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## Self-Powered Adaptive Switched Architecture Storage for Ultra-Capacitors

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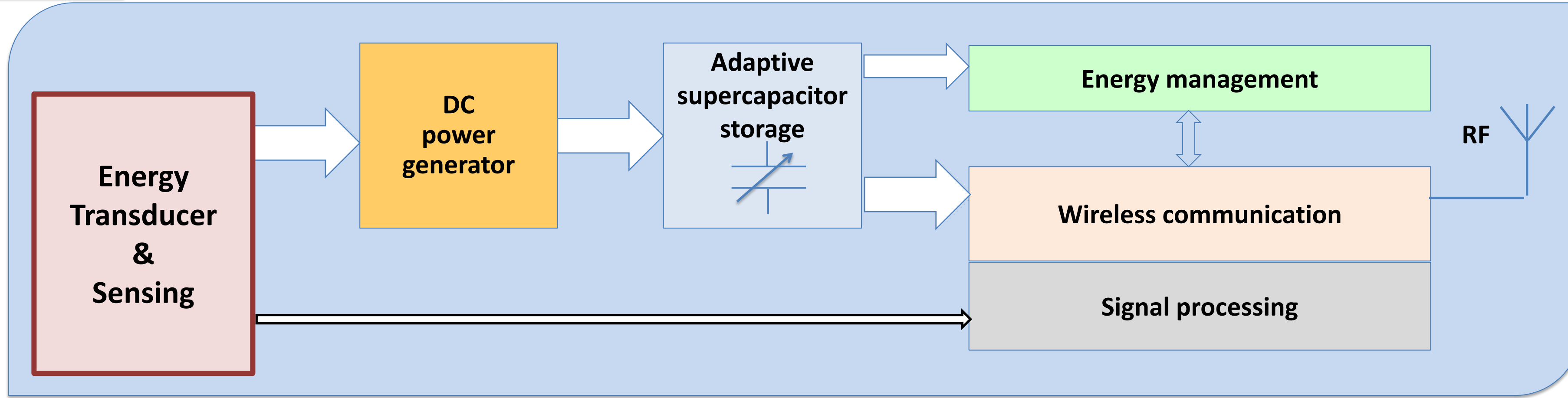
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## CONTEXT: Autonomous battery-free wireless sensor node

