Hybrid + Active ganging SiPM circuit

VD-PDS

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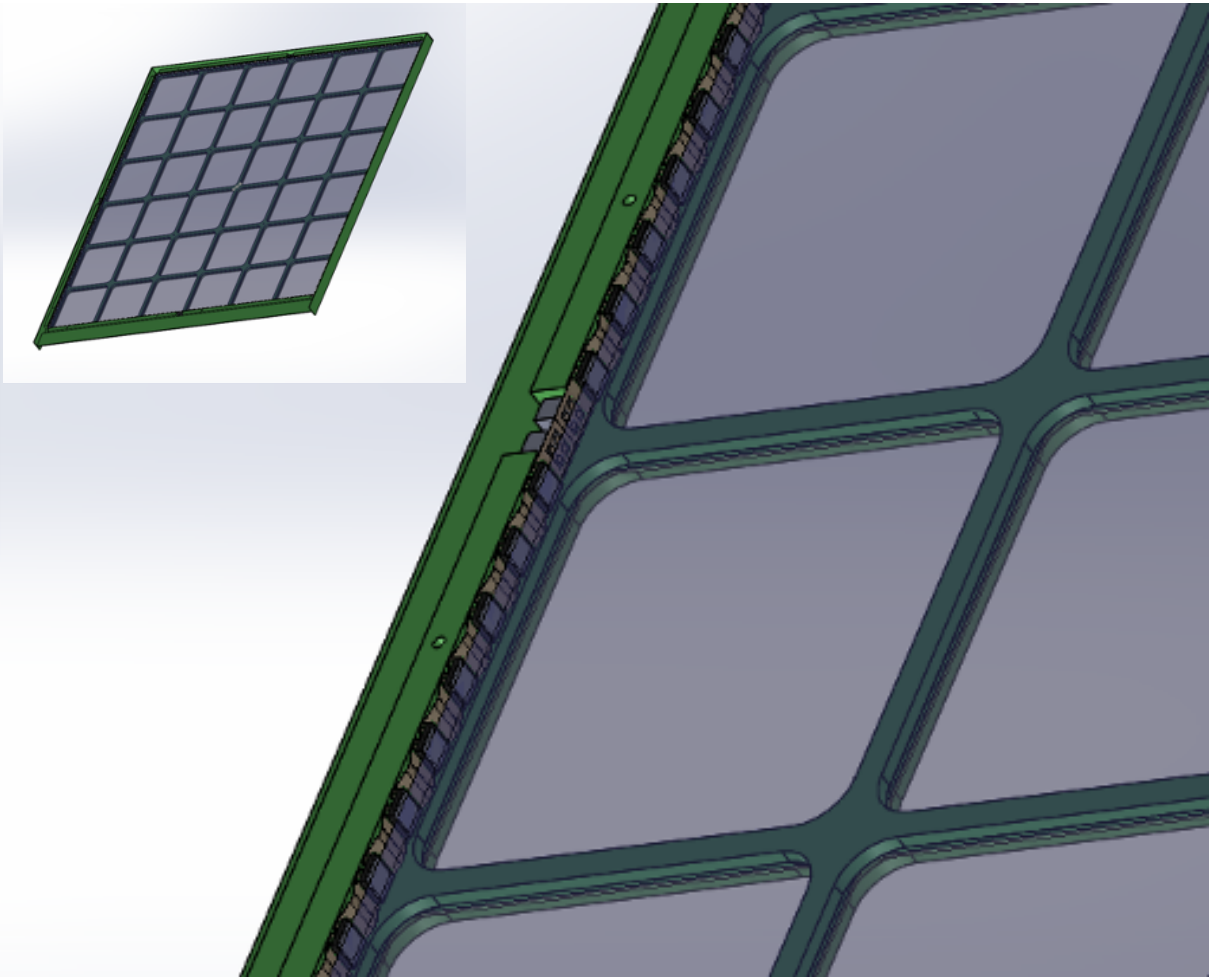
X-ARAPUCA tile

- Each X-ARAPUCA tile is populated with 160 SiPMs

- Organized in 8 groups of 20 SiPM.

- The 20 SiPM are passively summed in “hybrid" mode.

- The 8 groups then are summed in an active summing stage, using an OpAmp.



