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SiPM BIAS and AMPLIFIER CIRCUIT

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SIPM POWER SUPPLY

SiPM BIAS (I)

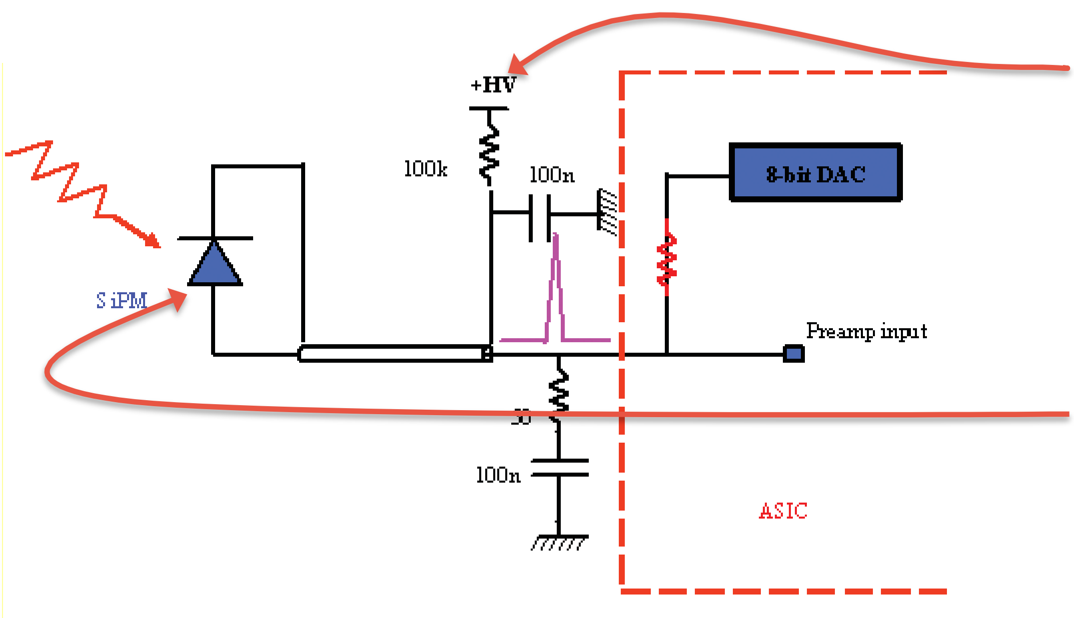
The Problem

- 8 SiPMs
- Each SiPM has a different working point

→ TWO POSSIBLE APPROACHES

I st : use a DAC to move SiPM reference

- Very cheap using multi-channels DAC
- Easy to integrate in ASIC design
- Very low ripple required in main HV generator
- SiPM working point setup is a bit tricky (single SiPM working points are not independent)



$HV = V_{BREAKDOWN} + V_{REF\ DAC}$

$V_{SIPM} = HV - V_{DAC}$

SiPM BIAS (II)

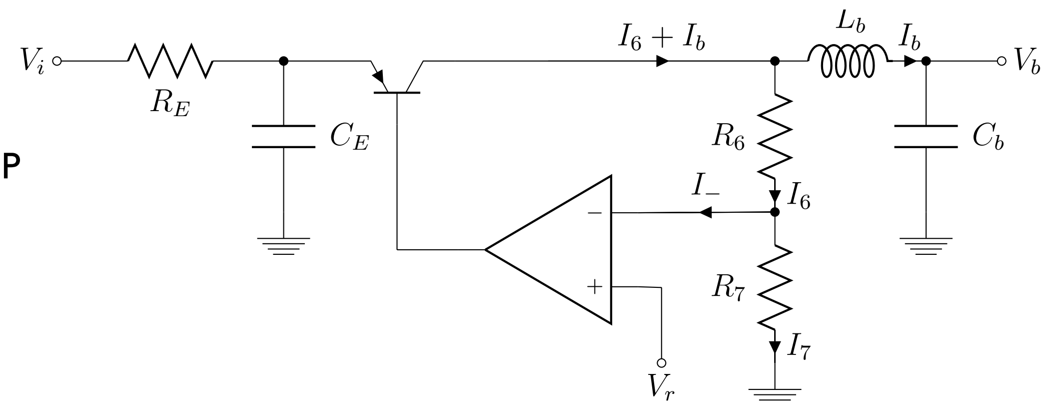
2^{nd} : use Main Voltage Generator and different regulators to adjust the single SiPM working point