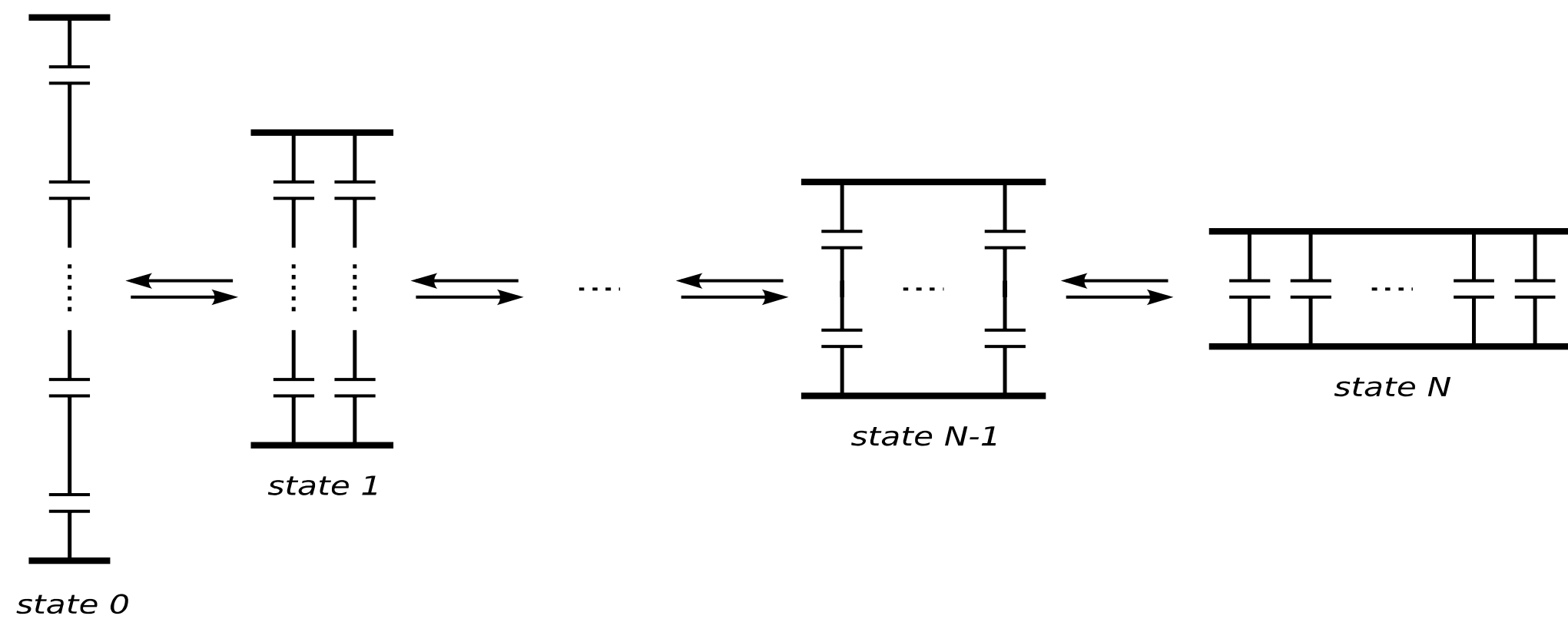


### Objectives

- Coupling energy harvesting & storage on supercapacitor (SC)
- Adaptive storage for early startup at charging (low capacitance value) and maximization of stored energy (high capacitance),
- Autonomy of the system and maximum energy usage rate.

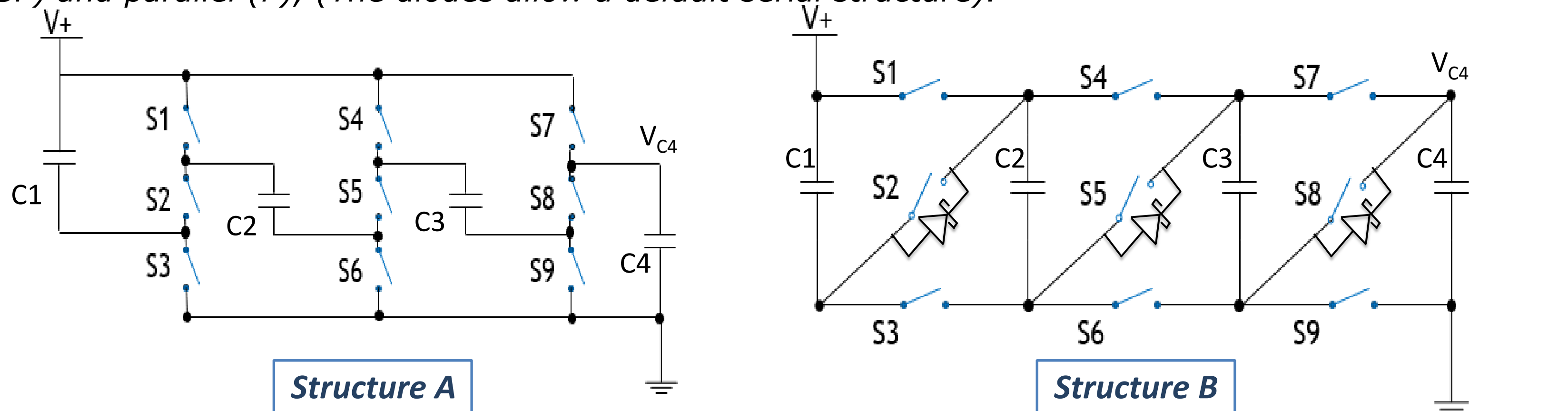
## Self-adaptive Architecture

The principle of this structure is to change the value of the total storage capacity according to the state of charge/discharge, to satisfy the objectives: fast charging time with a low capacitance  $C_{eq}=C/N$  (series configuration), maximization of stored energy with  $C_{eq}=C*N$  (parallel configuration).