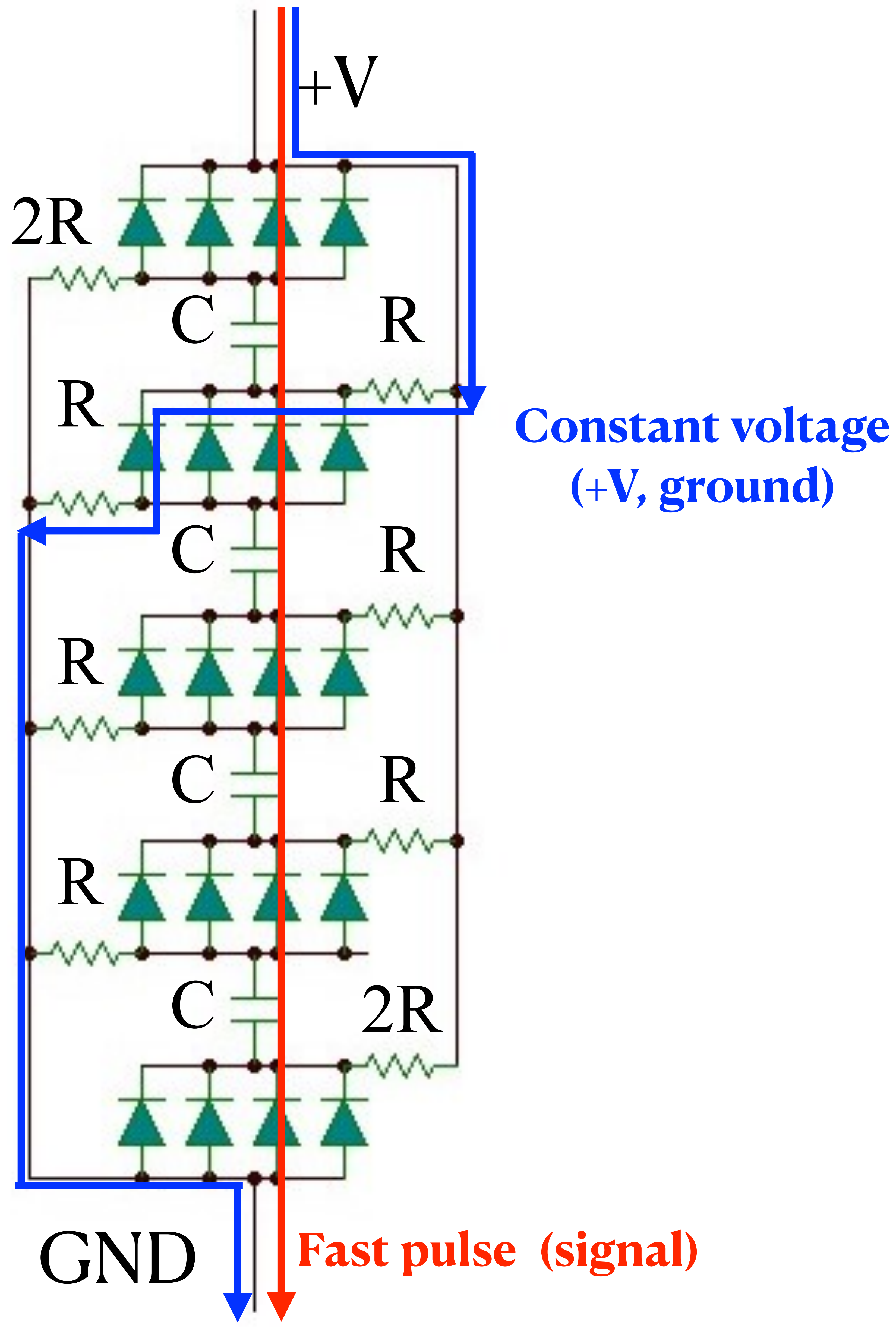
Hybrid circuit

The hybrid connection advantages:

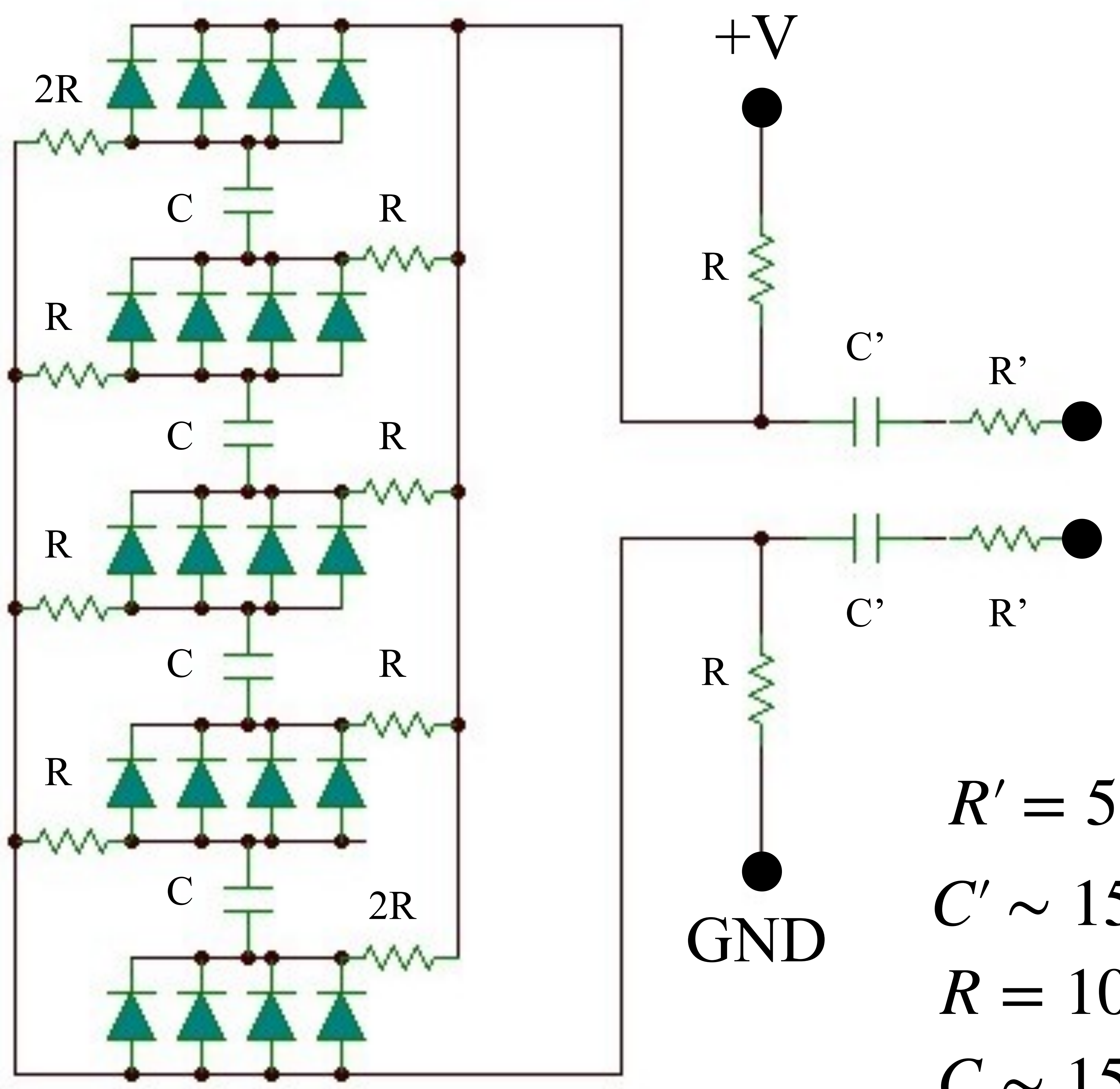
- Same potential on the surface of SiPM's.
- Small capacitance → short recovery time
- Same bias voltage of a single SiPM

DC current SiPM+2R ($R = 10\,k\Omega$).

AC current SiPM + C ($C \sim 15\,nF$)



The 160 SiPM's from each X-ARAPUCA tile are arranged in 8 subgroups of 20 SiPM passively connected in "hybrid mode".

