Current sensitive amplifiers for silicon photomultiplier MAPD-1

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Silicon photomultipliers

Novel type of solid-state detector to replace the conventional photomultiplier at some applications

Developed at Moscow Engineering and Physics Institute
Initial production at Pulsar plant, Moscow

At the moment are produced by a lot of manufacturers like SensL, Photonique, Hamamatsu, Voxtel Inc., STMicroelectronics

There is a number of projects which consider application of SiPMs: Super LHC, TESLA/ILC, astronomy, etc.

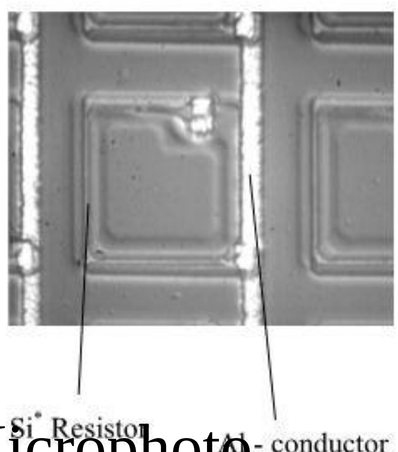
We are investigating the application of SiPMs for NICA (Nuclotron-based Ion Collider fAcility) in Dubna

What is SiPM

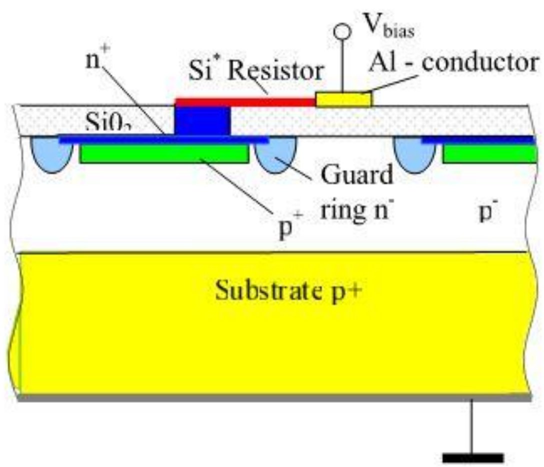
Avalanche photo-diode in geiger mode ($V_{Bias} > V_{breakdown}$)

Single photo electron generates an avalanche discharge: Device is sensitive to single photons, have high gain, and have essentially a digital output.

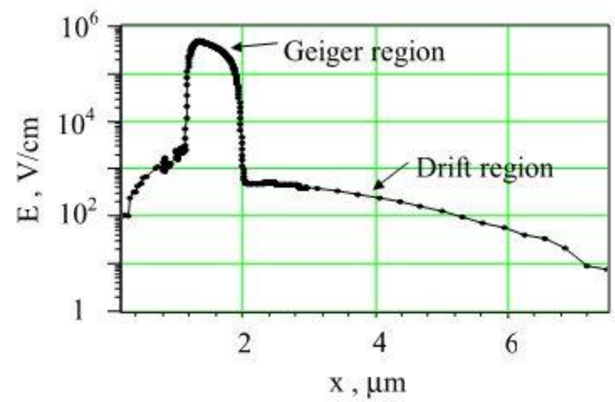
SiPM is a matrix of a lot of such diodes working in parallel



Microphoto



Topology

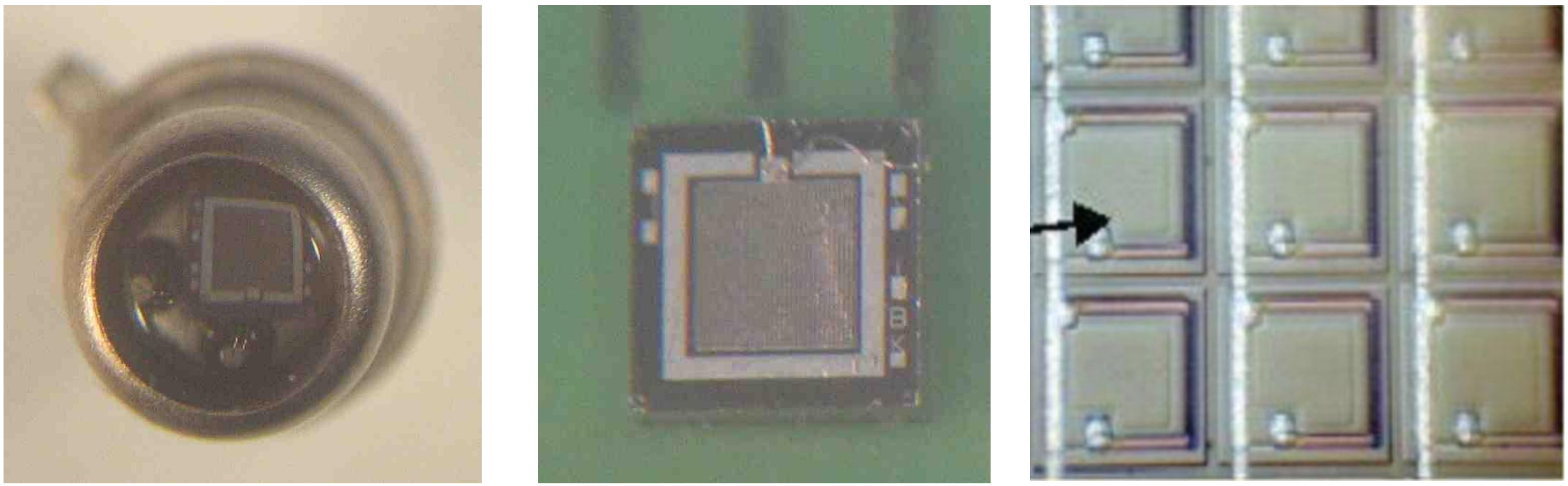


Field profile

What is SiPM

The diodes are discharging on a common electrode and are decoupled by resistors (~ 100 kOhm).
The avalanche is passively quenched by resistors
The single-pixel response is digital, but the device as a whole is analog (sum of single-photon responses).

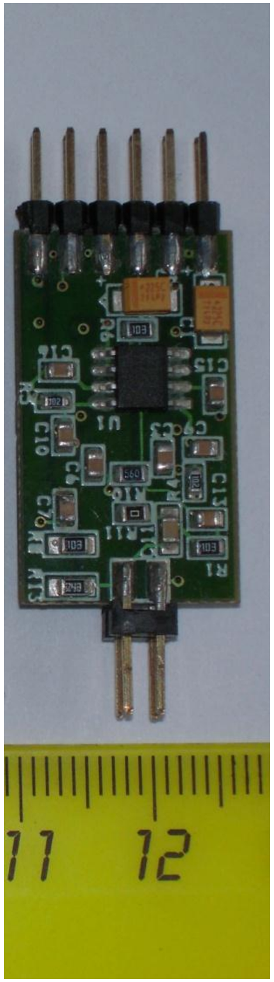
MAPD-1 SiPM: 1x1 mm^2, 564 pixels, ~10^6 gain



