Study of the timing properties of a Hamamatsu R9503U-04-M064M HPD – Applicability as a fast detector for μSR

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A recent publication [1] reports on a novel 64 channel Hybrid Photo Detector (HPD) based on a multi-pixel avalanche diode (MP-AD). The good timing properties and a proximity focusing structure make this device potentially attractive for applications requiring fast timing in high magnetic field environment.

For test purposes Hamamatsu Photonics provided an experimental sample of this type of HPD (R9503U-04-M64M, S/N: XE0003). The main aim of the investigations described in this document was to find out the applicability of this device as a photon detector in fast timing μSR experiments. We operated the HPD at a high voltage of -8 kV and a biasing voltage of the AD of 320 V (312 V after the voltage drop on a 1 MΩ biasing resistor). Because of the relatively low gain of the HPD ($5 \cdot 10^4$) a high gain broad-band amplifier had to be used, which immediately raised the problem of noise pickup. In order to overcome this difficulty the HPD was mounted directly on a board housing two amplifiers (see Figure 1). In this geometry the nearest distance from the HPD output pins (cathodes of the ADs) to the inputs of amplifiers was for the channels denoted as 6-2 (Ch1) and 6-6 (Ch2) on the accompanying data sheet. Consequently, these two channels had to be used for our studies. The AD biasing scheme and the scheme of the amplifier (single channel) are shown in Figure 2. The amplifier is based on MAR monolithic amplifiers from Minicircuits [2]. It has a 50 Ω input impedance, gain of ~ 80, and a bandwidth of ~ 400 MHz, and is operational in high magnetic fields [3].

Figure 3 shows one-photoelectron (1phe) signals from the HPD channel Ch1 recorded with a LeCroy WavePro 960 digital oscilloscope. The most probable amplitude for the 1phe pulses and the rms value of the high frequency noise are ~ 35 mV and ~ 2 mV, respectively, which gives the signal-to-noise ratio of about 17. Further reduction of the noise level was not possible, although the intrinsic noise of the amplifier was lower by a factor of 2. The response of the HPD is very fast with a signal rise-time of ~ 900 ps (limited by the amplifier bandwidth). The corresponding parameters measured for the channel Ch2 are in good agreement (within 10 %) with the values measured for Ch1.

Quite large (~ 14 %) optical cross-talk was measured between the test channels by shining light from a pulsed source (470 nm LED) on the photocathode area corresponding to Ch1 (the remaining area of the HPD input window was covered by black paper) and measuring the coincidence rates between the signals from Ch1 and Ch2 and that of the generator driving the LED (see Figure 4 and Table 1). Actually, illumination of any spot on the HPD input window (e.g., geometry 2 on Figure 4) was detected in the test channels by increasing coincidence rates with the LED driving pulses.

We believe that the cross-talk is caused by the light spreading within the HPD input window which is, presumably, just a monolithic quartz plate. For the same type of HPD,

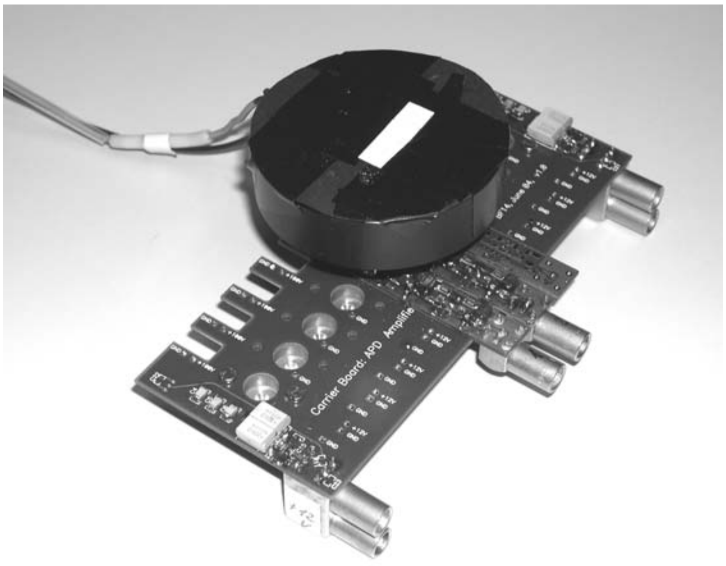

Figure 1: For the measurements the HPD was mounted on a board housing two broadband amplifiers. Connected are the HPD channels 6-2 (Ch1) and 6-6 (Ch2).

