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Universal single board tester for investigation of the avalanche photo detectors

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ABSTRACT: New electronic single board tester described here allows us to test and compare basic characteristics of new types of the avalanche photo diode (APD) (SiPMD, MCAPD, GAPD). It can measure the static and dynamic characteristics of the APD. We applied virtual periphery concept for very fast and simple way to measure the S/N resolution and own noise of the APD under investigation. The tester helps to define the main parameters of equivalent circuit of APD and using them for simulation. The tester can be useful for long time monitoring. New method for data analysis is suggested here.

KEYWORDS: Control systems; Photon detectors for UV, visible and IR photons (solid-state) (PIN diodes, APDs, Si-PMTs, G-APDs, CCDs, EBCCDs, EMCCDs etc)

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Contents

1 Introduction

The first types of Geiger-mode APDs (GAPD) were developed and studied for photon detection in the early 1960s [1]. In present time we know few types of single photon APD, e.g. Silicon Photo Multiplier Detector (SiPMD) or Micro Channel APD. These photo detectors are very similar. In order to measure precisely the absorbed photons some important parameters of avalanche photodiode (APD) must be controlled. The control parameters are temperature, the biasing voltage and dark current of APD. We will present the new readout module of the APD and similar avalanche photodiode (APD) operated in Geiger mode. In this mode, the APD is biased above the breakdown voltage with the breakdown occurring only when a thermal- or photo-generated primary electron initiates it. The APD's parameter measurements can be automated. It is possible to calculate Avalanche Gain (AG), Signal to Noise Resolution (SNR)). In this article we describe an electronic module, which allows easy measurement of Volt-Ampere Characteristics (VAC), Breakdown Voltage (BV), AG and SNR of APD with biasing voltage in the range 6–90 V. The module also can be applied as a fast trigger of single photons. New method for data analysis will be described here.

1.1 Short theory for tester application

We suggest here a new method of APD investigation [2]. It is based on consideration of the APD as an amplifier with feedback. For this purpose we need to define the main parameters of SPICE model of the APD and calculate Feed Back Coefficient of the APD . The equivalent APD schemes are shown in figure 1 (a,b,c). Part of the figure 1a is for a case when we do not consider the influence of feedback on avalanche amplification. It could be described by Miller's formula (1.1). Figure 1b show a case with feedback due to R_{fb}. It is in correspondence with formula (1.2). Figure 1c show a case with feedback due to R_{fb} and C_{fb}. It is in correspondence with formula (1.3) [3].

$$M_0 = \frac{1}{1-\left(\frac{V}{V_{\mathrm{br}}}\right)^n} \tag{1.1}$$

$$M = \frac{1}{1-\left(\frac{V-i\cdot R_{\mathrm{fb}}}{V_{\mathrm{br}}}\right)^n} \tag{1.2}$$