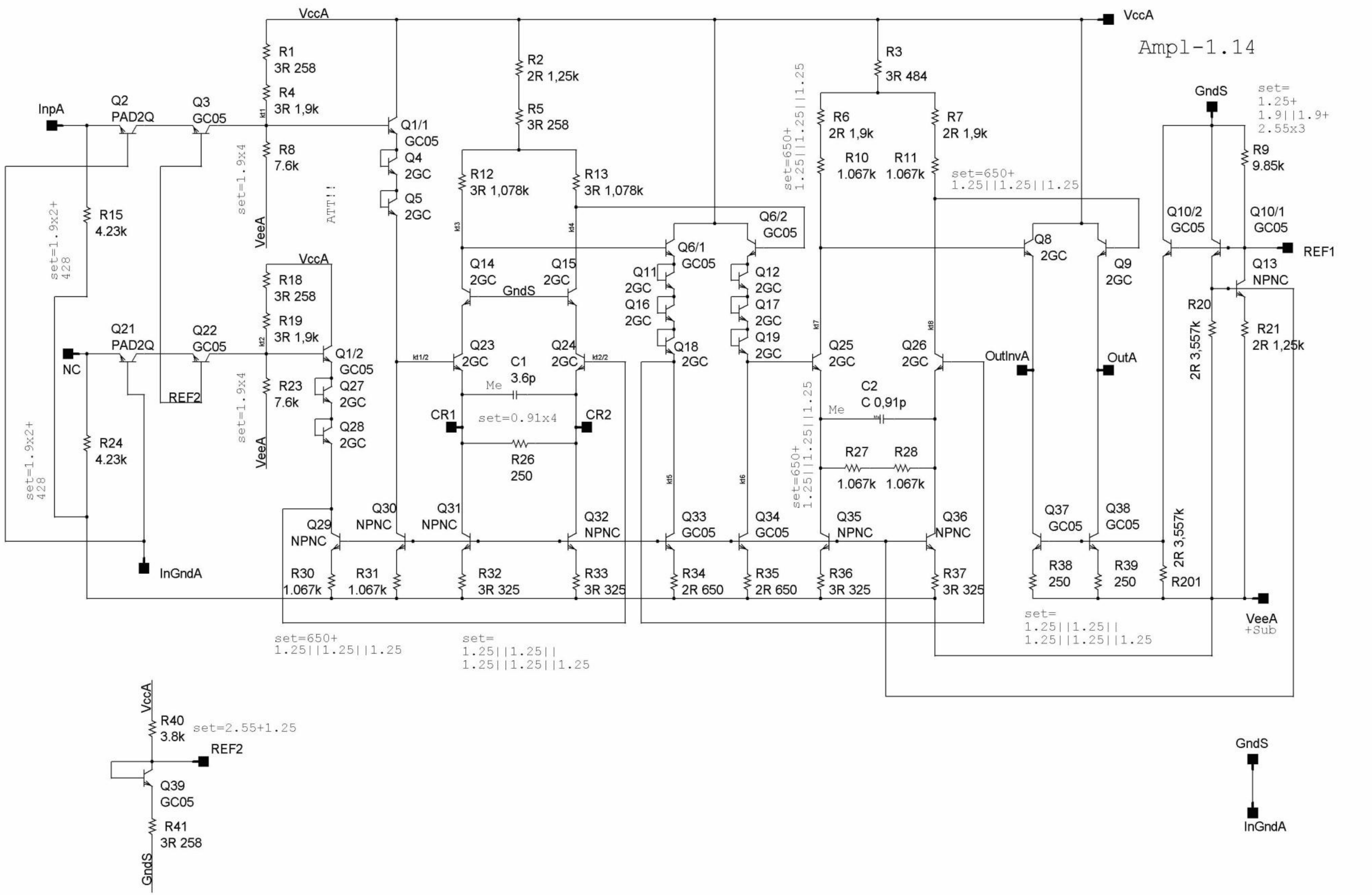
Amplifiers

A series of transimpedance amplifiers was designed in NC PHEP BSU
To work with MAPD-1 SiPMs on a Master-Slice ABMK-3.

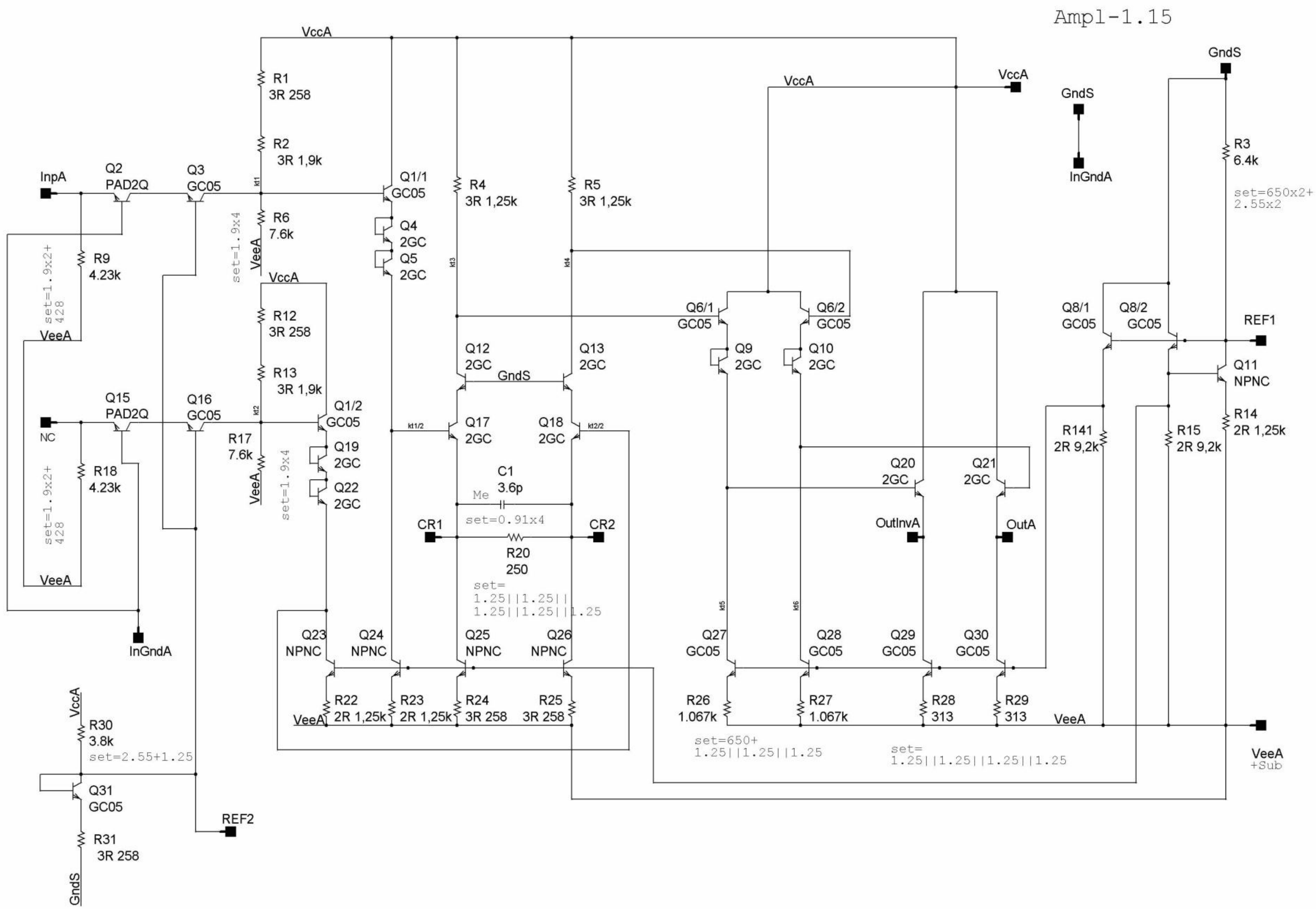
Amplifier	Ampl-1.14	Ampl-1.15	Ampl-1.17	Ampl-1.16
Voltage, V	5	5	5	3.5
Input impedance, Ohm	50,0	50,0	50,0	65
Gain diff., mV/mkA	20	10	1	15,6
Bandwidth, MHz	150	170	250	100
ENC at 10 pF input load, nA	110	80	170	145