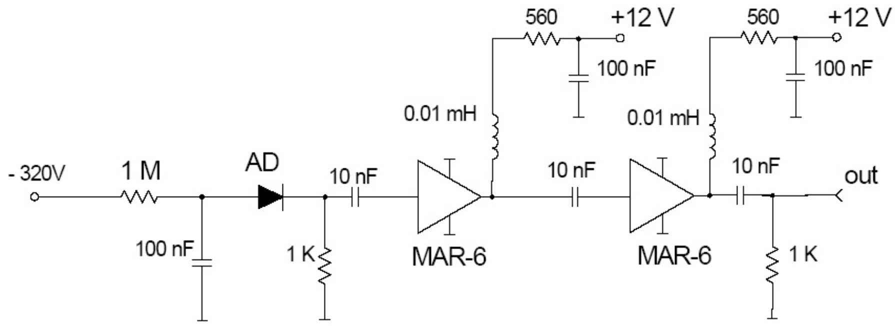

Figure 2: The AD biasing and the amplifier scheme (single channel). The cathodes of the ADs of non-used channels are grounded.

but with a fiber optic plate as input window a much smaller optical cross-talk (at the level of 1 %) was measured in [1].

However, advantage could be taken from the optical cross-talk in measurements of the HPD time resolution: as a light source we used Cherenkov light emitted by electrons from a ^{90}Sr source passing through the HPD input window (e.g., geometry 2 in Figure 4). The mean number of photoelectrons created per electron in Ch1 and Ch2 was less than 0.1. For signal shaping we used constant fraction discriminators model ORTEC 935 CFD. The time distribution (see Figure 5) of the signals from Ch2 with respect to that from Ch1 was measured using an ORTEC 9306 picosecond time analyzer. The data in Figure 5 are best fitted by a sum of two gaussian functions with equal mean values and standard deviations of 150 ps and 400 ps. The time resolution per channel of $150/\sqrt{2} = 107$ ps is in agreement with the result of [1], where a best value in the order of 80 ps was obtained. The deterioration of the timing properties (i.e., the presence of the broader component in the time spectrum) we tentatively attribute to a consequence of electrical cross-talk between the channels.

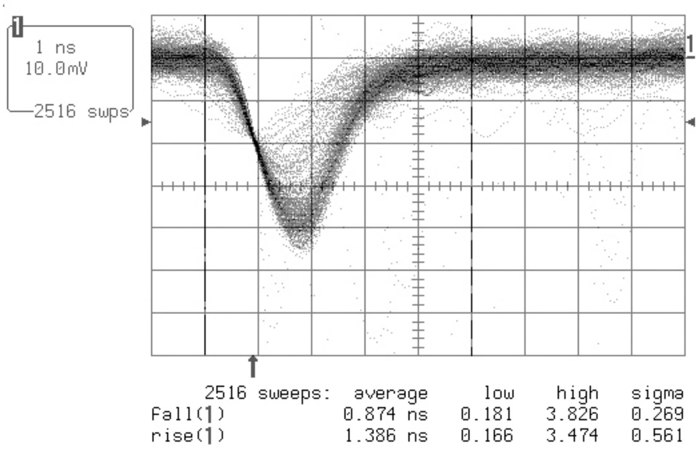

Figure 3: Oscilloscope screenshot of 1phe - pulses in channel Ch1.

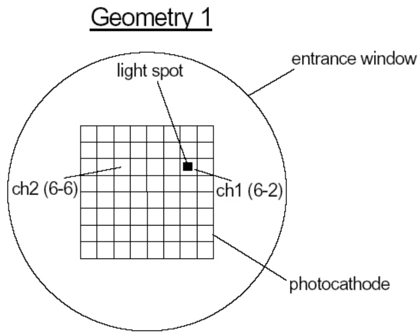

Figure 4: Two geometries for determining optical cross-talk. The spot illumination is achieved by an LED shining on a small hole in the black paper which covers the whole area of the HPD input window.

The electrical cross-talk displays itself as a signal of the opposite polarity in an HPD channel in the presence of a "real" signal in another channel. This is seen in Figure 6 where waveforms of the signals from Ch1 are shown at triggering the oscilloscope by the signals from Ch2. Both channels detect Cherenkov photons from ^{90}Sr electrons passing through the input window of HPD. Smaller pulse heights and longer rise and fall times for the signals compared to that shown in Figure 3 are due to the use of a 200 ns delay line (which is necessary to overcome the dead time of the ORTEC pTA 9306). The bands at about -10 mV and -20 mV correspond to 1phe and 2phe pulses in Ch1. The signals with positive polarity are cross-talk signals from Ch2 when no "real" signal in Ch1 was present. At simultaneous detection of signals in both channels their shapes are altered by the cross-talk signals and the time resolution deteriorates. We observed an extreme degradation of the time resolution at detection of rather intense light pulses from fast plastic scintillators. We were not able to separate between the cross-talk via external and internal (with respect to the HPD) electrical circuits. Further, more detailed investigations would be necessary to make this very important issue clear.