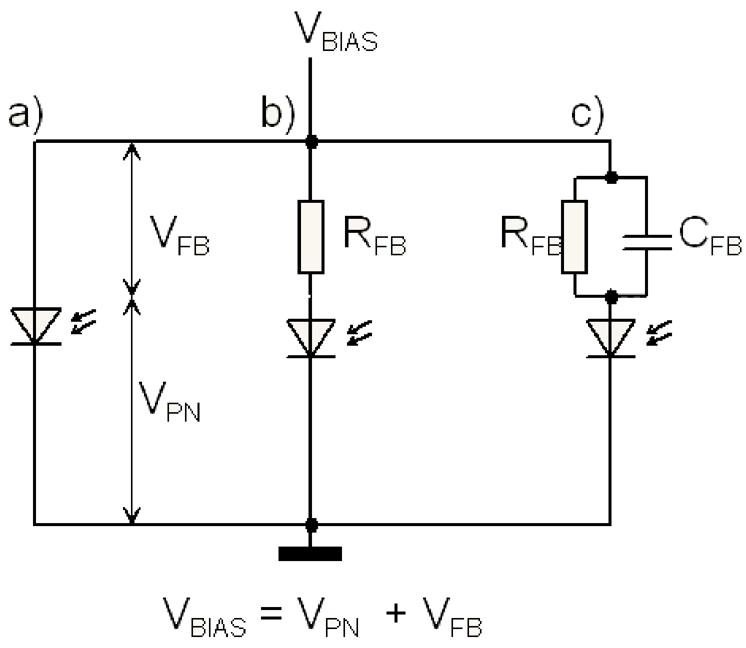

Figure 1. The equivalent circuits (a–c) of APD used in Miller's formula.

Let us rewrite formula (1.2) to common form (1.3). By algebraic transformation with form (1.3) it is possible to get formula (1.4).

$$M = \frac{1}{1 - \left(\frac{V - V_{\mathrm{fb}}}{V_{\mathrm{br}}}\right)^n} \tag{1.3}$$

Formula (1.4) shows the feedback coefficient in the general form to indicate that the feedback value is defined by the change of the voltage V_{fb}. On the other hand, in this expression a significant FB difference is clearly seen if the FB resistance consists of purely active component and if it contains the reactive component [4].

$$M(V) = \frac{M_0(V)}{1 - \beta \cdot M_0(V)} \tag{1.4}$$

here $\beta = \frac{V_{\mathrm{fb}}}{V_{\mathrm{br}}} = \frac{i \cdot R_{\mathrm{fb}}}{V_{\mathrm{br}}}$

In the first case external chains of APD connection define the rate of the avalanche multiplication suppression; in the second case, the influence of the reactive component on the rate of the avalanche multiplication suppression is strong. Due to this, the suggested model allows one to describe accurately the operation of APD with internal local negative FB. The FB locality implies that the process of the avalanche suppressing is much quicker than the changes in the parameters of external chains of APD power supply. Thus, we can choose parameters C_{fb} and R_{fb} in such a way that we can accurately describe the APD behaviour with negative local FB. A step further is more complicated as it is necessary to connect the obtained distributed parameters with topological and technological parameters of the APD under study. We can study the character of behaviour of the FB coefficient depending on the voltage changes.

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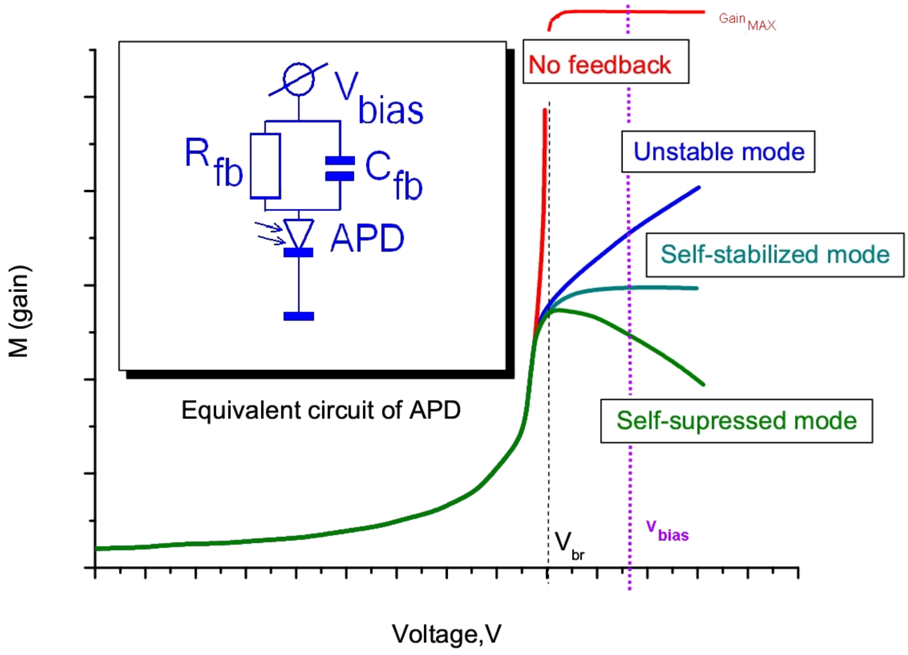

Figure 2. Classification of APD using model of FB.