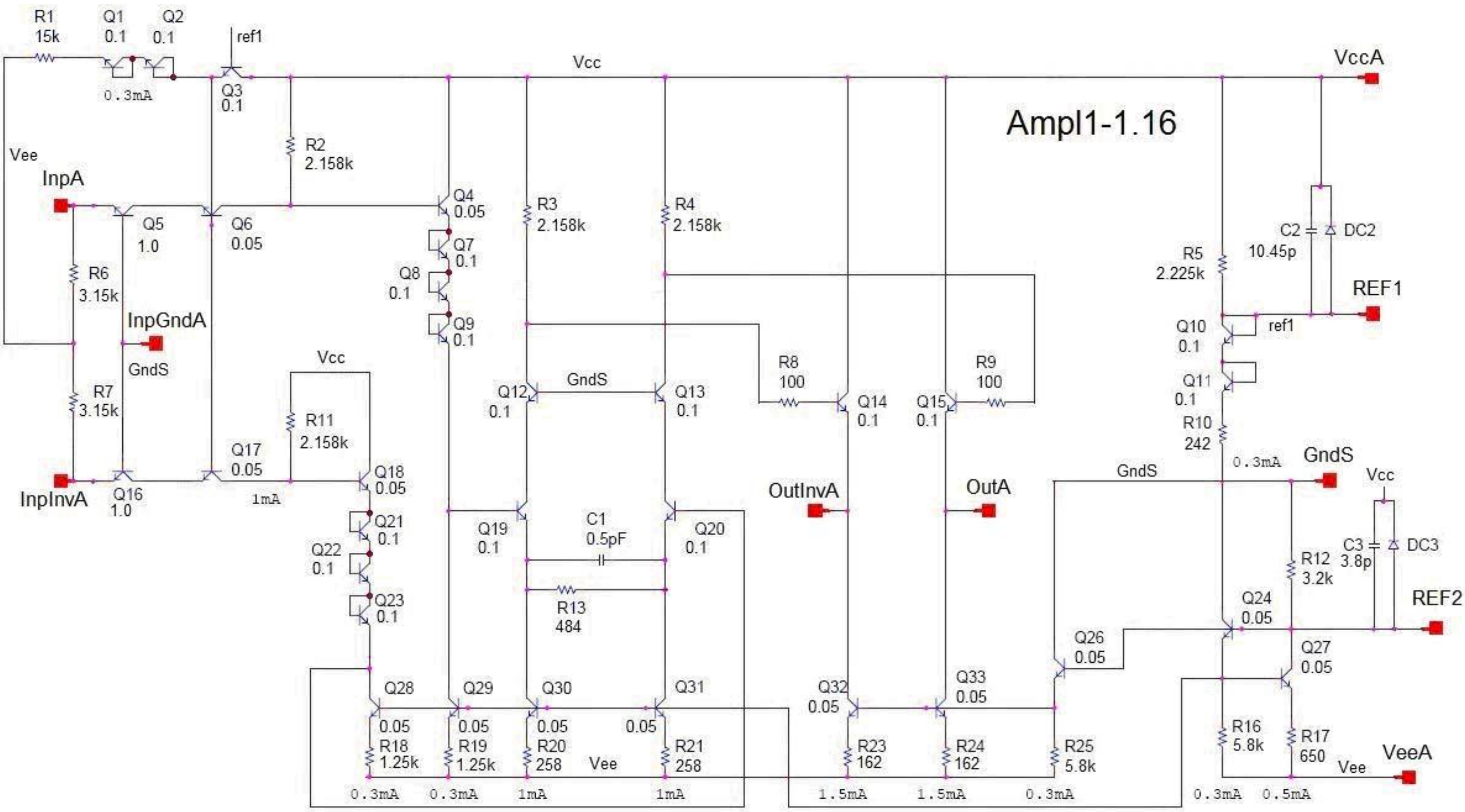
Ampl-1.14 — the amplifier part of IC AD-1.14



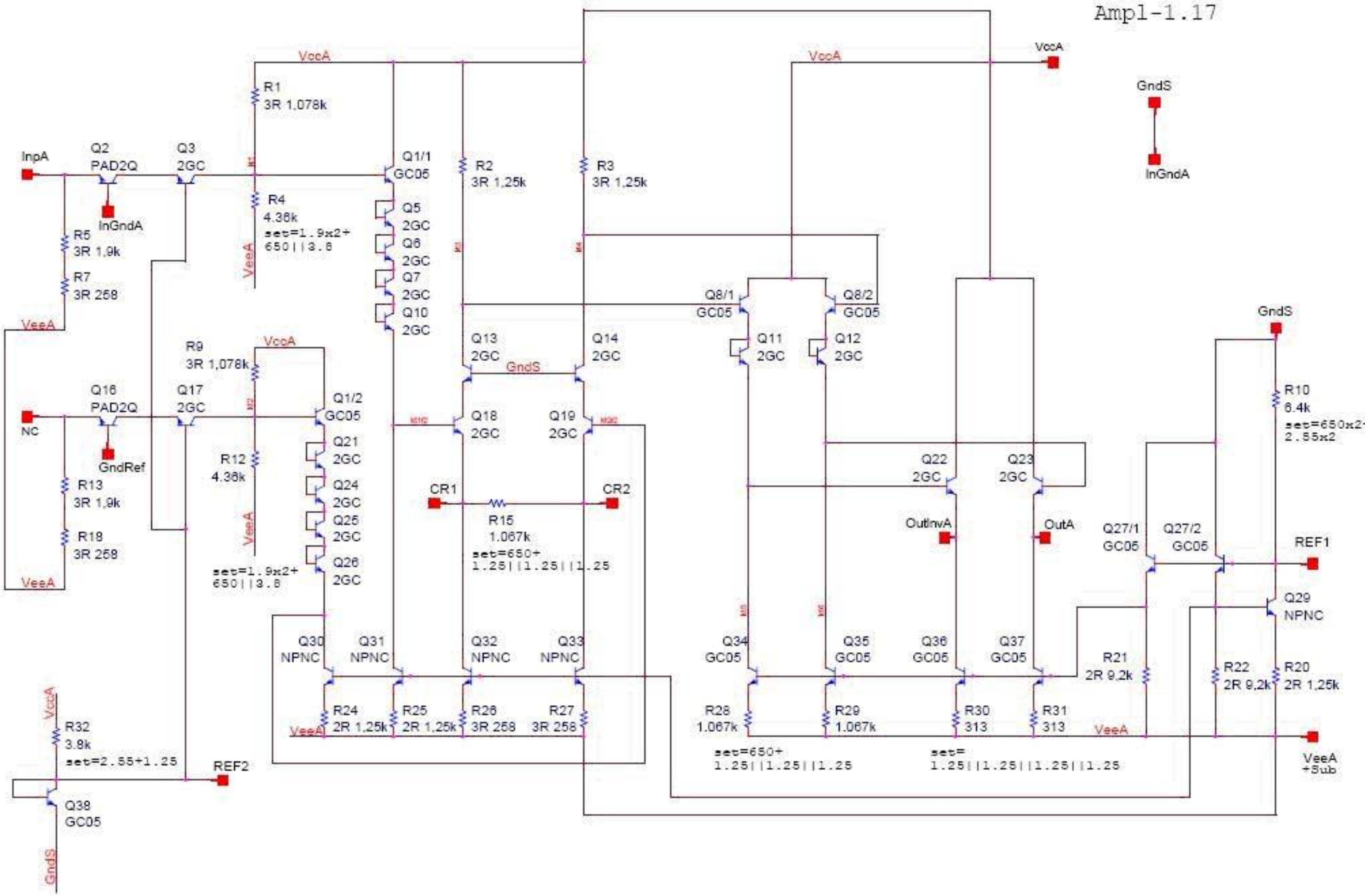
Ampl-1.15 — the amplifier part of IC AD-1.15