- The regulators behave also like a filter to reduce the Main Voltage Generator ripple
- Independent SiPM working points adjustment
- More components and PCB space required (size of the board increased)

Simplified version of Beissel voltage controlling circuit

IDEAL AMP OP

- gain=∞
- Z_{IN}=∞
- Z_{OUT}=∞
- BW=∞



HOW DOES IT WORK ?

- Assuming an ideal operational amplifier the voltage at the inverting node we'll be V_r, then $I_7=V_r/R_7$
- The same current will flow through R_6 (Z_{IN}=∞)→ $V_r/R_7= (V_b - V_r)/R_6$
- Then if Vi > Vb (the transistor must be polarized) → $V_b=(1+R_6/R_7)*V_r$

➡ Adjusting the R_6/R_7 ratio or V_r value we can adjust the SiPM working voltage

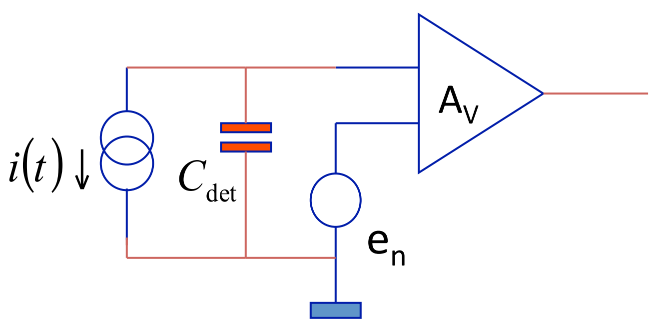
PREAMPLIFIERS

VOLTAGE PREAMPLIFIER

PREAMPLIFIER=INPUT AMPLIFIER

- Generally located on the detector (ON-DETECTOR ELECTRONICS)
- Amplify the signal optimizing the signal-to-noise ratio
- Three basic configurations:
  - Voltage preamplifier
  - Current preamplifier
  - Charge preamplifier

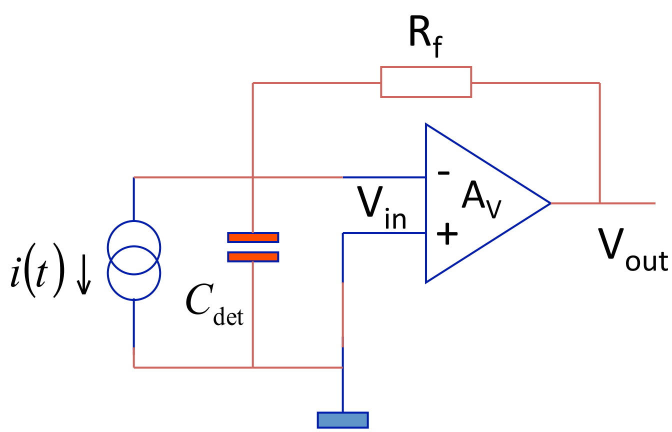
VOLTAGE PREAMPLIFIER (for sensors generating voltage signals or as second stage for sensors generating current signals)



$$V_{out} = \frac{Q_{in}}{C_{tot}} \qquad C_{tot} = C_{\det} + C_{conn} + C_{in\_pre}$$

C_{tot} can change as a function of detector working parameters or PT → Vout changes