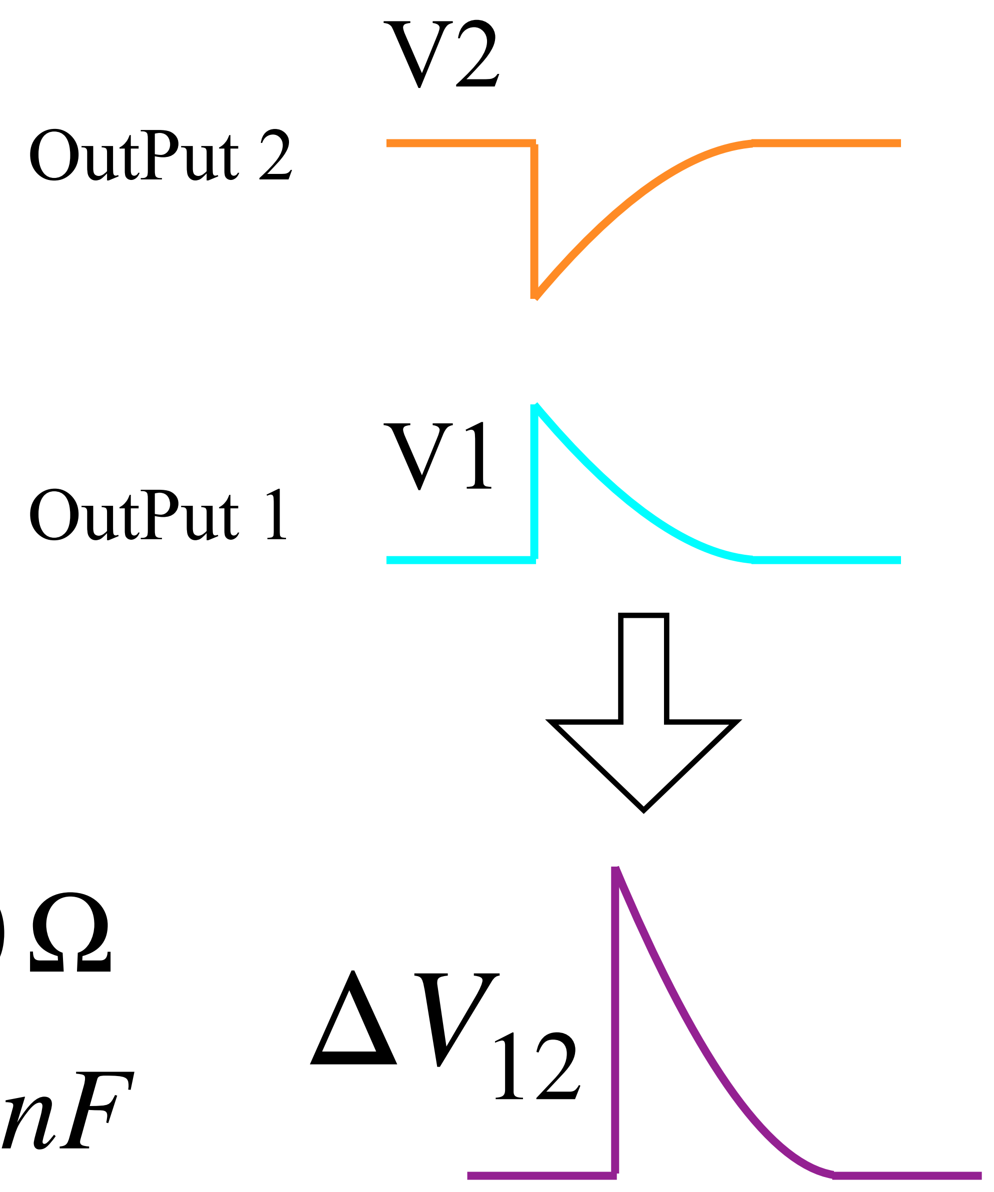


$R' = 50\,\Omega$

$C' \sim 15\,nF$

$R = 10\,k\Omega$

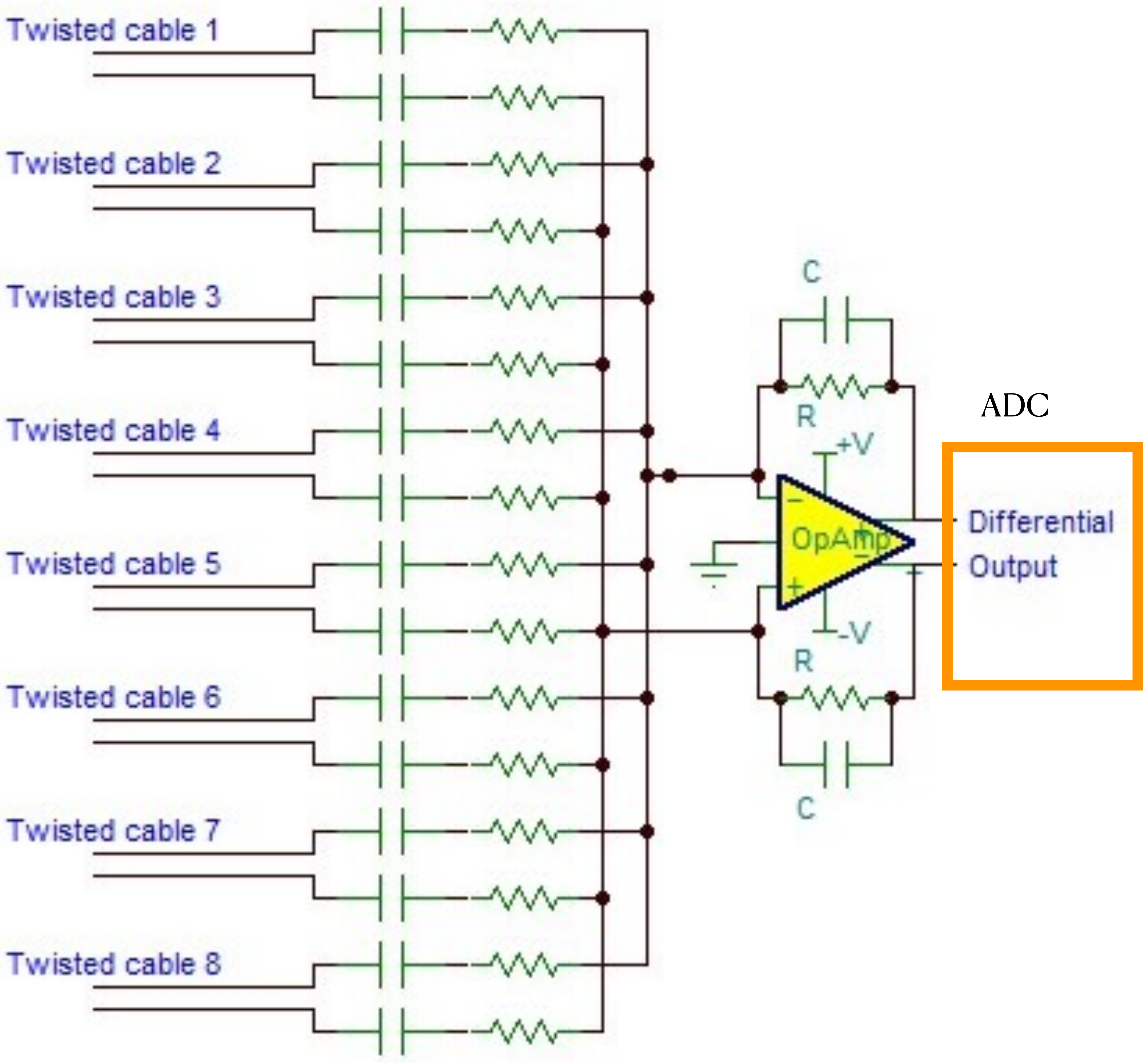
$C \sim 15\,nF$



RC stage before +V / GND provide the AC output. Signal can be read by both output.

Since the two outputs are specular, reading the signal in "differential" mode allows to increase the signal-noise ratio.

Active ganging



Each couple of outputs goes in an OpAmp stage: “active ganging stage”.

The OpAmp allows to sum multiple channels decoupling the capacitance of each channel.

At the same time it can provide a signal amplification (G ~ 10).

Increasing/tuning the signal in order to match:

- ADC dynamic range requirement
- SPE noise ratio
- Maximum number of photon collectable

A Full Differential OpAmp, together to read a better signal (combing the two outputs) is the best to match with the ADC device.

Multiple configuration