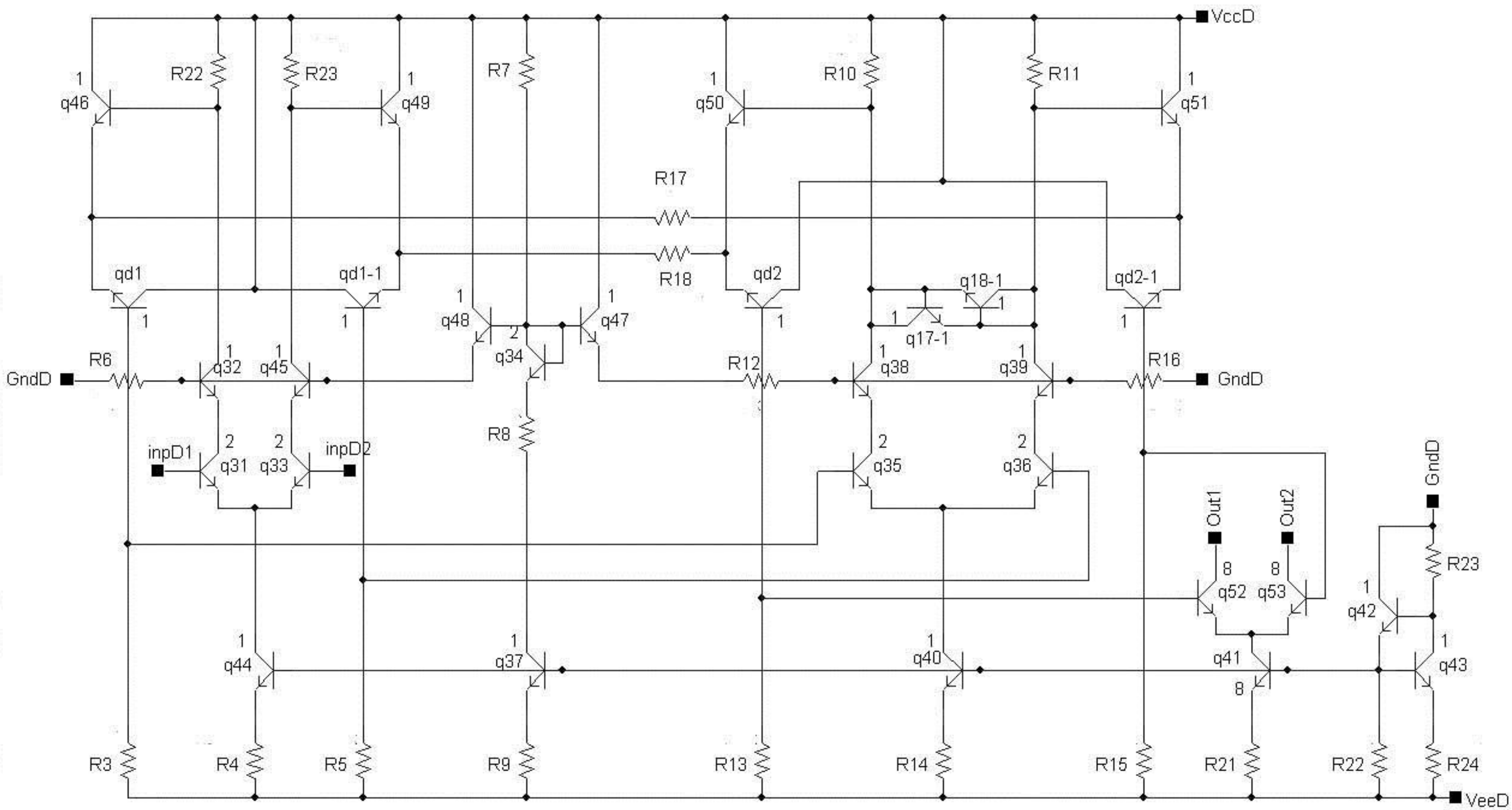
Ampl-1.16 — the amplifier part of IC AD-1.16