CURRENT PREAMPLIFIER



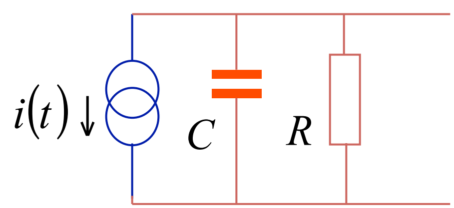
$$V_{out} = -AV_{in}$$
$$V_{out} - V_{in} = -R_f i_{in}$$
$$V_{out} = -R_f i_{in} \cdot \left(\frac{1}{1+\frac{1}{A}} \right)$$

$\Rightarrow$ $$V_{out} \approx -R_f i_{in}$$

INPUT IMPEDANCE

$$V_{out} = -AV_{in}$$
$$V_{out} = -R_f i_{in} \cdot \left(\frac{1}{1+\frac{1}{A}} \right)$$
$$-R_f i_{in} \cdot \left(\frac{1}{1+\frac{1}{A}} \right) = -AV_{in} \rightarrow V_{in} = \frac{R_f i_{in}}{1+A} \rightarrow Z_{in} = \frac{R_f}{1+A}$$

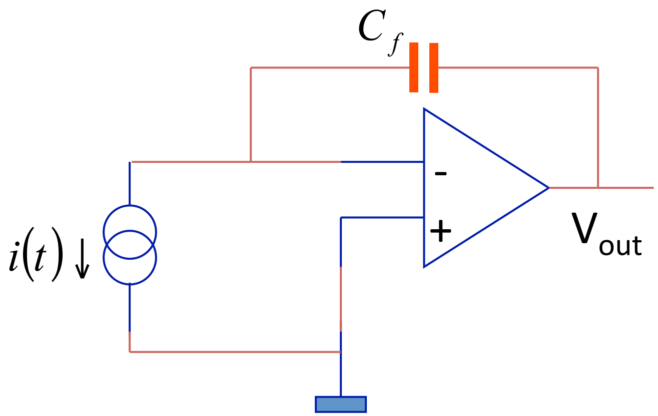
C_{in} CONTRIBUTION



- Input signal is convolved with an exponential.
- Increasing R_f increases both the preamplifier sensitivity and τ.

$$Z_{in} = \frac{R}{1+j\omega RC}$$

CHARGE PREAMPLIFIER



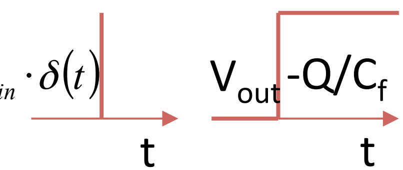
$$V_{out} = -AV_{in}$$

$$V_{out} - V_{in} = -\frac{i_{in}(\omega)}{j\omega C_f}$$

$$V_{out} = -\frac{i_{in}(\omega)}{j\omega C_f}\cdot\left(\frac{1}{1+\frac{1}{A}}\right)$$

$$V_{out} \approx -\frac{i_{in}(\omega)}{j\omega C_f}$$

$$i_{in}(t) = Q_{in}\cdot\delta(t)$$



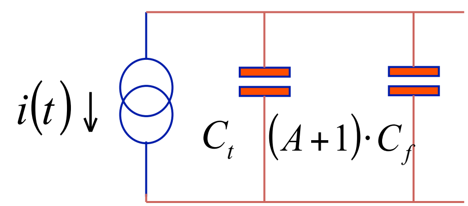
INPUT IMPEDANCE

$$V_{out} = -AV_{in} \qquad V_{out} = -\frac{i_{in}(\omega)}{j\omega C_f}\cdot\left(\frac{1}{1+\frac{1}{A}}\right)$$

$$-\frac{i_{in}(\omega)}{j\omega C_f}\cdot\left(\frac{1}{1+\frac{1}{A}}\right) = -AV_{in} \rightarrow V_{in} = \frac{i_{in}(\omega)}{j\omega C_f\cdot(1+A)}$$

$$C_{in} = (1+A)\cdot C_f$$

HOW MUCH SIGNAL ARE WE GOING TO LOOSE ?