If we define the avalanche gain efficiency coefficient in the form $G_{\text{ef}} = \frac{dM_0}{dV} - M_0^2 \cdot \frac{d\beta}{dV}$ the derivative on V from (1.4) will be in the form (1.5)

$$\frac{dM}{dV} = \frac{G_{\text{ef}}}{(1-\beta \cdot M)^2} \tag{1.5}$$

If we define the FB efficiency parameter in the form (1.6) it is possible to outline three characteristic cases of FB demonstration in APD in figure 2.

$$K_{\text{ef}} = \frac{\frac{d\beta}{dV}}{\frac{1}{M_0} \cdot \frac{dM_0}{dV}} \tag{1.6}$$

- $K_{\text{ef}} < 1$ — with the growth of voltage the feedback increases slower than the avalanche gain that corresponds to the APD operation in the unstable mode;
- $K_{\text{ef}} = 1$ — with the growth of voltage the feedback increases as quickly as the avalanche gain that corresponds to the APD operation in the self stabilization mode;
- $K_{\text{ef}} > 1$ — with the growth of voltage the feedback increases quicker than the avalanche gain that corresponds to APD operation in the self-suppressing mode.

A classification of this type allows us to define the character of the FB behavior.

2 APD tester in detail

2.1 Hardware

Our APD tester was developed as a simple system with two ways to control. The first way is a manual control when the system operates as a trigger for single photon events. The second way

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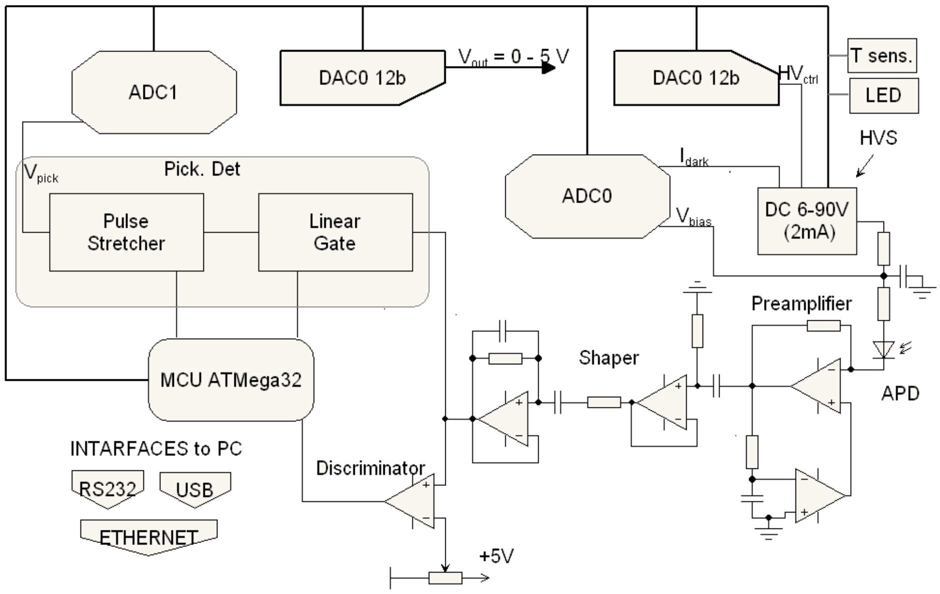

Figure 3. APD tester structure.

is a control by an external personal computer (PC) [5]. In the case of PC control the APD tester allows on-line monitoring of the APD that is under investigation, displaying data as AG, SNR. The APD tester can be used in many fields e.g. for calibration of detectors and for determination of their radiation hardness, and also for studying and comparison different types of APD.