Different configurations are under consideration for the signal transmission over fibers:

Digital transmission

- 1 ADC per X-ARAPUCA tile → 8 channels in a single Full Differential OpAmp.
- 2 ADC per X-ARAPUCA tile → 4 channels in a single Full Differential OpAmp.

Analog transmission

- 1 Analog transmitter → 8 channels in a single OpAmp (not differential mode).

However for all the cases the SiPM Hybrid configuration and the Summing Stage are expected to not have any significative changes.

Readout matching

SiPM equivalent electric circuit has been developed by **Gustavo Cancelo (FCC)** to study the device response. A solution for unwanted effects (undershot, changes in recovery time, signal distortions) seems to be available.

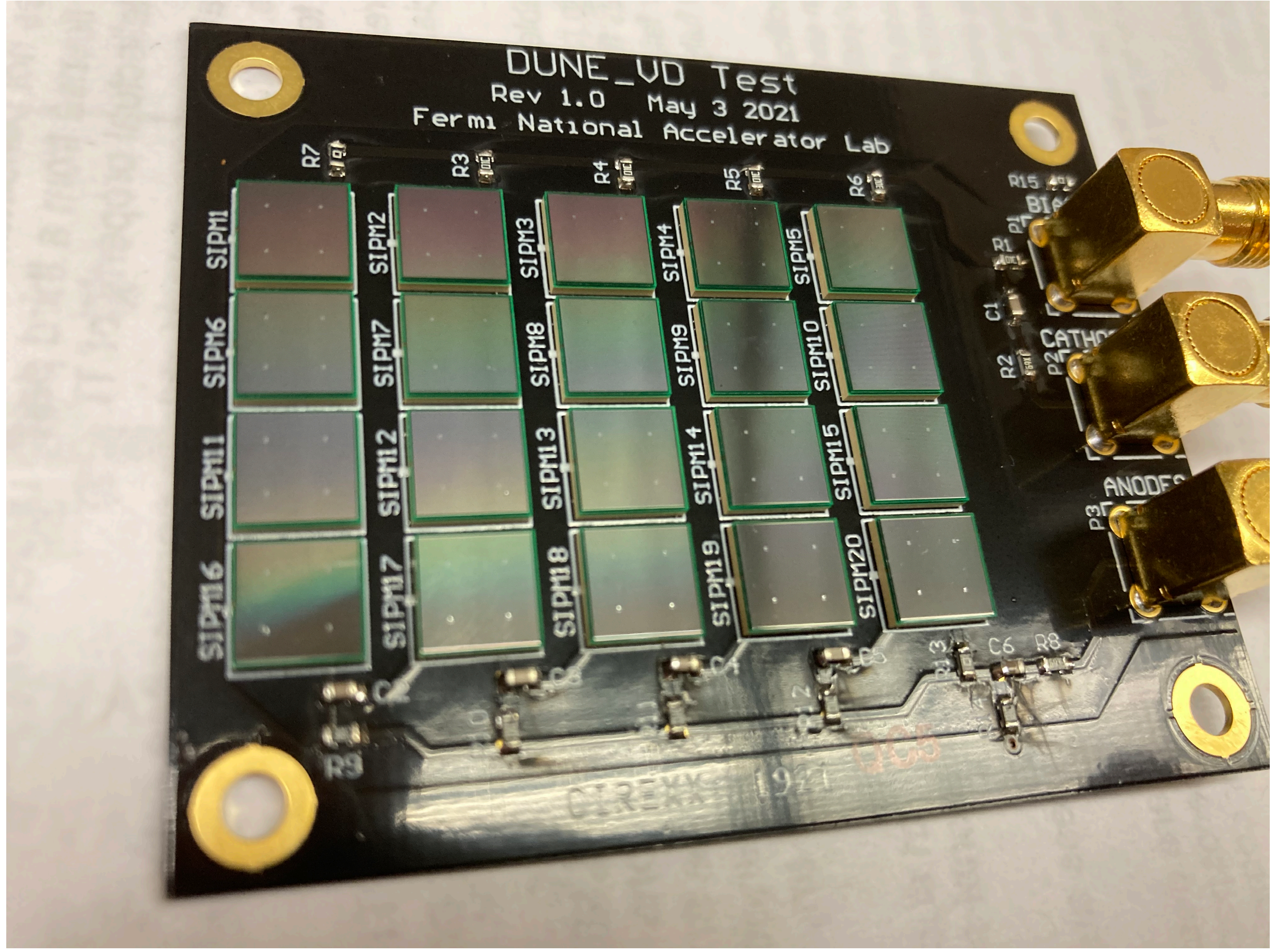
The RC components, at the readout stage, have to be careful evaluated to match the timing response of the circuit (dependent by the hybrid configuration as well the SiPM equivalent impedance).