$$\frac{Q_{amp}}{(1+A)\cdot C_f} = \frac{Q}{(1+A)\cdot C_f + C_t}$$

$$Q_{amp} = \frac{Q}{1+\frac{C_t}{(1+A)\cdot C_f}}$$

Es. $A=10^3$; $C_f=1$pF

$C_t=10$ pF → $Q_{ampl}/Q=0.99$

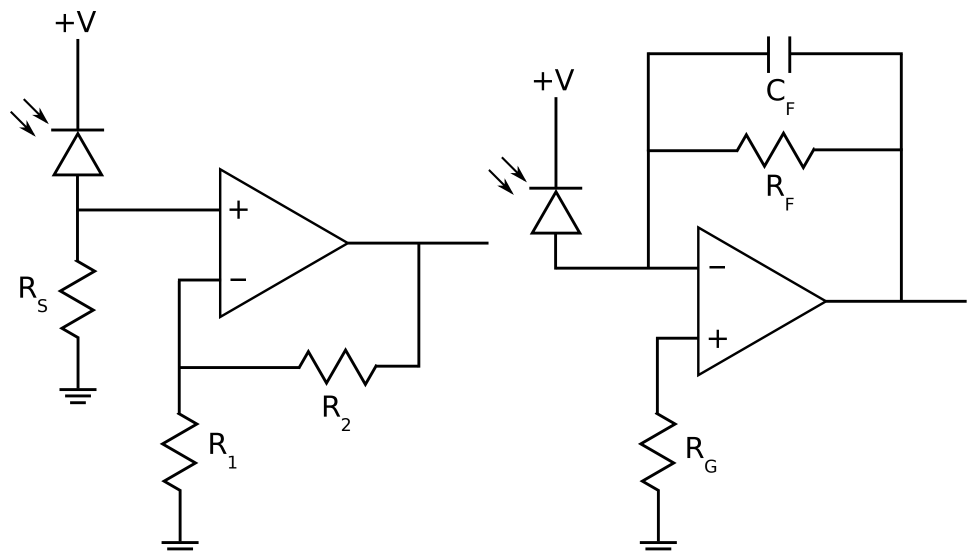
$C_t=100$ pF → $Q_{ampl}/Q=0.90$

WHICH AMPLIFIER ?

VOLTAGE, CURRENT OR CHARGE AMPLIFIER ?

- SiPMs output charge of the order of hundreds of fC
- SiPM devices have excellent timing properties.
- SiPM devices exhibit single photon resolution, but have a quite poor lineari response

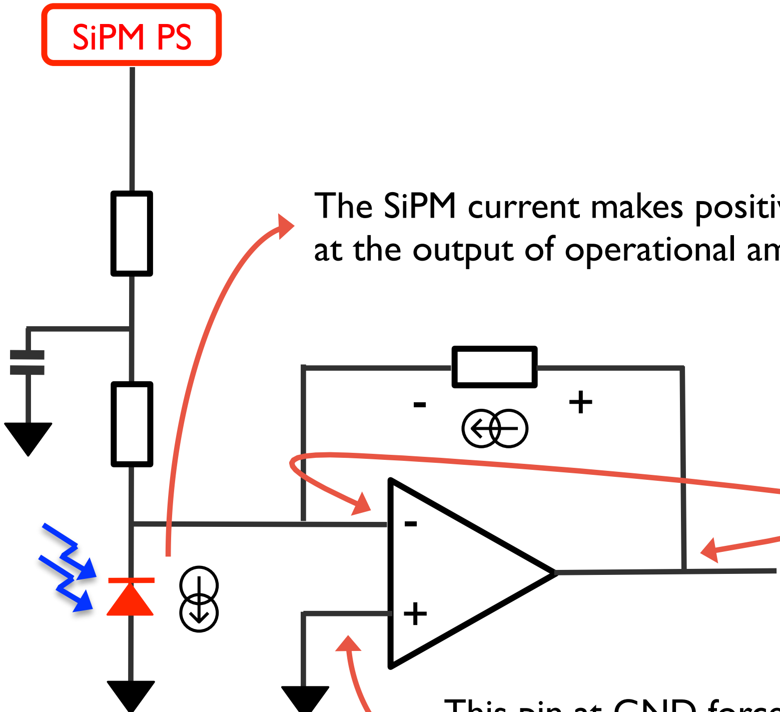
➡ Voltage or Current amplifiers configurations can be used as head-stage amplifiers