The main functions incorporated in the APD tester are (figure 3):

1. A preamplifier (Preamplifier) allowing to gain of G-APD signal in wide range of input voltages (10–500)mV;

2. A signal shaper (Shaper) allows effective rejection of noise for high frequency;

3. A pick detector (Pick. Det.) allowing to fix output signal for measurement of amplitude of signal in Multi Channel Analyzer (MCA) mode;

4. A discriminator (Discriminator.) allows set threshold and hysteresis for operation of tester in trigger mode;

5. A high voltage supply (HVS) that allows to generate 6–9–0 V (2mA) for biasing of APD with an accuracy of ± 24 mV;

6. A 22 bit ADC0 to measure the APD dark current in range 0–2 mA DC with an accuracy of ± 100 nA;

7. A 18 bit ADC1 to measure amplitude of the APD output signal in range 0 –5 VDC with an resolution of ± 100 uV;

8. A 12 DAC0 allowing to generate output voltage in range 0–5 VDC with an accuracy of ± 1.3 mV;

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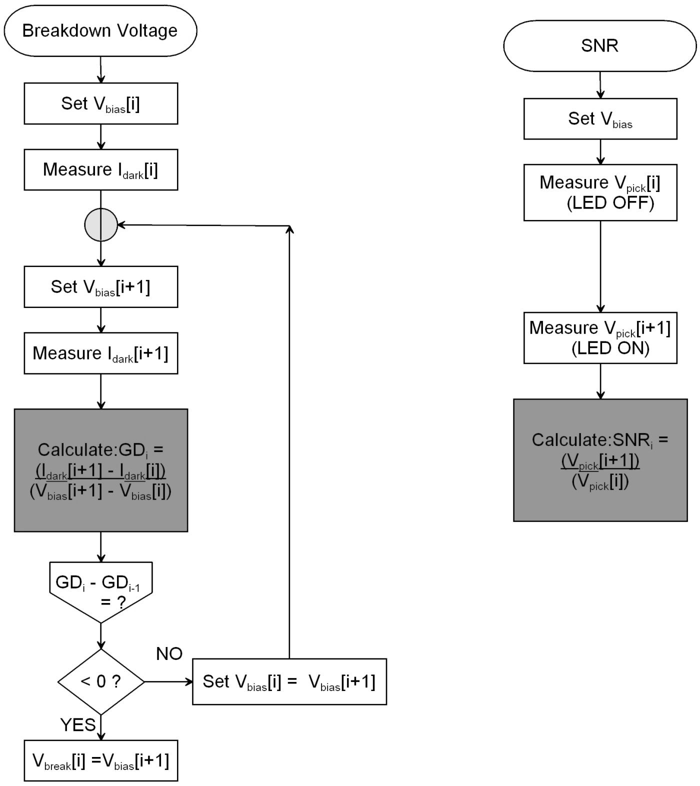

Figure 4. Examples of firmware algorithms.

9. A temperature sensor (T sens.) to measure the temperature in the range -20 + 80 $^\circ$C with an accuracy of ± 0.25 $^\circ$C and a resolution of 0.06 $^\circ$C;

10. LED pulse driver allows to generate pulses of light 10,20,30 nS length;

Electronics switches make the signal commutations inside the module. The control module is based on an MCU Atmega32 from ATMEL Co. that allows controlling all measurement processes. Also the MCU allows communicating with the external PC.

2.2 Firmware and software

The firmware of the MCU Atmega32 was created using BASCOM AVR Basic. The base algorithms for the measurements are shown in figure 4. After the power is switched on the APD tester operates in trigger mode. The parameters of measurement are used from previous setting (threshold voltage, hysteresis and biasing voltage).

