and transferred to the charge sensitive amplifier (CSA) is proportional to total number of the electrons, which are set free along the particle trajectory in the depleted detector volume (some electrons will recombinate before gathering). The time-domain waveform of the charge flow into the CSA input depends on various parameters, e.g. detector material and geometry, electron and hole mobility, gathering electrodes geometry, localization of the particle trajectory in depleted volume, input impedance of the CSA, etc. Detailed input waveform is usually not known and not monitored, important is a total signal response on the CSA output, or on the output of the whole analog preprocessing chain.

The solid-state detector photostimulation method is based on the fact, that free charge in the depleted volume can be generated by the photoeffect – e.g. in visible range – instead of charged particle coulomb interaction. Since the visible light photon has much lower energy, a single energetic particle must be replaced by large amount of the photons – to release equivalent free charge. To approximate the charge flow time waveform as much as possible, the photons must be injected to the detector in very short time, since a real energetic particle interaction time is very short ($\sim 10^{-8} \div 10^{-10}$ s).

In most applications the response of the analog preprocessing electronics (shaping time ~100ns ÷ ~10µs) is very slow in comparison with the particle interaction time, so that a very short optical pulse (~ ns) applied to the detector will produce the same response on the system output as in the case of a real energetic particle. The optical power (corresponds to number of injected photons) of respective optical pulse must be regulated to simulate required equivalent energy.

2 PROGRAMMABLE PHOTOSTIMULATION

For simulation of a real energetic particle incident flux to the semiconductor detector by the photostimulation with general time and energy distribution, a simple programmable device PPS (Programmable Photostimulator – see Figure 1) was developed. The PPS consists of memory of energies and of memory of time periods, so that each particle preprogrammed in the memory is described by its energy and by the time period from the previous particle. The required particles distribution scheme is generated by a simulation programm in PC and then downloaded to the PPS memory. After the download, the PPS simulates particle by particle according to the distribution scheme. Most common time distribution to simulate real natural processes (radioactive decay, cosmic rays) is stochastic with exponential distribution (Poisson process), special distributions (periodic, double-pulse, etc.) is a matter of course. The energetic distribution depends on the concrete simulated process.

A special attention is paid to specialized pulse digital-to-optical converter (DOC), which must be able to generate very short optical pulses with high repetition rate and with required optical power resolution. All other parts of the PPS could be in principle replaced by dedicated PC.

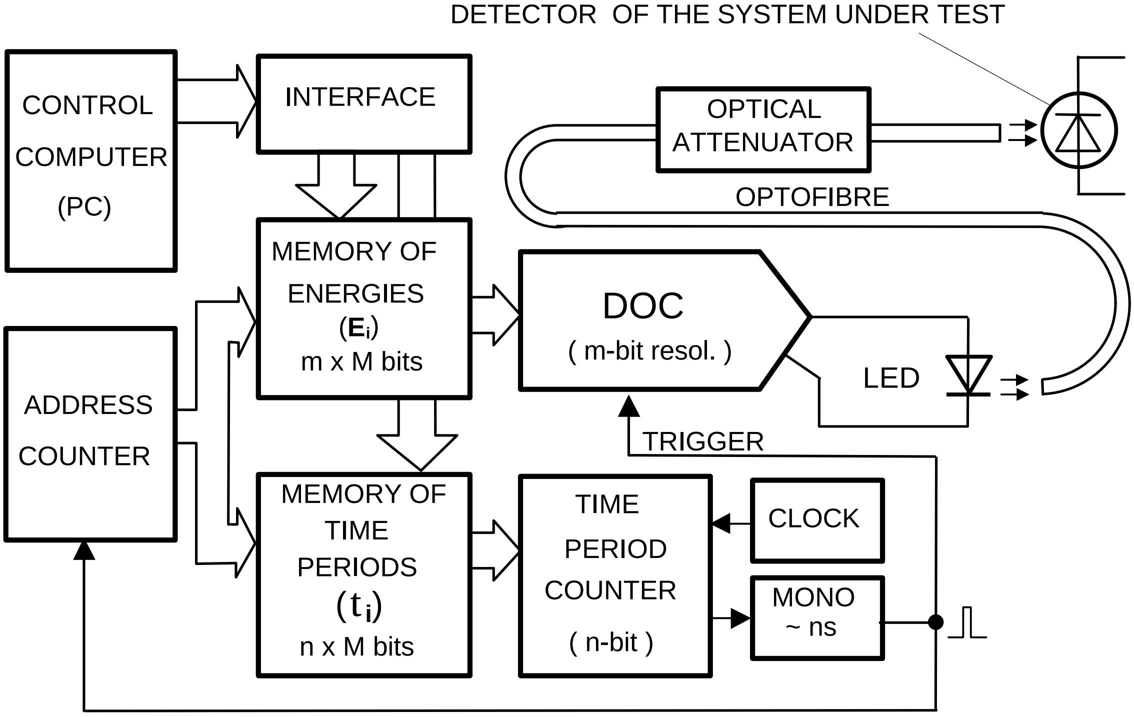

Figure 1. Programmable photostimulator PPS

The first version of the PPS (the PPS-1) was practically implemented with m = 8-bit optical power resolution, n = 24-bit time period resolution and with M = 32 768 memory size.