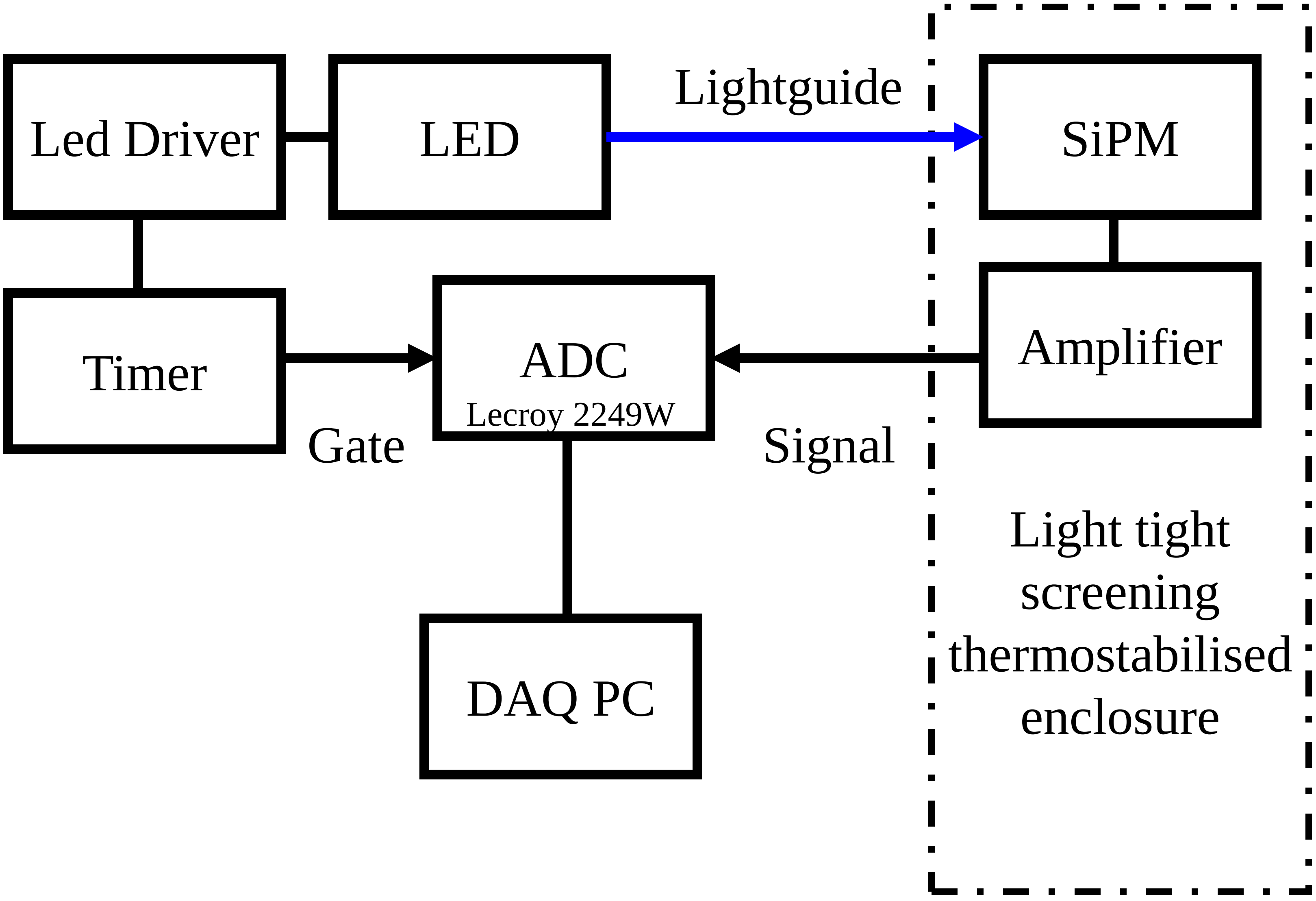
Ampl-1.17 — the amplifier part of IC AD-1.17



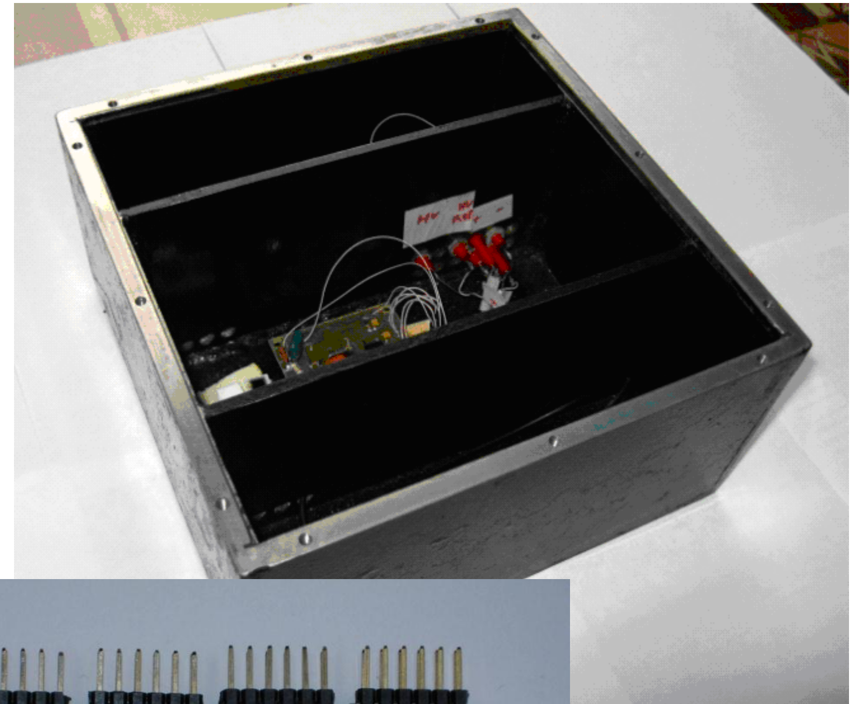
Disc-1.4 — a comparator part of ICs AD-1.14 — AD-1.17

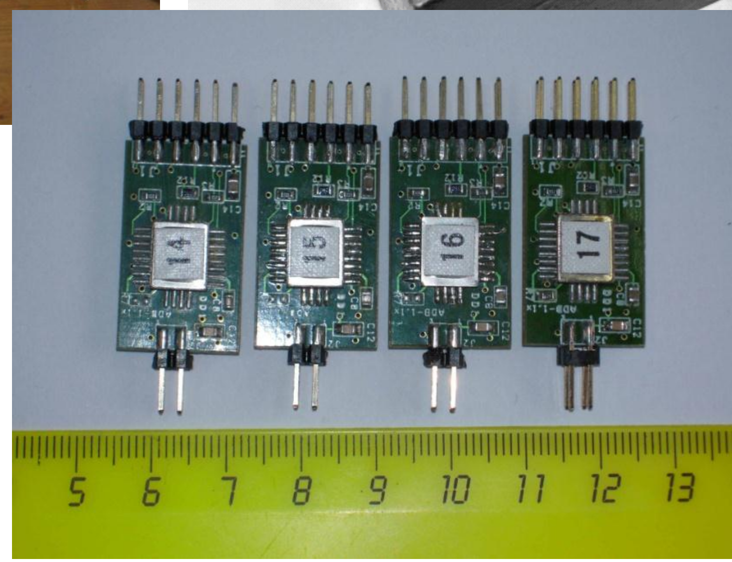


Experimental setup



Experimental setup





Single-photon spectra

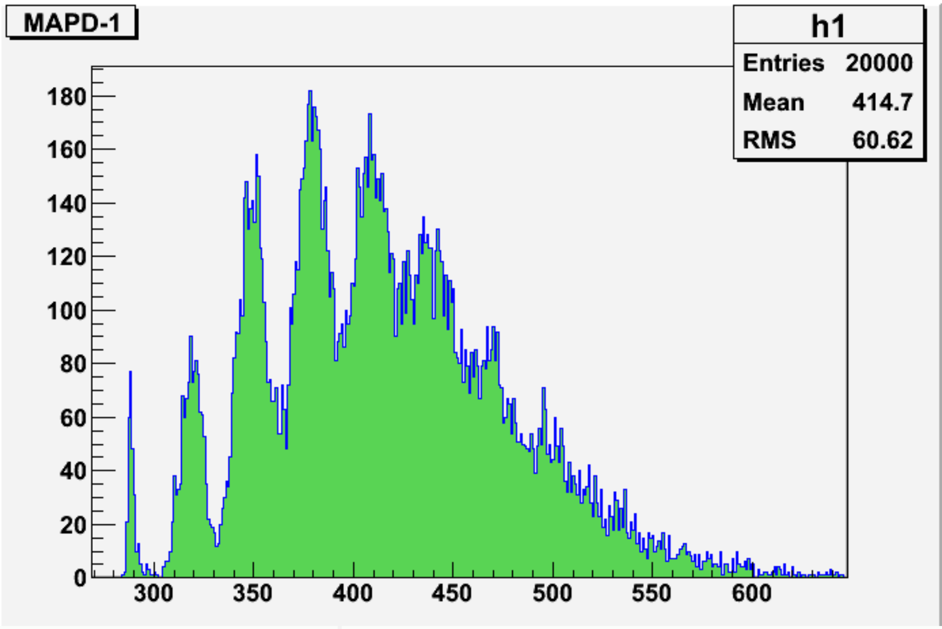
Illumination by short weak light pulses (LED)