Table 1: Measurements of the optical crosstalk with the geometries as shown in Figure 4. N_L is the rate of a generator pulses driving the LED; N_{L1} and N_{L2} are the rates of coincidence between the signals of the LED generator and that from the channels Ch1 and Ch2.

Geometry	N_L, 1/s	N_{L1}, 1/s	N_{L2}, 1/s	N_{L2}/N_{L1}
1	90000	5000	700	0.14
2	90000	7500	7000	~ 1

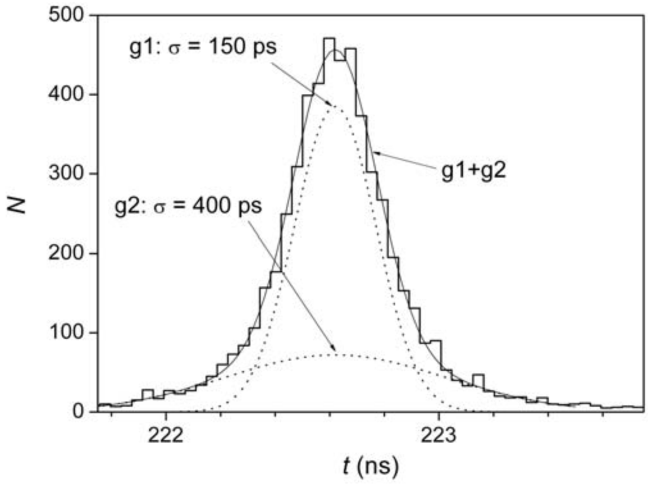

Figure 5: Time distribution of the signals from Ch2 relative to Ch1 at detection of Cherenkov light from ^{90}Sr electrons passing through the input window of the HPD. The data are well fitted with two gaussian functions with equal mean values (shown by dotted lines).

Summary

We carried out test measurements with a Hamamatsu R9503U-04-M64M HPD (S/N: XE0003). We confirm good amplitude resolution and timing properties of the device in the single-photoelectron mode: signal-to-noise ratio ~ 17, signal rise time ~ 900 ps, and time resolution $\sigma \sim 110$ ps. We have to mention, however, a far from easy operation of such a relatively low gain device in a high-speed low-light-level detection mode due to the noise pickup in the high-gain broad-band amplifier that has to be used.

We believe that the observed huge optical cross-talk (14 % between the channels 6-2 and 6-6) is not an intrinsic feature for this type of HPDs, but comes from to the construction of the input window of this particular device.

A more severe problem is the electrical cross-talk displaying itself as a signal of opposite polarity in an HPD channel in the presence of a “real“ signal in another channel. If signals appear simultaneously in several channels, the time resolution is completely destroyed due to this effect.

Apart from the drawbacks discussed above, the device is promising when fast timing in the presence of a high magnetic field is the main goal. Having in mind this application we would like to express our potential interest in a single-channel proximity focussing

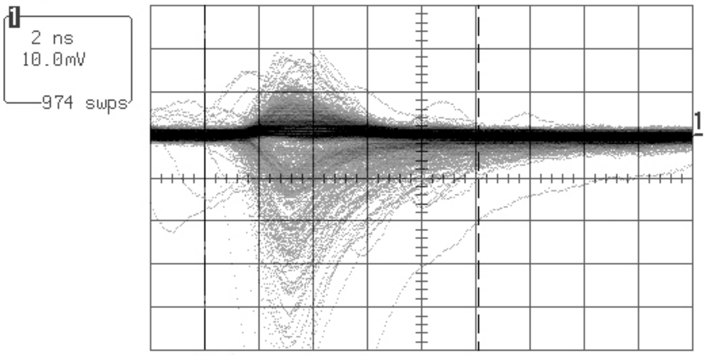

Figure 6: Oscilloscope screenshot of the pulses from channel Ch1 when triggering with signals from Ch2. Both channels detect Cherenkov photons originating from ^{90}Sr electrons passing through the input window of HPD. Smaller pulse heights and longer rise and fall times for the 1phe signals compared to that shown in Figure 3 are due to the use of a 200 ns delay line. The signals with positive polarity are cross-talk signals from Ch2.

HPD (active area 5 x 5 mm^2) based on a high-gain (> 200) low-capacitance (≤ 100 pF) avalanche diode.

Acknowledgement

We express our gratitude to Hamamatsu Photonics for providing the HPD for test measurements.

References

[1] M. Suyama *et al.*, NIM A **523**, 147 (2004).

[2] `http://www.minicircuits.com`

[3] A. Stoykov *et al.*, NIM A **550**, 212 (2005).