In voltage amplifiers increasing R_S increases input amplifier voltage, but amplifier input voltage noise increase and bandwidth decreases.
Current (or transimpedance) amplifier allows to overcome voltage amplifier limitations in terms of gain and bandwidth still maintaining a good signal-to-noise ratio (but stability problems could arise because diode parasitic capacitance).

AMPLIFIER STABILITY

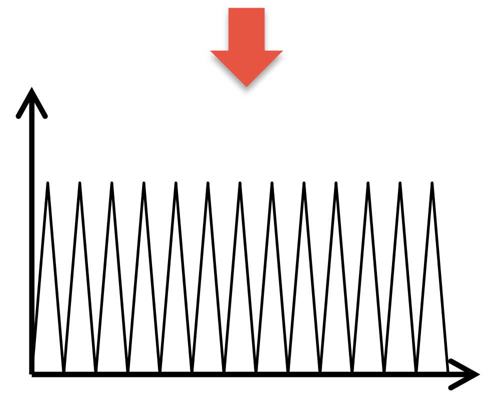
SiPM AMPLIFIER (I)



The SiPM current makes positive voltage at the output of operational amplifier

This pin at GND force this pin to GND (virtual GND)
REMIND → GAIN=∞

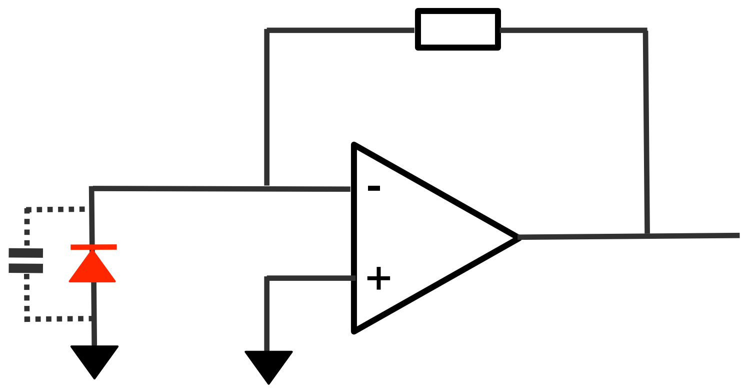
BUT most likely if you use high bandwidth amplifier looking at the output with a scope

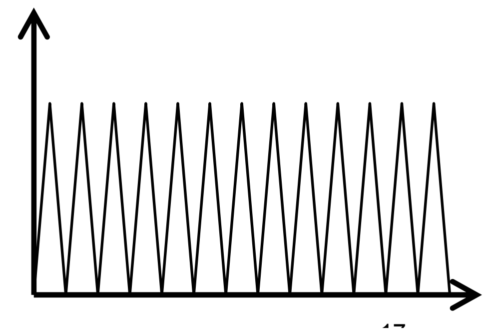


THE AMPLIFIER OSCILLATES !! WHY ???