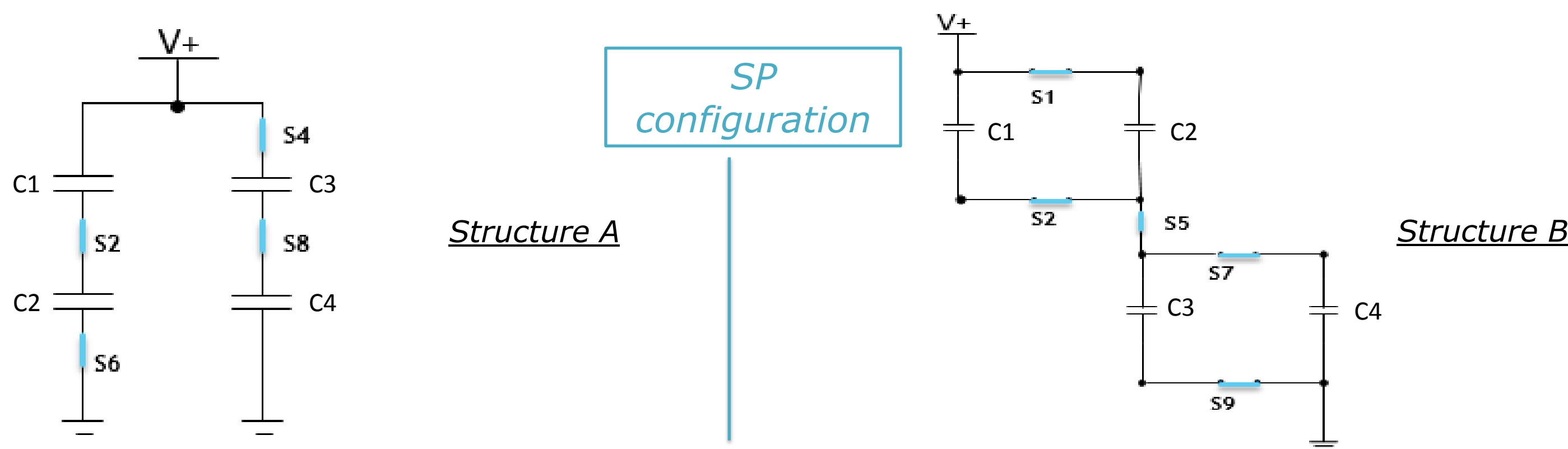
## Self-adaptive architectures under study

Each of the two types of adaptive structures consists of 4 identical supercapacitors (SC) + 9 switches + 3 Schottky diodes for structure B, allowing three possible configurations: Series (S), series-parallel (SP) and parallel (P), (The diodes allow a default serial structure).



## Analysis of the two self-adaptives architectures

Both structures are identical, they have the same number of SCs, switches and configurations (S, SP, P). However, they differ in the SP configuration.



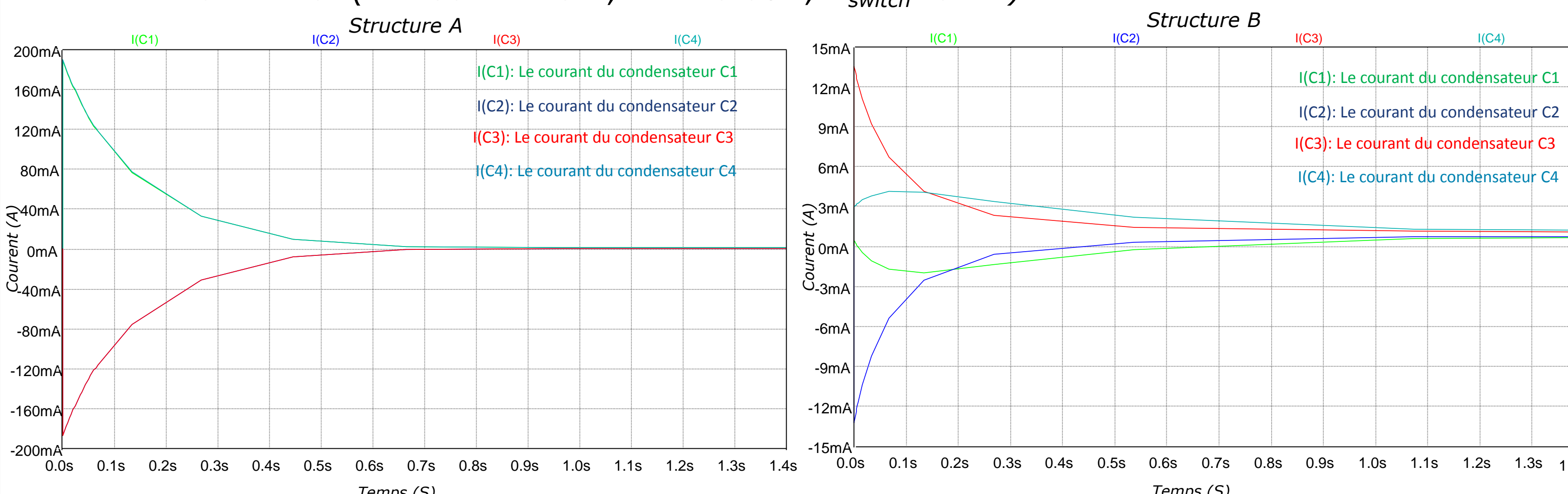
### Impact of the dispersion in capacitance values on losses (worst case)