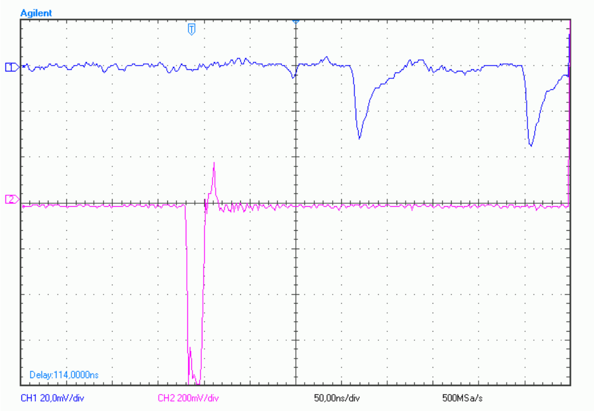
Peaks correspond to number of photoelectrons

Easy to calculate gain with calibrated readout system

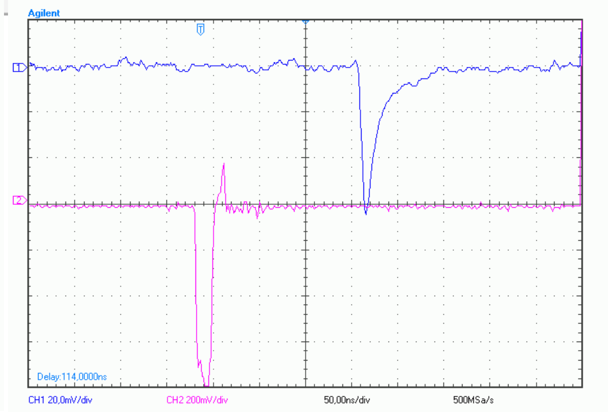
Pixel recovery time ~ $C_{pixel}R_{pixel}$=100-500ns