3 DIGITAL-TO-OPTICAL CONVERTER

As a light source for the DOC there was a high-luminosity LED-diode selected with wavelength in visible range (660nm) . The LED is coupled to the optical fibre, feeding the light pulses to the detector compartment. Number of the photons generated during electrical pulse length of 't ' through the LED crystal is assumed to be proportional to the expression

$$N_p \sim \int_0^t i(t)\,dt = q_t \qquad (3.1)$$

which practically means a charge flow during respective time period 't '.

As an optimal short pulse DOC seems a special digitally controlled current source, which is switched ON/OFF by a logical trigger signal. The LED current in OFF state must be zero, the current in ON state must be preset with required amplitude resolution in the time shorter than required time resolution. Principal functional block diagram of such a device is shown in Figure 2.

Even in the case of ideal digital-to-current conversion such a design cannot guarantee linearity of digital-to-light power conversion – due to the LED nonlinearity in 8-bit-coded dynamical range (even at fully static operation). Unfortunately, any feedback linearization is at required high-speed pulse operation unpractical. Due to very fast transitions during switching the current on-off across the LED, very fast dynamical output response of applied current source is required. Moreover, the real amount of the charge transferred to the process of electrical - light conversion in the LED is significantly influenced by parasitic capacitances of the LED itself, of the electronic switch and of all the wiring around. Another relevant evidence is, that the current source is not loaded with usual zero-impedance zero-voltage summing point, but with a nonlinear load – the LED diode.

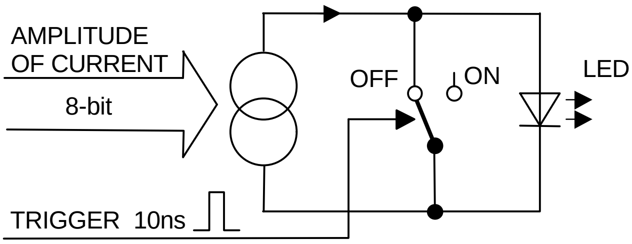

Figure 2. Principal functional diagram of the DOC based on digitally-controlled current source and high-speed switch.

Taking to account above mentioned facts, as most practical solution of (pseudo)current source was simple D/A converter selected, with binary weighed resistors and high-speed p-channel MOS switches. Practical implementation of the DOC is described in electrical scheme in Figure 3.

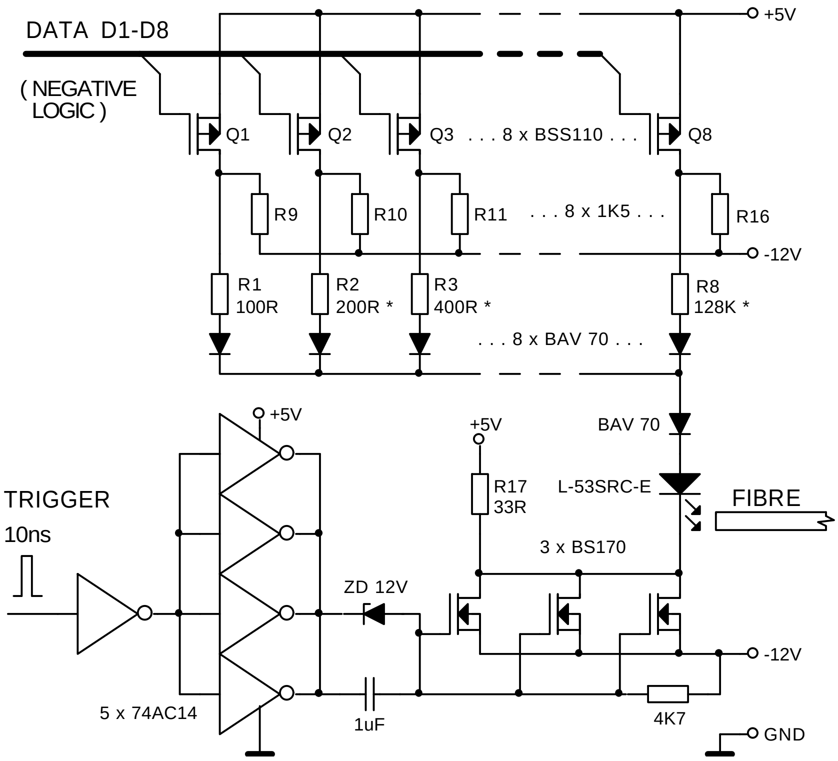

Figure 3. Practical implementation of the DOC for Programmable photostimulator PPS-1.