Input	Output				$E_{MAX}$ loss
Tolerance range $C=100\mu F \pm 20\%$	C1 (F)	C2 (F)	C3 (F)	C4 (F)	
Structure A	0.12	0.08	0.08	0.12	2.08%
Structure B	0.08	0.08	0.12	0.12	2.16%

$E_{max}$  loss expressed in % of the stored energy

### Balancing currents, simulation result of the worst case, High current in second switching SP→P (low current in first switching S→SP)

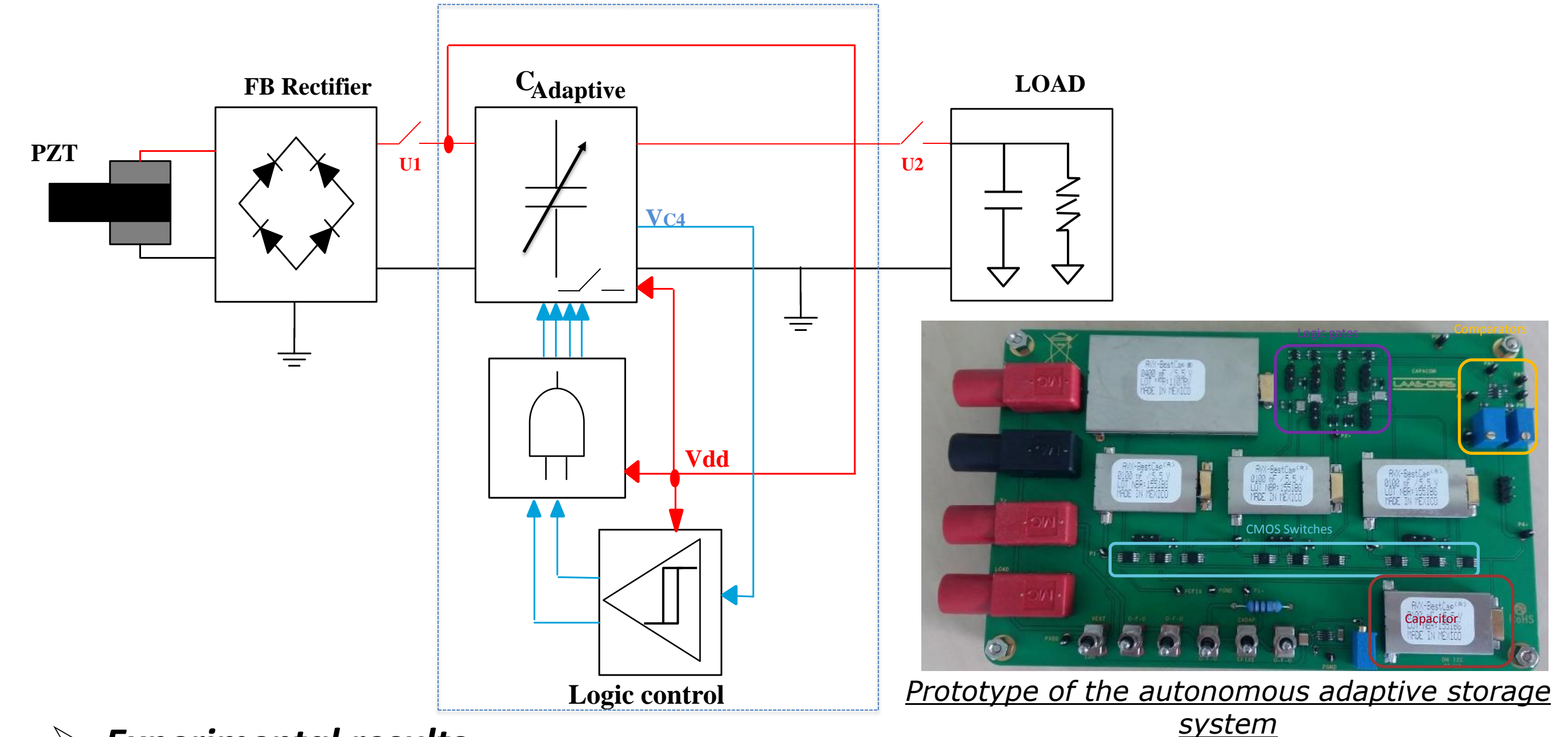
For these simulation, we model each switch by a resistor, and the ultra-capacitor by a capacitor in series with a resistor ( $C=100\mu F \pm 20\%$ ,  $ESR=0.08\Omega$ ,  $R_{switch}=0.4\Omega$ ).



