INVESTIGATION OF PIXEL CAPACITANCE AND SHUNT CAPACITANCE OF SILICON PHOTOMULTIPLIER

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The investigation results of the modern silicon avalanche photomultiplier capacitance are presented. A photodiode of the well-known manufacturer Hamamatsu by the S13360-1325CS series was chosen as the test sample. Experimental and theoretical methods were used to determine the capacitance of pixels and the shunt capacitance of the photodiode.

Keywords: silicon photomultiplier, capacitance, parasitic capacitance, multi pixel photon counter.
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INTRODUCTION

The development of high-energy physics, nuclear medicine, and cosmology required the development of high sensitive detectors that could replace traditional vacuum photomultiplier tubes (PMTs). One of the first silicon photodiodes with performance characteristics comparable to modern PMTs is described in [1]. These structures have launched a new generation of semiconductor photodetectors. More than 20 commercial organizations and numerous research institutes around the world are improving silicon photodetectors and use them in detector systems in areas such as medicine, LIDAR, high-energy physics, and optoelectronics [2-3]. Insensitivity to magnetic fields and high photo detection efficiency made it possible to use silicon photomultipliers (SiPMs) in such international research centers as CERN, JINR and others. There are a lot of works regarding on performance of photodiodes [4-6], however, insufficient attention was paid to the determination and identification of photodetector’s parasitic capacitance. One of the main problems of SiPMs today is the small active area and the lack of speed, which limits their use in time of flight experiments and large scale detectors of high-energy physics. The fact is that an increase in the size of photodiodes leads to an increase in capacitances, both of the photodiode itself and parasitic capacitances which play a key role in the detector's recovery time, avalanche gain, and photo response.

EXPERIMENTAL SETUP AND RESULTS

At the first stage of checking the circuit and measurement method, a HAMAMATSU photodiode S13360-1325CS [7] series was measured (60pF photodiode capacitance according to the manufacturer). It is known that the temporal characteristics of a photodiode are determined by the product of its two factors - resistance and capacitance (R*C). To determine the photodiode resistance, we used the method of measuring the volt-ampere characteristics. The technique is to connect the photodiode in the direction of forward bias. The voltage from the Keithley 6487 picoammeter was applied until (+ 1.3V) revealing the full linearity of the function (fig. 1), where the applied voltage completely drops to the quenching resistance R_q of the photodiode.

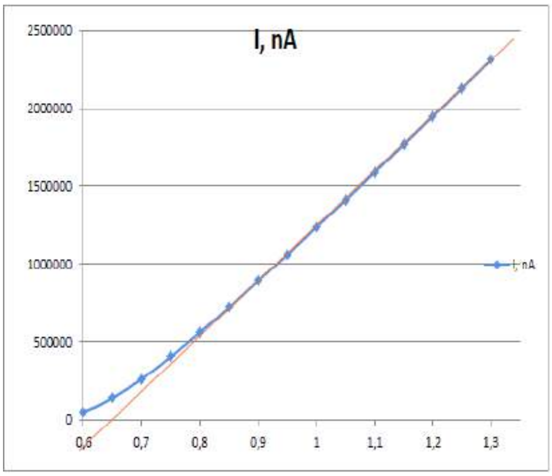

Fig. 1. Volt-ampere characteristic of the forward bias of the photodiode.

From the obtained volt-ampere characteristics the resistance R_q is calculated as follows:

$$R_q = \frac{\Delta U}{\Delta I} \approx 280\ [Ohm]$$

A standard circuit (fig. 2, left) for measuring and comparing capacities of photodiodes has been assembled. The AFG3202 generator supplied a pulsed signal U_g is 300 mV. A signal was taken from the Hantek oscilloscope (fig. 2, right).

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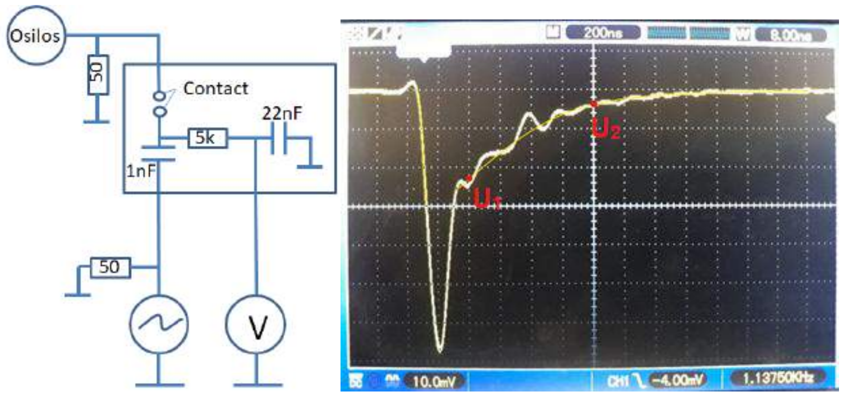

Fig. 2. Experimental design (left), signal from HAMAMATSU S13360-1325CS photodiode (right).

