Study of the SiPM double component recovery time

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Abstract. The recovery time of the Hamamatsu SiPM linear assembly was measured. The assembly contains eight SiPMs of 2.8mm active area diameter; pixel size is 15x15mkm². The assembly is used for Phase1 upgrade in hadron calorimeter of the CMS experiment. Recovering process is found to depend on the number of the pixels fired and varied from 7 ±1 ns to 23 ± 3 ns for 50 Ohm readout impedance.

1. Introduction
Hamamatsu S10943-4732 SiPM linear assembly of eight SiPMs with 2.8 mm active area diameter and pixel size of 15 x 15 mkm² with 27500 pixels inside is selected as the replacement of the currently used HPD photodetectors in CMS Hadron Calorimeter during CMS upgrade [1].

The pixel recovery time is one of the parameters responsible for the proper calibration of the SIPMs and SiPM-based detectors which determines effective dynamic range for a given total number of pixels in SiPM and registered light pulse shape. As was shown in [2] using SiPM electrical model analysis, the recovery time of discharged pixels is a function of a number of fired pixels, with two time constants involved: τ₁ - single fired pixel recovery time and τₙ - recovery time for all pixels fired.

The best way to measure the single pixel recovery time would be to deal with a single pixel, activated by the tightly focused laser beam. But the small pixel dimensions of the Hamamatsu S10943-4732 and similar pixel size devices make the measurements difficult as the electrical signal of the single pixel is weak. In [3] the recovery time was measured illuminating different number of pixels, 90000 pixels and 2000 pixels, and the single pixel recovery time was found using the afterpulsing technique. The measured recovery time is longer for larger amount of fired pixels, as predicted by [2].

2. Experimental setup
The method of the measurements presented is similar to [3]. The experimental setup is shown in the Fig. 1.

Two picosecond (FWHM=40ps) 660nm lasers are used to generate two light pulses with variable delay between them. The lasers are externally triggered by signals from the dual channel pulse generator. The time difference between channels was changed in steps, up to delay time of 200 ns. The first laser pulse is used to fire pixels in the illuminated spot; SiPM response to the second laser pulse used to measure degree of fired pixels recovery.
Figure 1. The microscope system diagram. DUT – the device under test (SiPM).

The laser light outputs are joined in one optical fiber and send on the SiPM via microscope system. The illuminated spot size can be changed by tuning the fiber collimator that is build-in into the microscope system. Fig. 2 shows picture of the laser spot focused on the SiPM under test.

The tested SiPM is loaded on 50 Ohms impedance. SiPM signal is digitized and stored for off-line processing using digital storage oscilloscope Tektronix TDS3052. The recorded waveforms are an average of 512 events. Example of the stored double signal event is shown in Fig.3.

Figure 2. Laser spot on the SiPM.

Figure 3. The averaged double pulse signal is shown.
3. Data processing and results
The recorded data are processed as following: from every double signal waveform for a given setting of the light spot (number of the fired pixels) the previously recorded first signal only reference waveform was subtracted in order to get the second pulse shape. Waveforms for raw double signal, reference first signal and recovered delayed second signal are shown in Fig. 4a; Fig. 4b shows a set of the second signal waveforms for different delay times for a light spot covered 90 pixels.

![Figure 4](image)

**Figure 4.** d – the double discharge signal; s – single signal; e – extracted second signal obtained by subtracting the single signal from the full double signal. There is the visible difference between the peak position of the extracted signal and the second peak position of the double discharge signal (here, approximately 0.8 ns). (b) - the dashed signal on the left side is the reference signal. The rest is the set of the restored second pulses for different delays. The A scale is in arbitrary units.

Then the values for the second pulse amplitudes and amplitude time positions are extracted and the dependence of the amplitude versus time is plotted. The process repeated for all light spot sizes.

The resulting plots for 4 different light spots shown in Figures 5.

Finally the plotted data are fitted by the following function, taken from [2]:

\[
A(t) = A_0 \left( 1 - \frac{n}{N} \right) e^{-\frac{t-t_0}{t_1}} - \frac{n}{N} e^{-\frac{t-t_0}{t_2}} + b,
\]

where 
- \( n \) – the number of pixels fired;
- \( N \) – the total number of pixels in SiPM = 27500;
- \( t_1 \) – short recovery time parameter;
- \( t_2 \) – long recovery time parameter;
- \( A_0 \) – normalization factor;
- \( b \) – pedestals at \( t = t_0 \).

The values \( t_1 \) and \( t_2 \) were found as \( t_1 = 7 \pm 1 \text{ ns} \), and \( t_2 = 23 \pm 3 \text{ ns} \).

For the small number of fired pixels recovery time is mostly defined by parameter \( t_1 \) (Fig. 5 (c), (d), and contribution from \( t_2 \) is negligible, while for the number close to the total number of pixels \( t_2 \) is the main factor and the \( t_1 \) contribution can be discarded. (Fig. 5 (a)). As to the intermediate numbers of pixels both of them are responsible (Fig. 5 (b)).

The recovery time of one pixel fired and all pixels fired for the same Hamamatsu SiPM were also calculated following the technique presented in [2]. The recovery time values calculated are 6.5 ns and 17.1 ns respectively.
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References
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Figure 5. The recovery curves for different numbers of pixels fired. (a) – the number of pixels fired npix = 26900; (b) – npix = 16900; (c) – npix = 700; (d) – npix = 6. The total number of pixels in SiPM is Npix = 27500.