### Conclusion

- Low losses  $\Rightarrow$  balancing circuit not necessary
- Structure B exhibits lower balancing currents

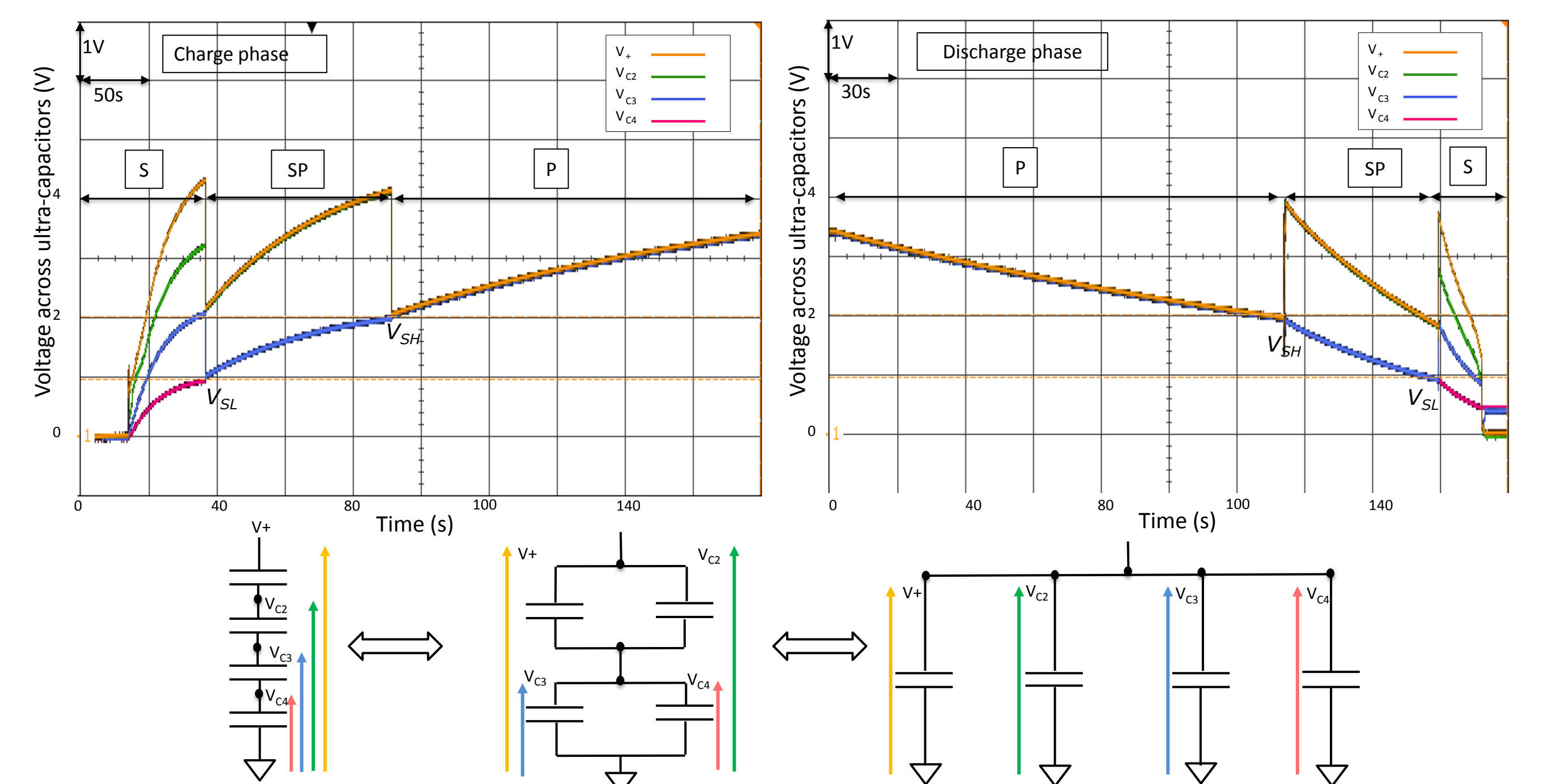
## Self-powered and adaptive storage system