The model developed match with a SPICE simulation.

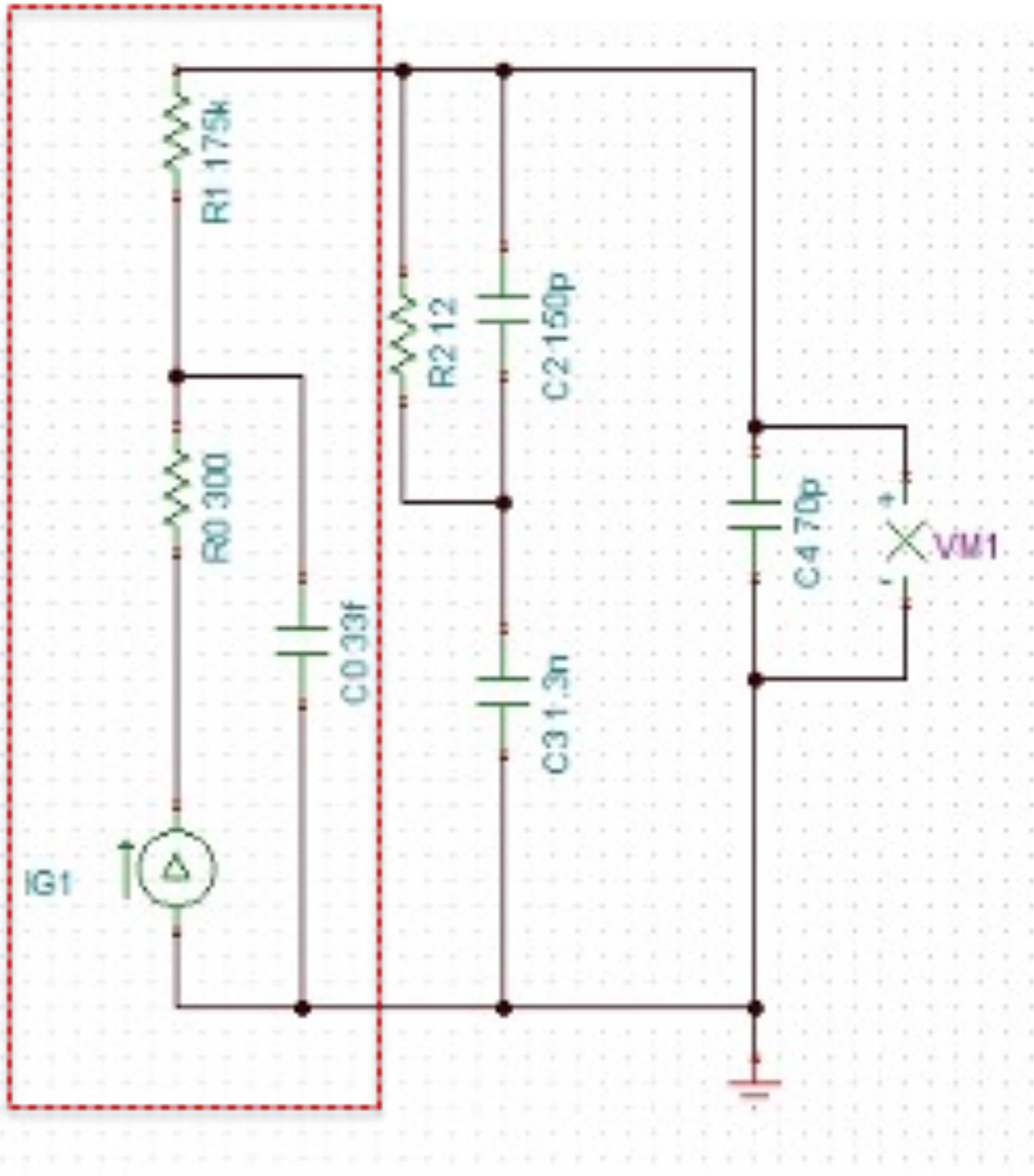
A "version-zero" of an hybrid circuit board (20 SiPM) has been delivered yesterday.

Tests will be performed to characterize the hybrid circuit and prove the model validity.

As first stage, we aim to define the hybrid circuit response in term of: SPE gain, signal amplitude, signal noise ratio, etc…