The software for the control and the graphic user interface (GUI) of the APD tester was created in the Lab Windows CVI environment — see figure 5. External control extends the usage of the APD tester. First of all, by using external software one can apply the APD tester for online monitoring of the APD under investigation. Furthermore, one can use the embedded functions for sending alarm messages. One can select also the maximum limit of temperature, and the maximum

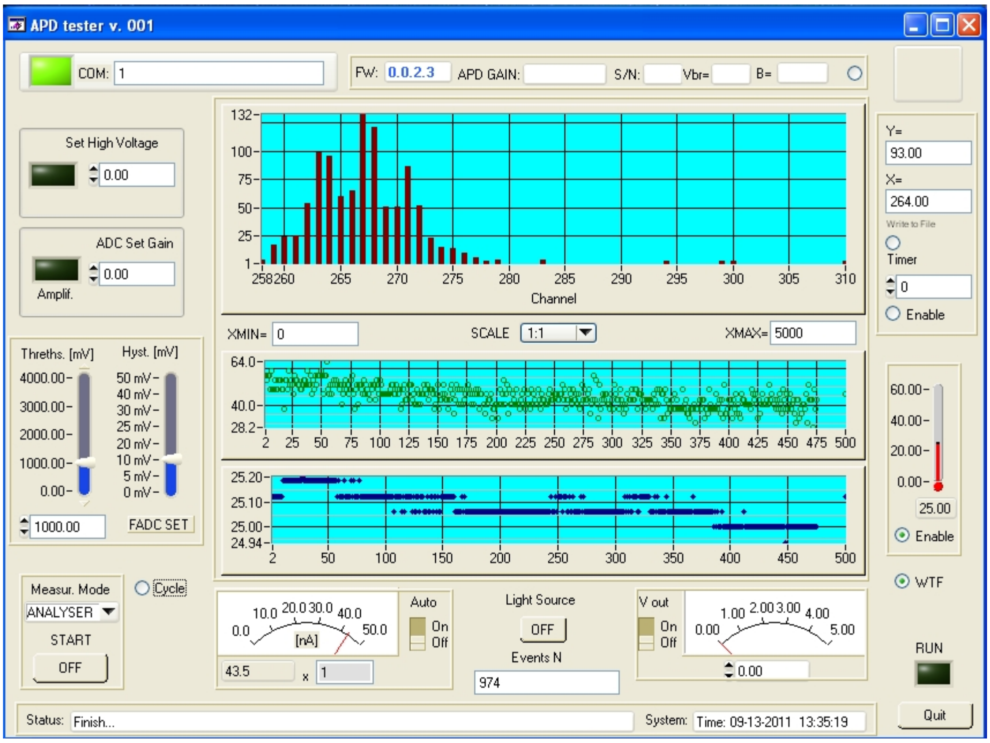

Figure 5. GUI of APD tester.

value of dark current. When the maximum temperature (dark current) is reached a short message can be sent to a pre-defined e-mail address.

2.3 Example of SPICE simulations

The APD tester was used for investigation of two different types of APD MRS APD [2, 6] and MCAPD [7]. Figures 6 and 7 show a comparison of experimental and simulated results. Both distributions show a reaction of the APD on rectangular pulse of light.

3 Conclusion

Our APD tester allows to investigate of the G-APD, SiPMD, MCAPD, APD with biasing voltage in range 6-90 VDC. It is a practical device for application in a wide area of nuclear physics experiments. The current version of this device is using the small commercial ADC and DAC. Automatic calculation have been used for the all important parameters of APD (BV, AG, SNR, VAC). The APD tester can be controlled manually or by computer by RS232, USB, TCP/IP interfaces. We can obtain the main parameters for simple SPICE model for the APD simulations. We can calculate the NF coefficient to define different types of the APD and to compare the stabilities of the different types.