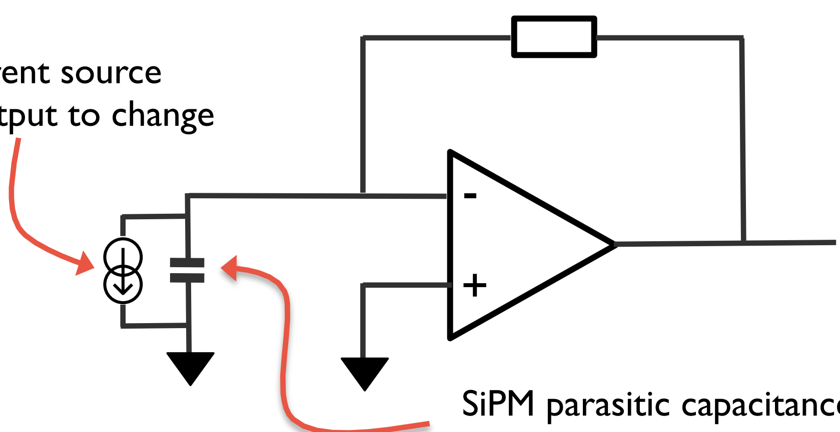
SiPM AMPLIFIER (II)

THE PROBLEM: oscillation are caused by SiPM parasitic capacitance on input





SiPM current source forces output to change



SiPM parasitic capacitance lag the feedback signal

FEEDBACK LAG IS BAD

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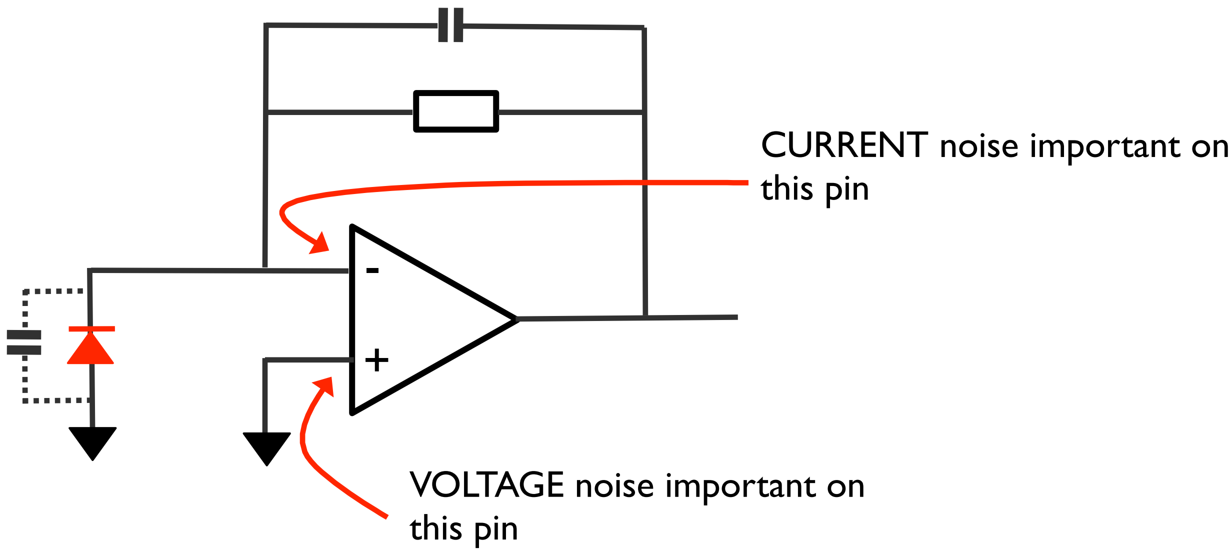
SiPM AMPLIFIER (III)

THE SOLUTION: insert a capacitance to compensate for the phase lag



NEXT PROBLEM: noise (current noise & voltage noise)

AMPLIFIER NOISE

- Hard to match low current noise and low voltage noise requirement on the same device
- JFET amplifiers have low current noise
- Bipolar amplifiers have low voltage noise

- More on this in Noise Introduction slides ….

BIBLIOGRAPHY

[1] Front-end Electronics for Silicon Photomultipliers, Johannes Schumacher
[2] Photodiode amplifier – G. Lochead