Hybrid model and simulations

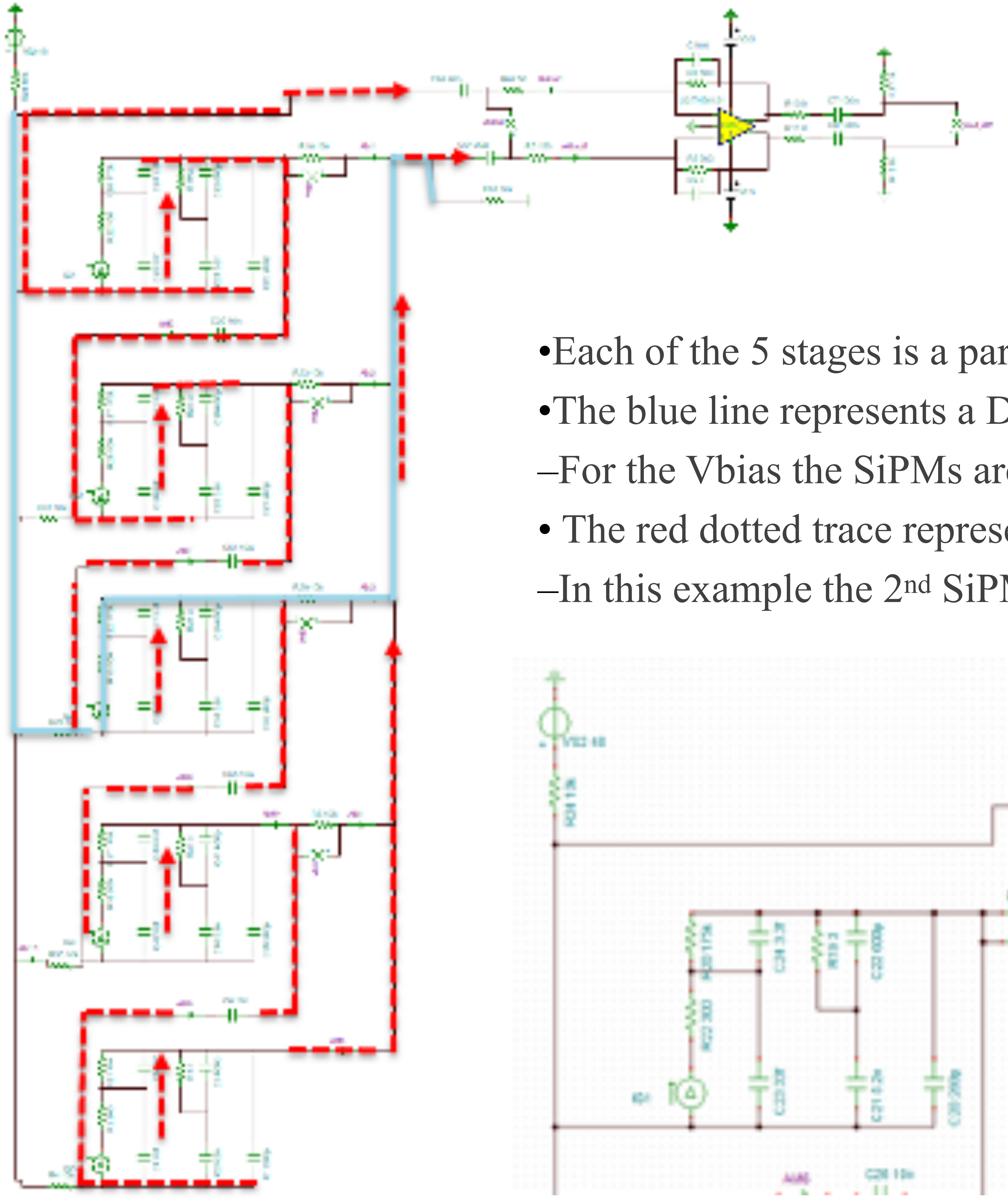


•The dynamics of a firing microcell in a multi microcell SiPM can be represented by a passive electric circuit and a current source (Seifert, 2009),(Corsi, 2007), (Wangerin,2008).

•The model parameters can be extracted from the SiPM datasheet (e.g. Hamamatsu S13360-5060VE).

•A typical 6x6mm 50 μm pitch SiPM has the following model.

- The part inside the rectangular red line represents the firing microcell. The part outside are the N-1 passive microcells which act as a load.
- We started with the study and simulation of a single SiPM and finalize with a full 4 x 5 hybrid model.
- The hybrid model is biased and also loaded by an Op Amp stage with gain based on the THS4131 high bandwidth fully differential amplifier.



5 x 4 hybrid with bias and preamp

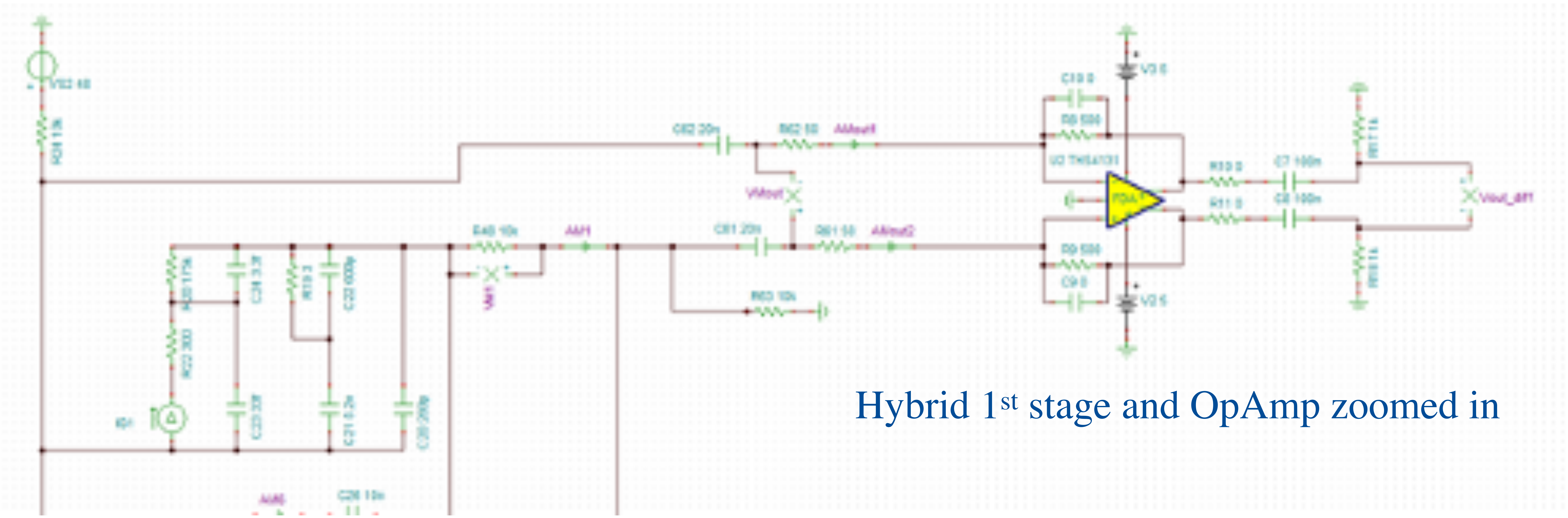
•Each of the 5 stages is a parallel of 4 SiPMs

•The blue line represents a DC bias path.