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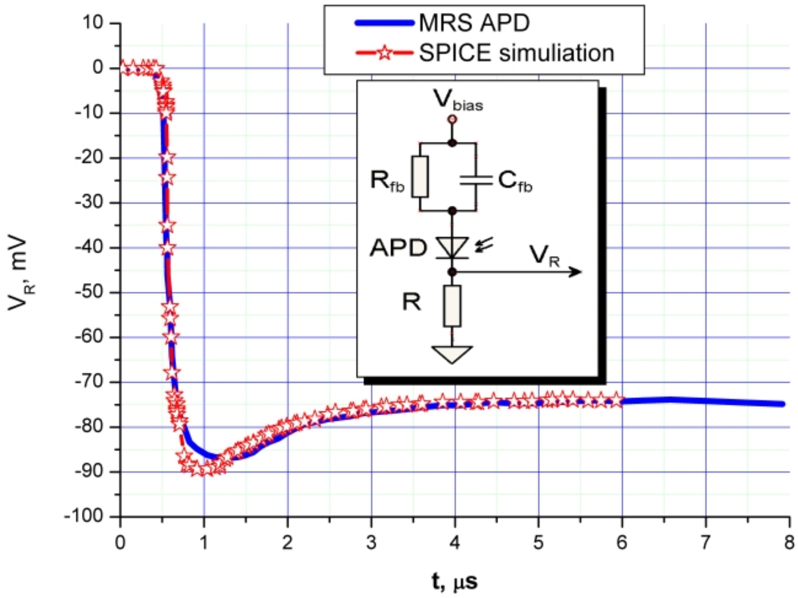

Figure 6. Experimental signal from MRS APD and SPICE simulation.

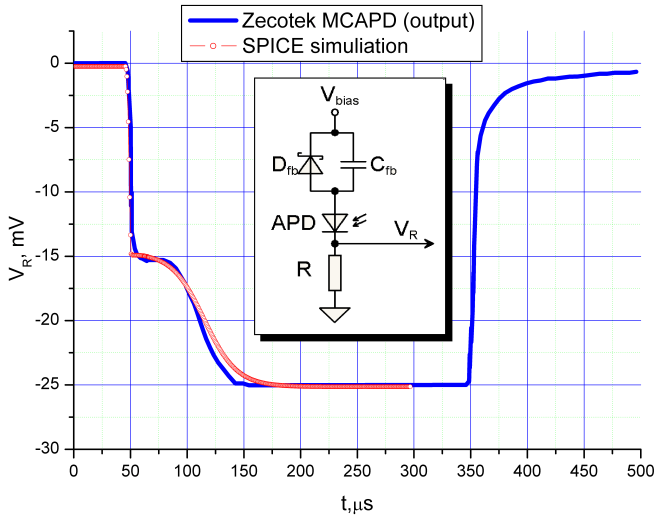

Figure 7. Experimental signal from MCAPD and SPICE simulation.

Acknowledgments

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References

[1] Y. Musienko, *Advances in multipixel Geiger-mode avalanche photodiodes (silicon photomultiplies)*, *Nucl. Instrum. Meth.* **A 598** (2009) 213.

[2] V.V. Kushpil, *Application of simple negative feedback model for avalanche photodetectors investigation*, *Nucl. Insttum. Meth.* **A 601** (2009) 204.

[3] D. Bisello et al., *Metal-Resistive layer-Silicon (MRS) avalanche detectors with negative feedback*, *Nucl. Insttum. Meth.* **A 360** (1995) 83.

[4] F. Zappa, A. Lacaita and C. Samori, *Characterization and modeling of Metal-Resistance-Semiconductor photodetectors*, *IEEE Trans. Nucl. Sci.* **44** (1997) 957.

[5] H.J.W. Spoedler, *Virtual instrumentation and virtual environments*, *IEEE Instrum. Meas.* **2** (1999) 14.

[6] A.V. Akindinov et al., *New results on MRS APD*, *Nucl. Insttum. Meth.* **A 387** (1997) 231.

[7] Z. Sadygov et al., *Microchannel avalanche photodiode with wide linearity range*, `arXiv:1001.3050`.