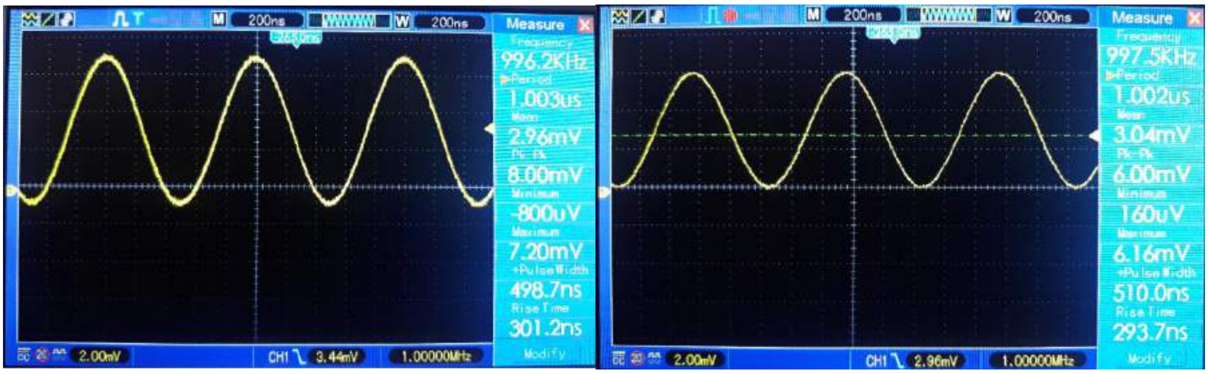

Fig. 3. Sinusoidal signal from photodiode (left), from reference capacitor (right).

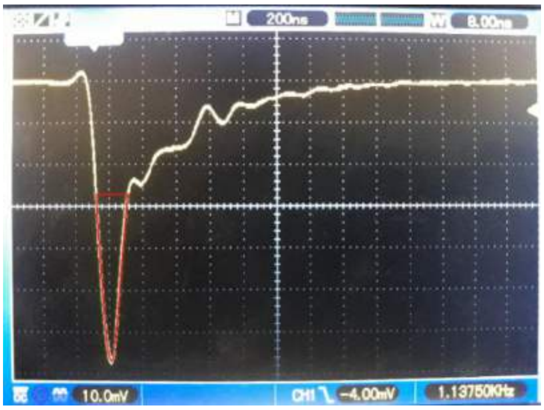

Fig. 4. Front view of the signal, regarding parasitic capacitance.

The main part of R*C is approximated and two arbitrary points (red points) of the exponent of the function (U_1, U_2) are taken and calculated by the following definition:

$$U = U_0 e^{-\frac{t}{RC}}$$

$$U_1 = U_0 e^{-\frac{t_1}{RC}}$$

$$U_2 = U_0 e^{-\frac{t_2}{RC}}$$

$$\frac{U_1}{U_2} = e^{\frac{t_2 - t_1}{RC}}$$

$$C = \frac{\Delta t}{R * ln\frac{U_1}{U_2}} \qquad (1)$$

where U_1 is the value at time t_1, U_2 is the value at time t_2, C is the capacitance of the photodiode, R is the total resistance taking into account the resistance of the system (load resistor 50 Ohm).

$$R = R_{SiPM} + R_{load} = 280 + 50 = 330$$

Capacitance of diode is calculated from the definition (1),

$$\mathrm{C} = \frac{32 * 10^{-9}}{330 * ln\frac{23.27}{3.79}} = 49{,}4 * 10^{-12}[F]$$

To verify the result, we calculate the capacitance of the photodiode (power supply is 50V; generator: 1MHz, +200mV, -200mV) according to the sinusoidal method (fig. 3, left):

$$Z = \frac{1}{\omega C}$$

$$I = \frac{U_R}{\frac{1}{\omega C}} = U_R 2\pi f C = \frac{U_R}{R} = \frac{4 * 10^{-3}}{50} = 8 * 10^{-5}$$

$$C = \frac{8*10^{-5}}{6.28*10^{6}*0.2} = 6.37 * 10^{-11} =$$

$$= 63.7 * 10^{-12}[F]$$

where Z is the resistance of the capacitor, U_R is voltage drop on the load resistance R, f is frequency of the sine wave. The error of this measurement is determined by the error of the used oscilloscope, in our case the error of the result is 5%.

To confirm the experimental measurement system (without changing the equipment parameters), a nominal capacitance of 47pF was applied (Figure 3 right).

$$\frac{A_1}{A_2} * 47 * 10^{-12} = 62{,}7 * 10^{-12}[\Phi]$$

A_1-amplitude when measuring the photodiode (4 mV), A_2-amplitude when measuring the nominal capacitance (3 mV). Obtained value of capacitance is confirmed by experimental data.

It is known that, the front of the signal contains a charge (fig. 4), shunting capacitance C_s (parasitic capacitance of pixels). The charge of parasitic capacitance:

$$Q = \frac{U * t}{2R} = \frac{4 * 10^{-3} * 8 * 10^{-9}}{2 * 50} = 3{,}2 * 10^{-12}$$

$$Q = U_g C_s = 3{,}2 * 10^{-12}$$

$$C_s = \frac{Q}{U_g} = \frac{3{,}2 * 10^{-12}}{0.3} = 10666 * 10^{-15}[F]$$

Based on calculations, where the pixel capacitance of the photodiode is 49.4 pF (according to the manufacturer, this photodiode capacitance is 60 pF, experimentally 62.7 pF). The missing part, ~62.7-49.4=13.3 pF, is the parasitic capacitance of the photodiode.

As shown in the calculations, the parasitic capacitance, which plays a key role in the formation of the front edge of the pulse, occupies about 21 % of the total capacitance of the photodiode. Theoretically and experimentally, with an accuracy of 5%, the capacitance of the HAMAMATSU S13360-1325CS photodiode was determined to be 60 pF according to the manufacturer.

ACKNOWLEDGEMENT

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