SiPM recovery much faster at low occupancy





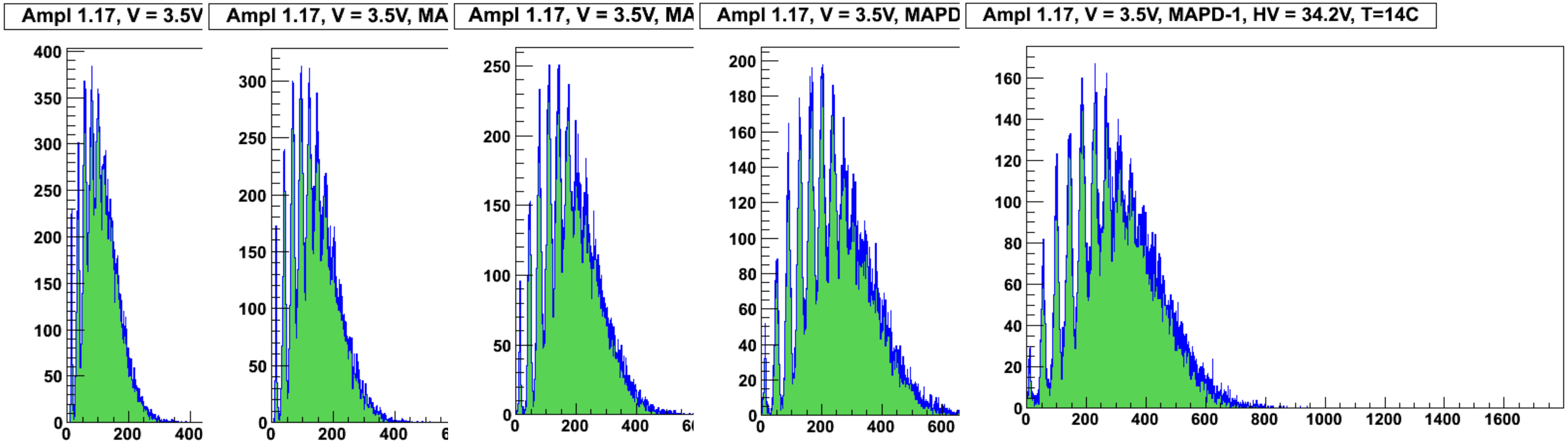
1pe signal

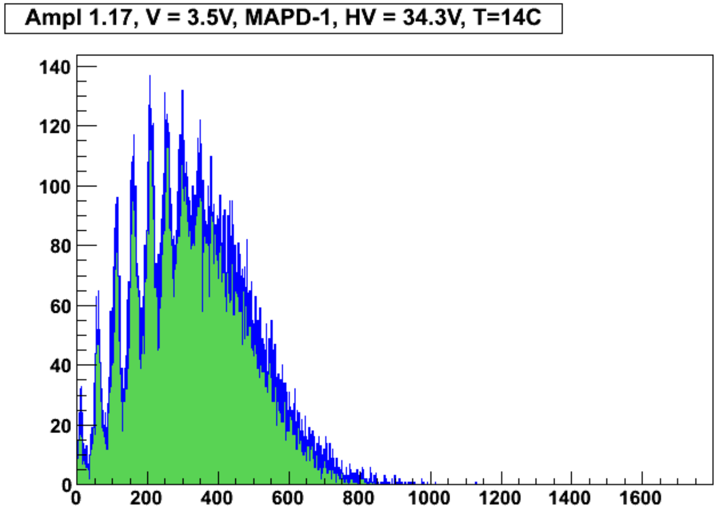


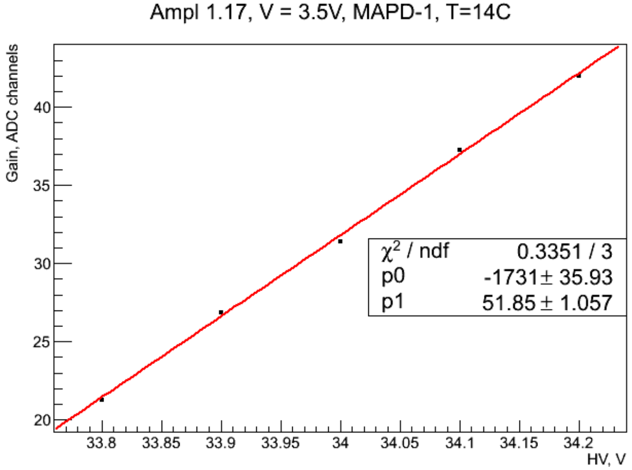
2pe signal

Gain vs V

Linear $Q = C_{pixel}(V_{bias}-V_{br})$ Ampl 1.17, voltages 33.8 – 34.3 V

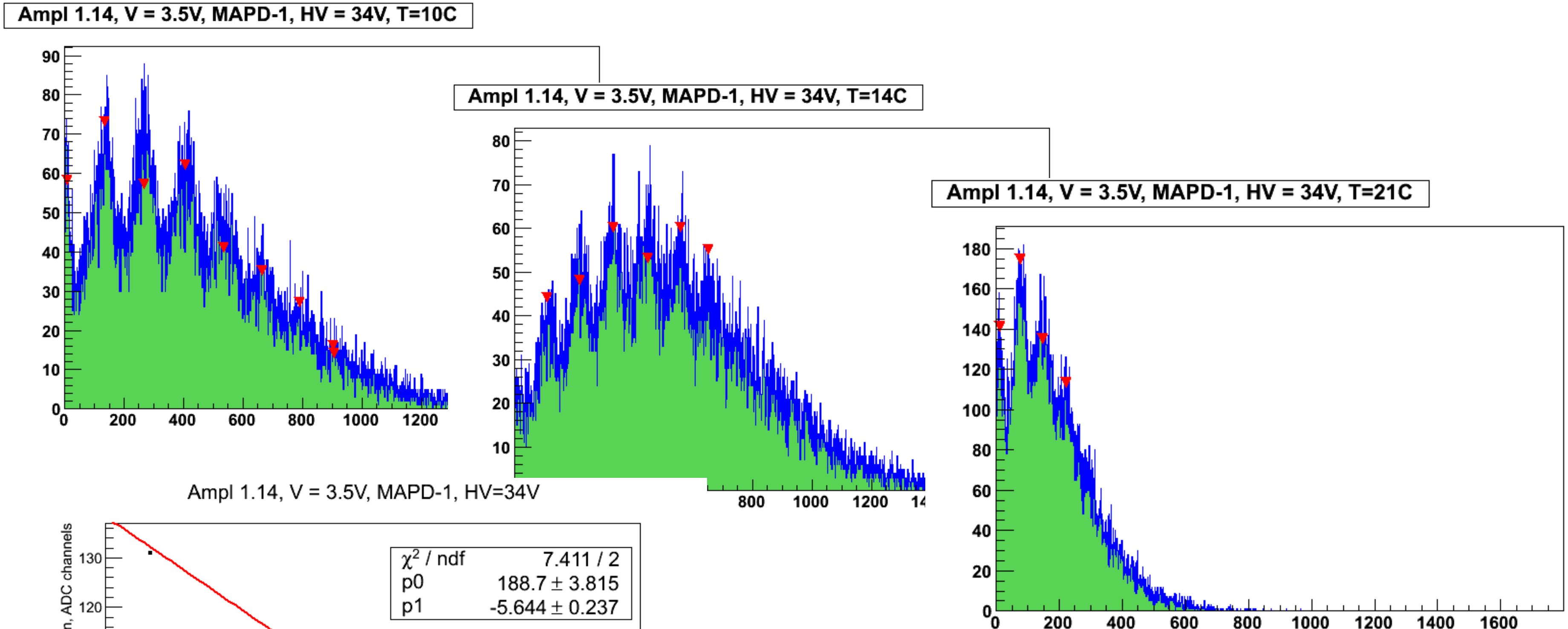


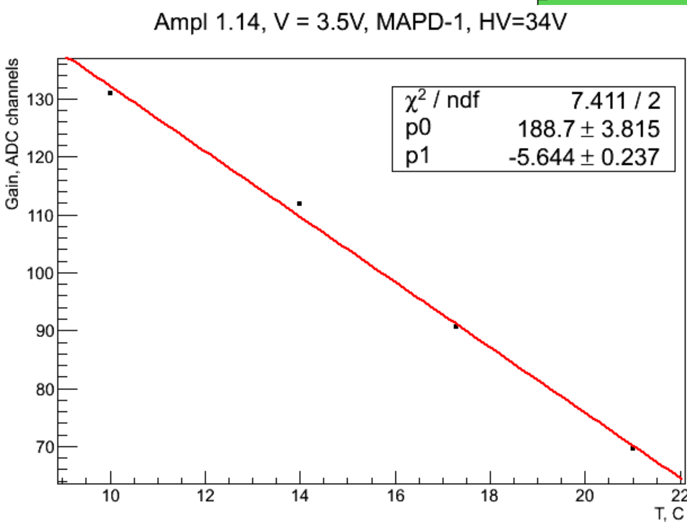




Temperature dependence

Ampl 1.14, 34V, temperatures 10, 14 and 21 C

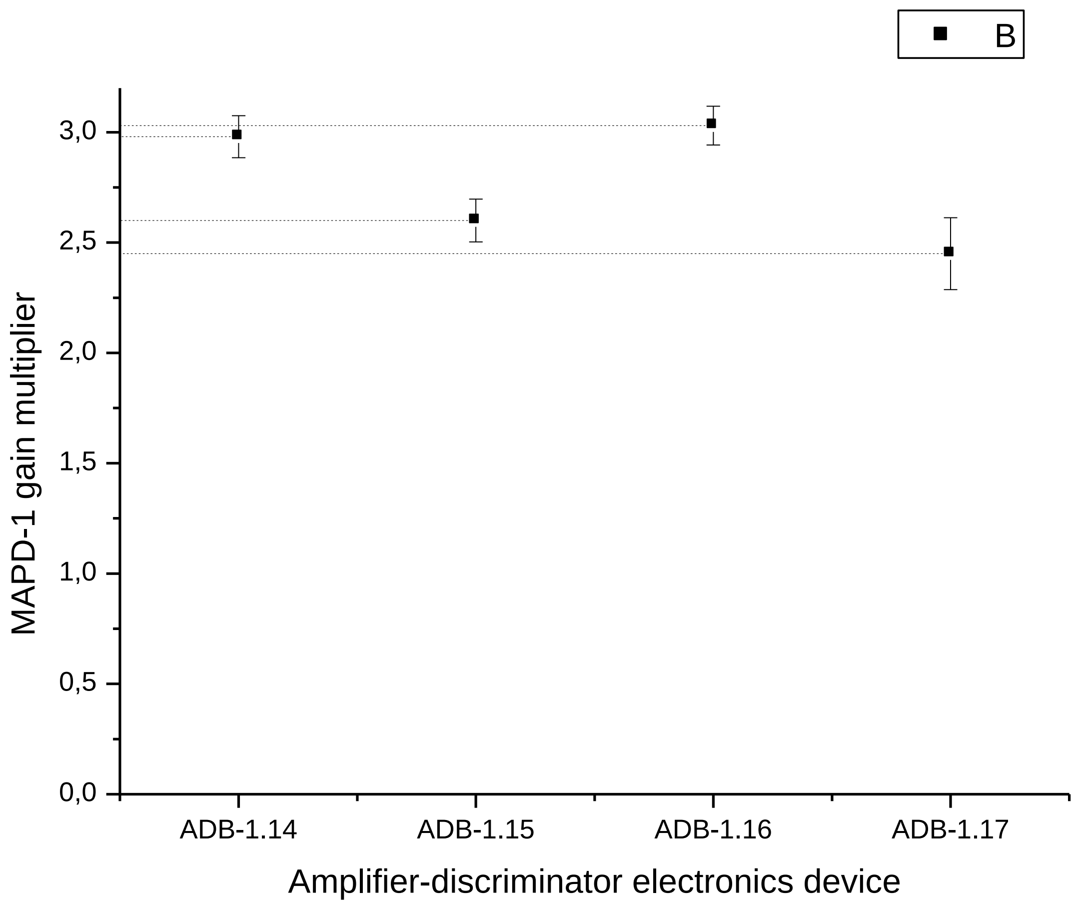




Linear gain drop with temperature due to V_{br} temperature dependence

An increase of MAPD-1 avalanche gain K_D by voltage supply growth 0,5 V (from 33.6 to 34.1 V) measured using Ampl-1.14

$$M_{KD} = \frac{Gain(34{,}1V)}{Gain(33{,}6V)} = \frac{I_{light} \cdot K_D(34{,}1V) \cdot K_{IU} / \Delta U_{кв}}{I_{light} \cdot K_D(33{,}6V) \cdot K_{IU} / \Delta U_{кв}} = \frac{K_D(34{,}1V)}{K_D(33{,}6V)} = \frac{125{,}1}{41{,}96} = 2{,}98.$$