–For the Vbias the SiPMs are in parallel, so Vbias hybrid is equal to the bias of a single SiPM.

• The red dotted trace represents the serial path of the signal.

–In this example the 2nd SiPM fires and the signal goes through 1st stage.



Hybrid 1st stage and OpAmp zoomed in

The hybrid transfer function was modeled using the Laplace transform

Passive hybrid SiPM array

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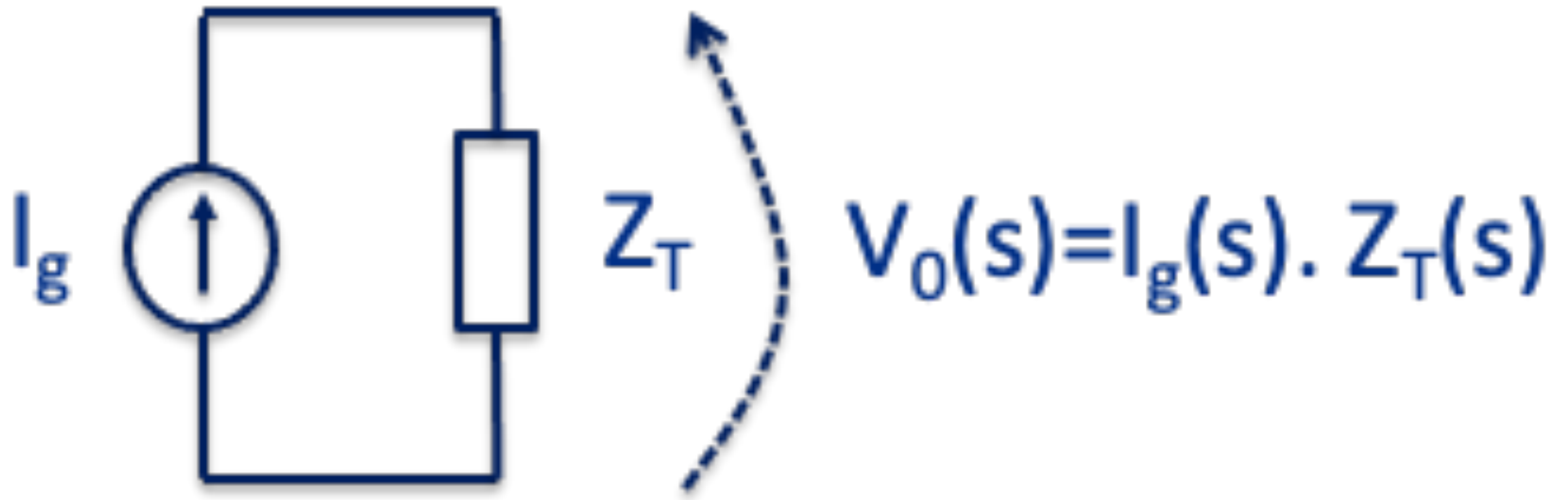
$$Z_T = Z_{234}||Z_L = \frac{(1+ST_0)(1+ST_L)}{S^3C_3T_1T_L + S^2(C_LT_0 + C_3(T_1+T_L)) + S(C_L+C_3)}$$

$$Z_T = \frac{1}{C_3T_1T_L}\frac{(1+ST_0)(1+ST_L)}{s(S^2+S\omega_n/Q+\omega_n^2)}$$

where

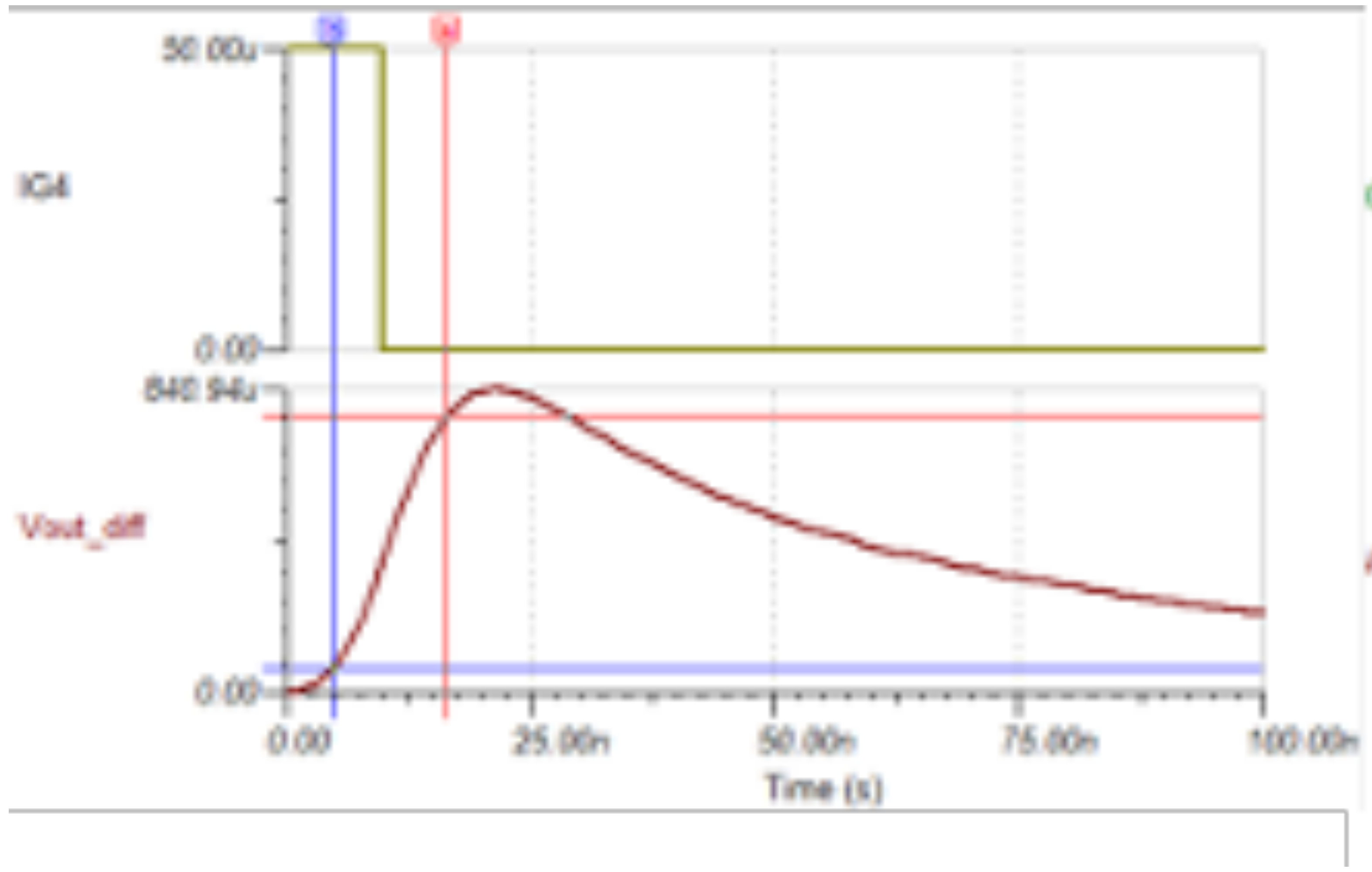
$$\omega_n/Q = \frac{C_LT_0 + C_3(T_1+T_L)}{C_3T_1T_L}$$