The LED is fed from (pseudo)current source implemented by weighed resistor set $R_1 \div R_8$ and by set of p-channel SIPMOS transistors $Q_1 \div Q_8$. The cross influence is suppressed by set of low-capacitance diodes. To keep current character of the LED feeding, relatively high (precisely regulated) supply voltage 17V across the system is used. The low-side switch is implemented by three high-speed n-channel TMOS transistors in parallel, to charge/discharge parasitic capacities of the network as quick as possible. The switch works at level –12V, the logic level shift is performed by Zener diode bypassed with a capacitor. Since the parasitic capacities of the MOS transistors play important role in the design, the high-side switches must be set at least 30 ns in advance of the low-side switch action. This allows to balance the charges on the parasitic capacities by the resistor set $R_9 \div R_{16}$ in time.

Quick return of the LED cathode potential after switch-off is performed by relatively low pull-up resistance R17. Its power dissipation at maximal duty cycle (10ns/50ns) is 1,75W. Backward charge flow through the LED is reduced by additional low-capacitance diode in serial with the LED. To suppress influence of parasitic impedances, the weighed resistances $R_1 \div R_8$ were implemented by small SMD chip resistors and with appropriate low-capacitance PCB design. Simple binary weighing (100, 200, 400Ω...) is not an optimal solution, since influence of the LED nonlinearity and of the parasitic capacitances is not negligible, especially for large resistances at LSB side. For that reason the values of the $R_2 \div R_8$ were experimentally optimized for the best monotonicity of the conversion characteristic.

The DOC data/trigger control is compatible with +5V powered high-speed CMOS logic, high-side switches are directly controlled from the memory of energies (in negative logic). Due to the nature of particle simulating process (see formula 3.1), the trigger pulse must be well defined and stable.

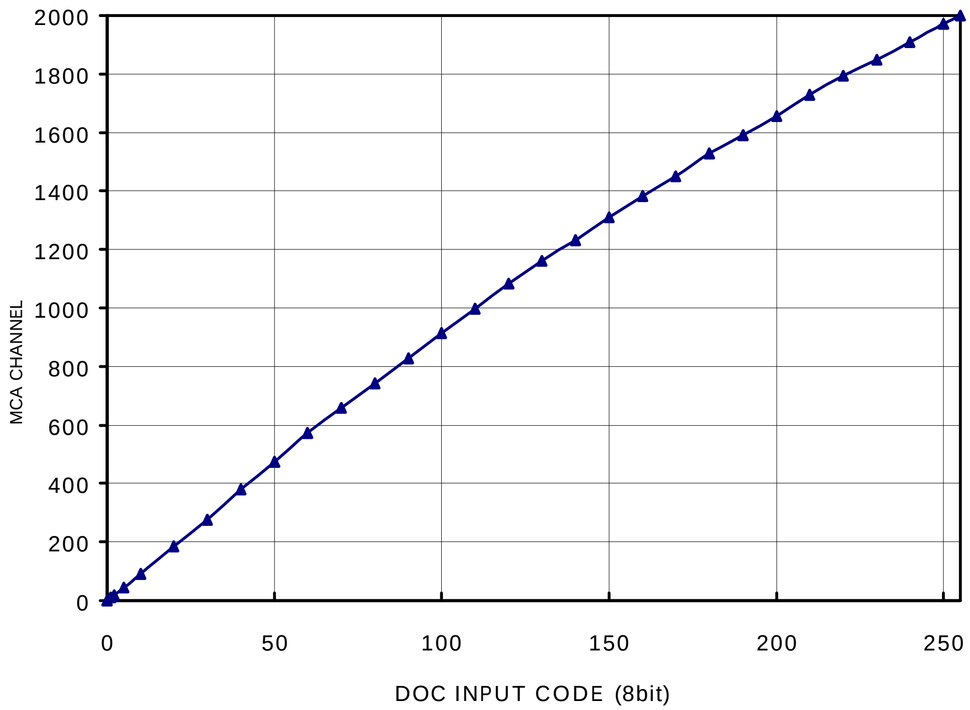

Figure 4. Digital-to-optical conversion characteristic with the L-53SRC-E LED-diode.

4 CONCLUSION

For practical implementation of the DOC for PPS-1 there was a high luminosity LED-diode type of L-53SRC-E (KINGBRIGHT) selected. The final conversion characteristic with this diode is shown in Figure 4 and was recorded by solid state ion-implanted detector type of PD25-12-100AM (CANBERRA) with a standard signal preprocessing analog electronics (shaping time 1µs) and with a multichannel analyzer. To exclude any pile-up and dead time effects, the calibration was performed with periodic stimulation at appropriate low-frequency. The conversion characteristic represents a plot of 8-bit DOC input code, versus respective (responding) channel of the multichannel analyzer, connected to the output of preprocessing electronics (which was assumed to be perfectly linear).

The DOC design for PPS-1 exhibits integral nonlinearity error upto 5 % (best fit), which is apparently caused by the LED-diode saturation effect. The differential nonlinearity error is at level approx. 1 LSB, so that 8-bit resolution requirement becomes critical. The integral nonlinearity error is in practical use reduced by a software included in particle energy distribution modelling.

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