An increase of MAPD-1 avalanche gain K_D by voltage supply growth 0,5 V (from 33.6 to 34.1 V)

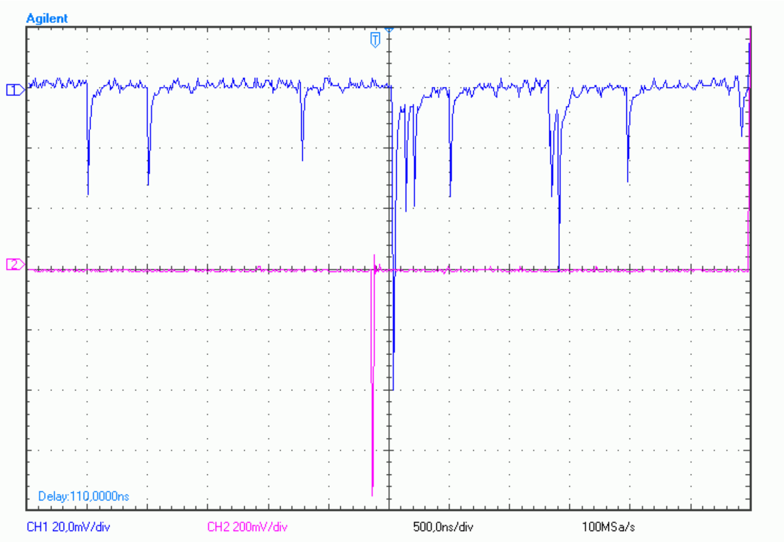
Анализ показывает, что значения M_{KD}, измеренные с помощью усилителей, имеющих два больших значения коэффициента преобразования, а именно Ampl-1.14 (K_{IU}=20 мВ/мкА) и Ampl-1.16 (K_{IU}=15,6 мВ/мкА), весьма близки: они отличаются от среднего значения M_{KD} = 3,005 всего лишь на ±0,083 %.

В то же время усилители с двумя меньшими значениями коэффициента преобразования, а именно Ampl-1.15 (K_{IU}=10 мВ/мкА) и Ampl-1.17 (K_{IU}=1,0 мВ/мкА), также показывают близкие значения M_{KD}: среднее значение равно 2,525 с отклонениями ±2,97 %. По всем четырем измерениям среднее значение составляет 2,765 с максимальными отклонениями +8 % и –11,4 %, что может считаться неплохим результатом при разбросе коэффициентов преобразования от 1 мВ/мкА до 20 мВ/мкА.

Noise

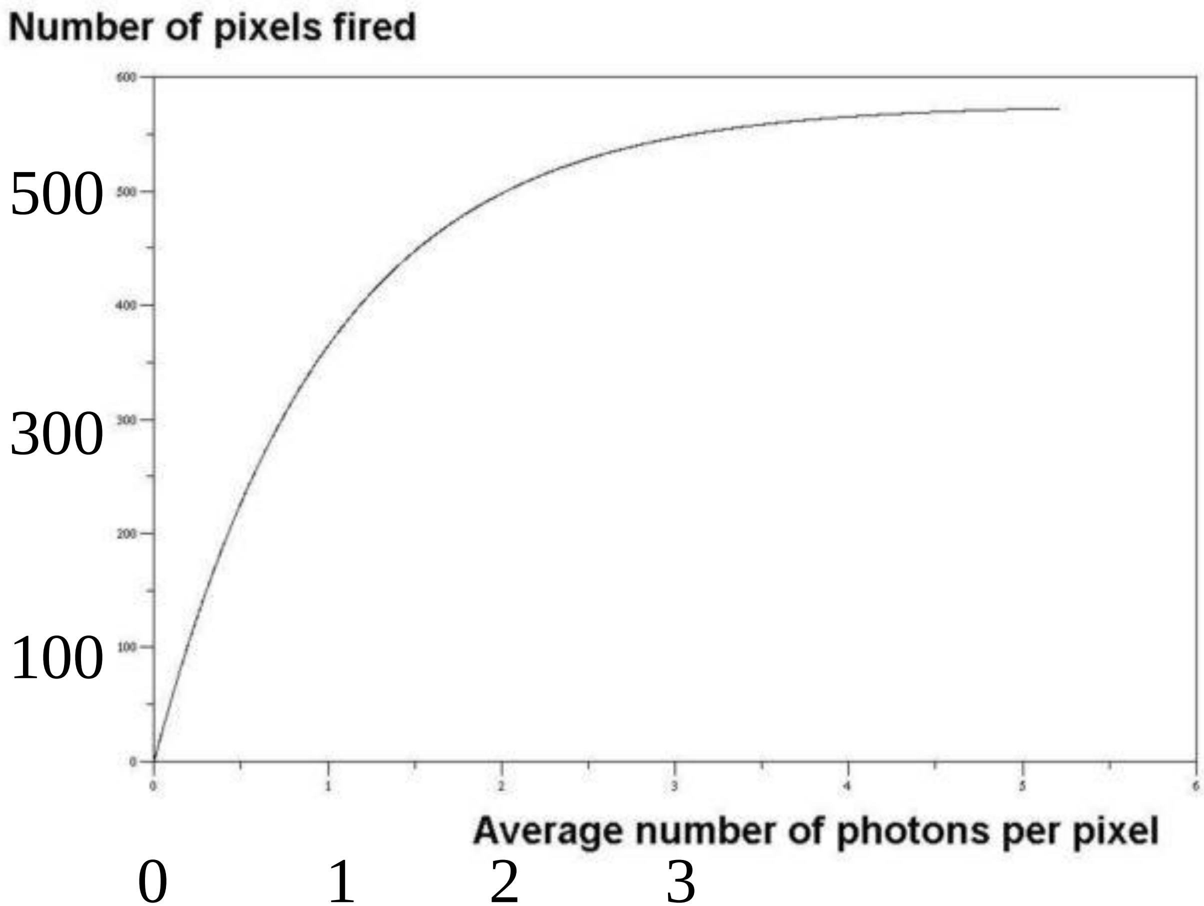
Low electronic noise (high gain=> high s/n ratio),
Dark rate noise is a problem pixels firing due to thermally generated carriers. Unit signals.
About a few MHz/mm^2 at room temp, 1 kHz/mm^2 at 100K° =>
Strongly depends on temperature. (~2x/8°)

MAPD-1 noise level ~ 1 MHz at room temperature



Dynamic range is limited by the number of pixels
Linear up to about 0.6 photo electrons per pixel

560 pixels



Future work

- Test setup with cooling and temperature control
- Test setup for 9-chip hybrid with cooling
- Better led driver

THANK YOU