### Experimental results

Energy harvester simulated by a Thévenin generator

$$E_{th}=5V, R_{th}=1k\Omega, R_{LOAD}=1k\Omega, C=100mF, C_{fix}=400mF, V_{SH}=2V, V_{SL}=1V$$



### Charge profile:

- ✓ The S configuration allows for a fast charging and startup (low  $C_{eq}$ ).
- ✓ The P configuration allows for the storage of a large amount of energy (high  $C_{eq}$ ).

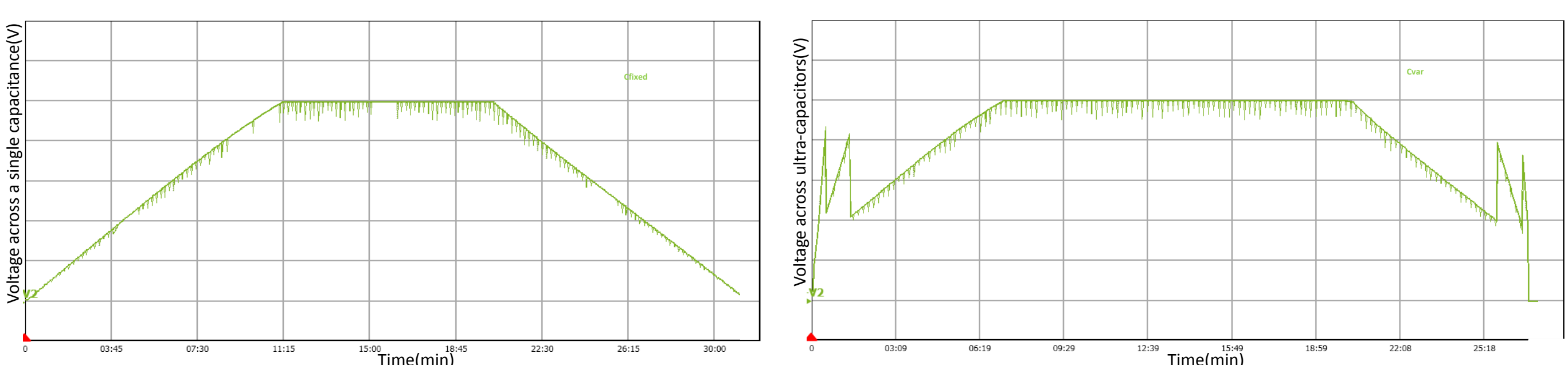
### Discharge profile:

- ✓ The S configuration allows a maximum energy usage rate in the case of a system powered by an energy harvesting source.

Diagram for the system startup time supplied by self powered and adaptive structure or by a single capacitance

## Measurement and calculation of losses

Source and load modeled by a constant current source



$I = \pm 3.5mA$ ,  
 $V_{+MAX\_CHARGE} = 5V$ ,  
 $V_{+MIN\_DISCHARGE} = 1.55V$ ,  
 $C_{variable} = 100mF$ ,  
 $C_{fixed} = 400mF$

	Charge		Discharge	
	$\Delta E/C_{fixed}$ (J/F)	$\Delta E/C_{variable}$ (J/F)	$\Delta E/C_{fixed}$ (J/F)	$\Delta E/C_{variable}$ (J/F)
Theoretical calculation	12.25	12.25	11.05	12.18
Measurement	12.46	12.89	11.01	12.23
Losses		Delivered energy rate		
☹️ 1.7%		☹️ 5.2%		
		☹️ 10%		

## Perspectives

Silicon integration of the self-powered and adaptive storage.

## Acknowledgments

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