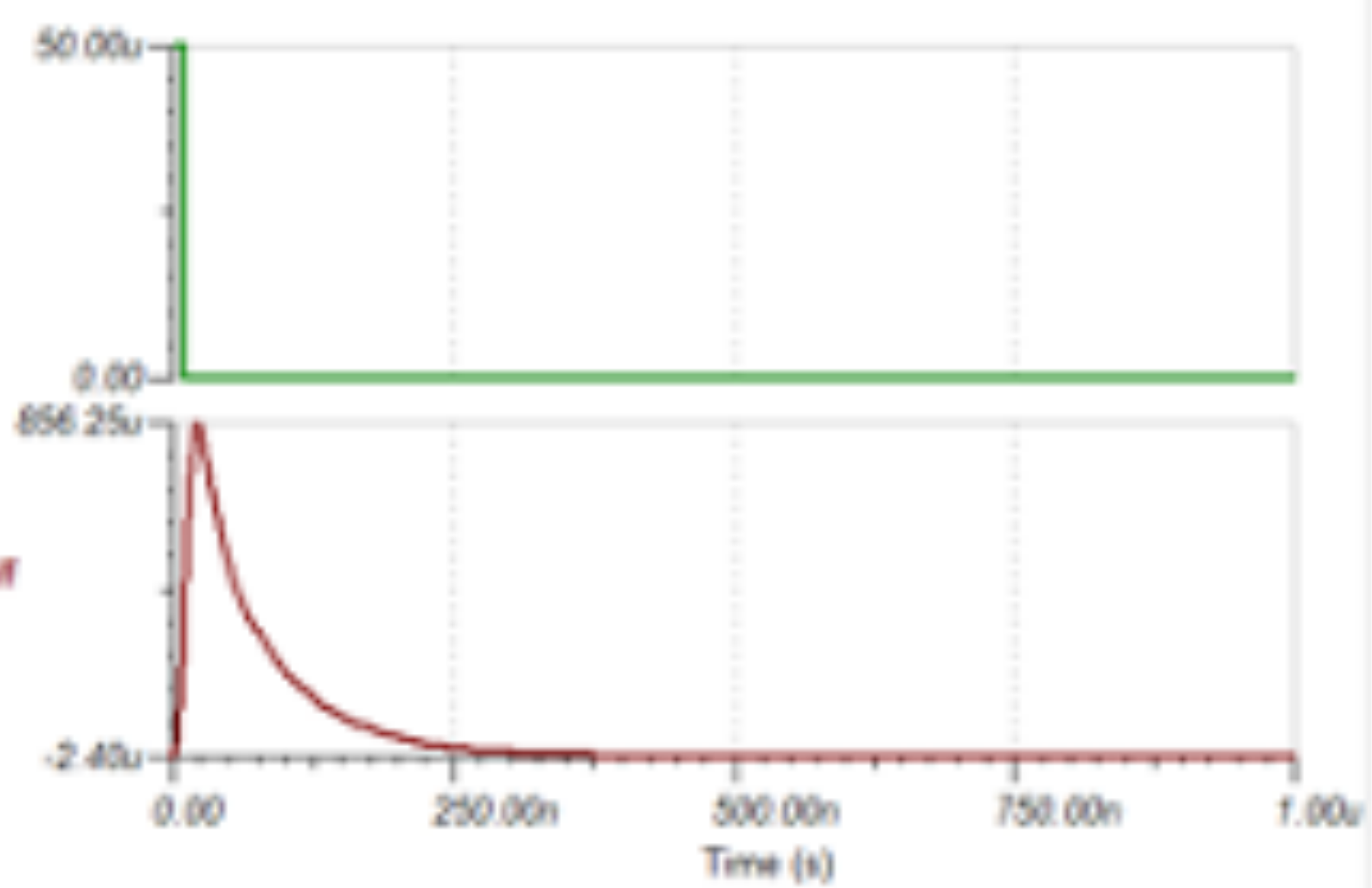
$$\omega_n^2 = \frac{C_L+C_3}{C_3T_1T_L}$$



$$V_{out}(t) = V_0\left[\left[1-e^{-S_1t}+\frac{t}{T_0}\right] - \left[1-e^{-S_1(t-t_0)}+\frac{t-t_0}{T_0}\right]u(t-t_p)\right]$$

- The transfer function of the dynamic model is obtained using the Laplace transform in the frequency domain. Then the time response is obtained using the inverse transform.
- The dynamics is a function of the poles and zeros of the transfer function given by C and R's in the circuit.
- Simulations agree with analytical derivations.





Signal rise time = 12ns
No undershoot.
840uV for a single PE and for amplifier gain of 10